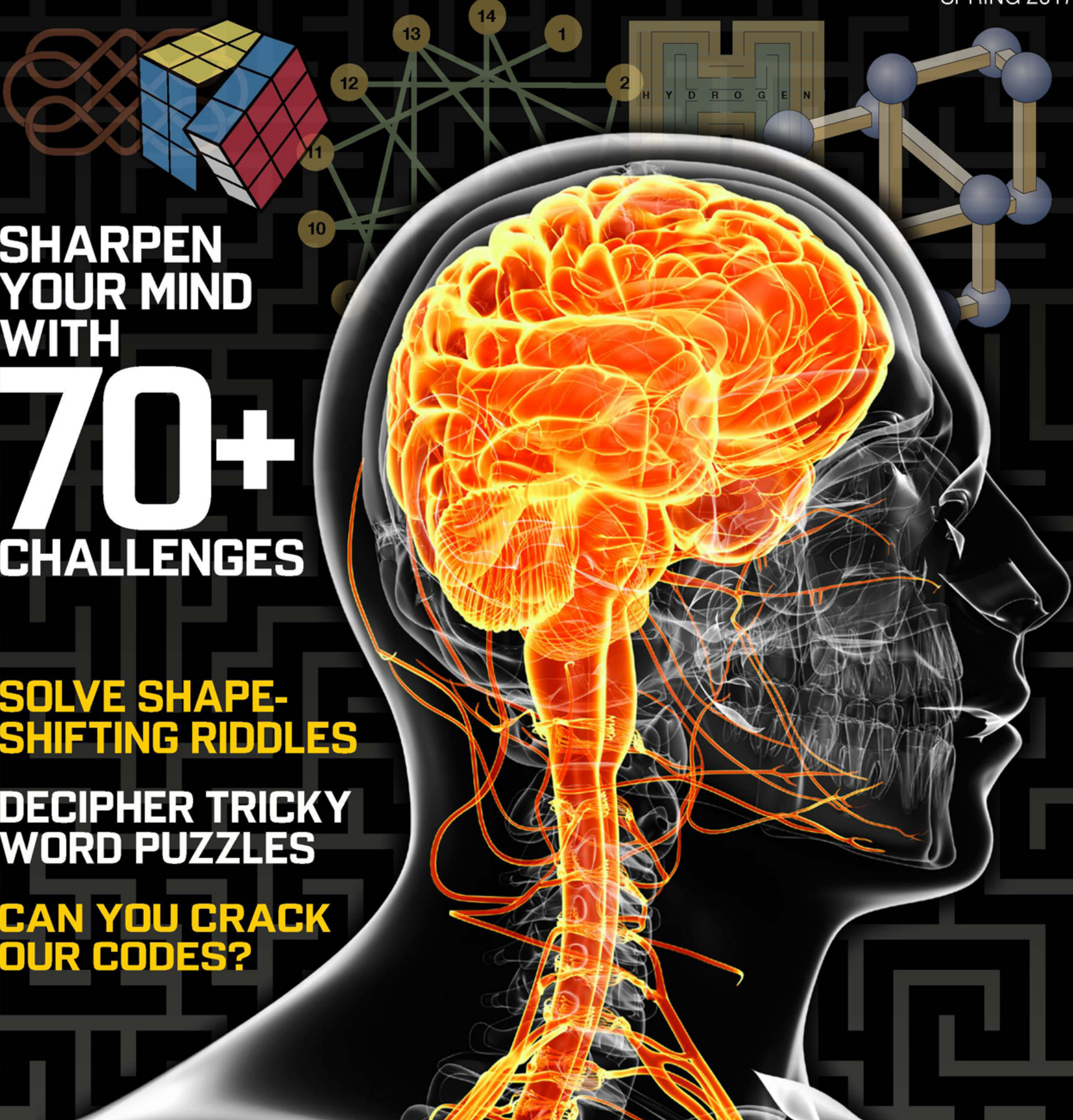
SPECIAL ISSUE

Discover

UNLOCK YOUR BRAIN'S MEMORY

MIND GAMES

SPRING 2017



SHARPEN YOUR MIND WITH 70+ CHALLENGES

SOLVE SHAPE-SHIFTING RIDDLES

DECIPHER TRICKY WORD PUZZLES

CAN YOU CRACK OUR CODES?

SOLO OR 2
PERSON PLAY!

DEVELOPS
SPATIAL SKILLS!

ZOBRIST CUBE™

20,000 Puzzles in a Box!

33 POLYCUBE PIECES & 52 PAGE CODE BOOK

Never get bored by a cube assembly puzzle again. Each code in the code book specifies a different set of pieces that assemble into a cube. The codes are sorted by difficulty from easy to hard. There are even two sections of simple puzzles for children. Extra pieces allow two player competition, all packed in a beautiful box.

1 (855) 962-7478 www.ZobristCube.com Ages 6 - Adult

TABLE OF CONTENTS

KELLIE JAEGER/DISCOVER

Cover illustration by Sebastian Kaulitzki/Shutterstock (brain); Yuri Gayvoronskiy/Shutterstock (maze); Kellie Jaeger and Roen Kelly/Discover (game drawings)

EDITOR'S LETTER

Take Your Brain for a Spin

Nothing is quite as gratifying as figuring something out. Whether it's where you left your keys or how to solve a Rubik's Cube, life's puzzles can vex us all in the moment. But they're oh-so-satisfying on the other side.

That's what this special *Mind Games* issue is all about — the sense of supreme satisfaction after nailing an answer that's doing its best to hide from you. This collection, gathered from the archives of *Discover*'s best columns by Scott Kim and Eric Haseltine — Bogglers, Mind Games and NeuroQuest — is guaranteed to stretch your brain in every direction: word-based puzzles, number games, visual illusions and more.

While the answers are in the back of the book, I urge you to use them sparingly. Dive in and discover the thrill of finding the solution.

Happy hunting,

Bill Andrews

WILLIAM ZUBACK/DISCOVER

Some of the puzzles might require you to cut, write on, or otherwise mutilate the paper they're printed on. Instead of damaging your copy of *Mind Games*, visit **www.discovermagazine.com/mindgames** and print them out for yourself.

MIND GAMES

Bill Andrews EDITOR
Dan Bishop DESIGN DIRECTOR
Alison Mackey ASSOCIATE ART DIRECTOR
Ernie Mastroianni PHOTO EDITOR
Karri Stock COPY EDITOR

CONTRIBUTING WRITERS
Scott Kim
Eric Haseltine

DISCOVER MAGAZINE
Becky Lang EDITOR IN CHIEF
Kathi Kube MANAGING EDITOR
Gemma Tarlach SENIOR EDITOR
Mark Barna ASSOCIATE EDITOR
Eric Betz ASSOCIATE EDITOR
Lacy Schley ASSISTANT EDITOR
Dave Lee COPY EDITOR
Elisa R. Neckar COPY EDITOR
Amy Klinkhammer EDITORIAL ASSISTANT

DISCOVERMAGAZINE.COM
Carl Engelking WEB EDITOR
Nathaniel Scharping WEB STAFF WRITER

ADVERTISING
Steve Meni ADVERTISING SALES MANAGER
888 558 1544
smeni@discovermagazine.com

RUMMEL MEDIA CONNECTIONS
Kristi Rummel CONSULTING AND MEDIA SALES
608 435 6220
kristi@rummelmedia.com

Melanie DeCarli MARKETING ARCHITECT
Bob Rattner RESEARCH
Daryl Pagel ADVERTISING SERVICES

KALMBACH PUBLISHING CO.
Daniel R. Lance SENIOR V.P., SALES & MARKETING
Stephen C. George VICE PRESIDENT, CONTENT
James R. McCann VICE PRESIDENT, FINANCE
Nicole McGuire V.P., CONSUMER MARKETING
James Schweder VICE PRESIDENT, TECHNOLOGY
Ann E. Smith CORPORATE ADVERTISING DIRECTOR
Maureen M. Schimmel CORPORATE ART DIRECTOR
Kim Redmond SINGLE COPY SPECIALIST
Mike Soliday ART AND PRODUCTION MANAGER

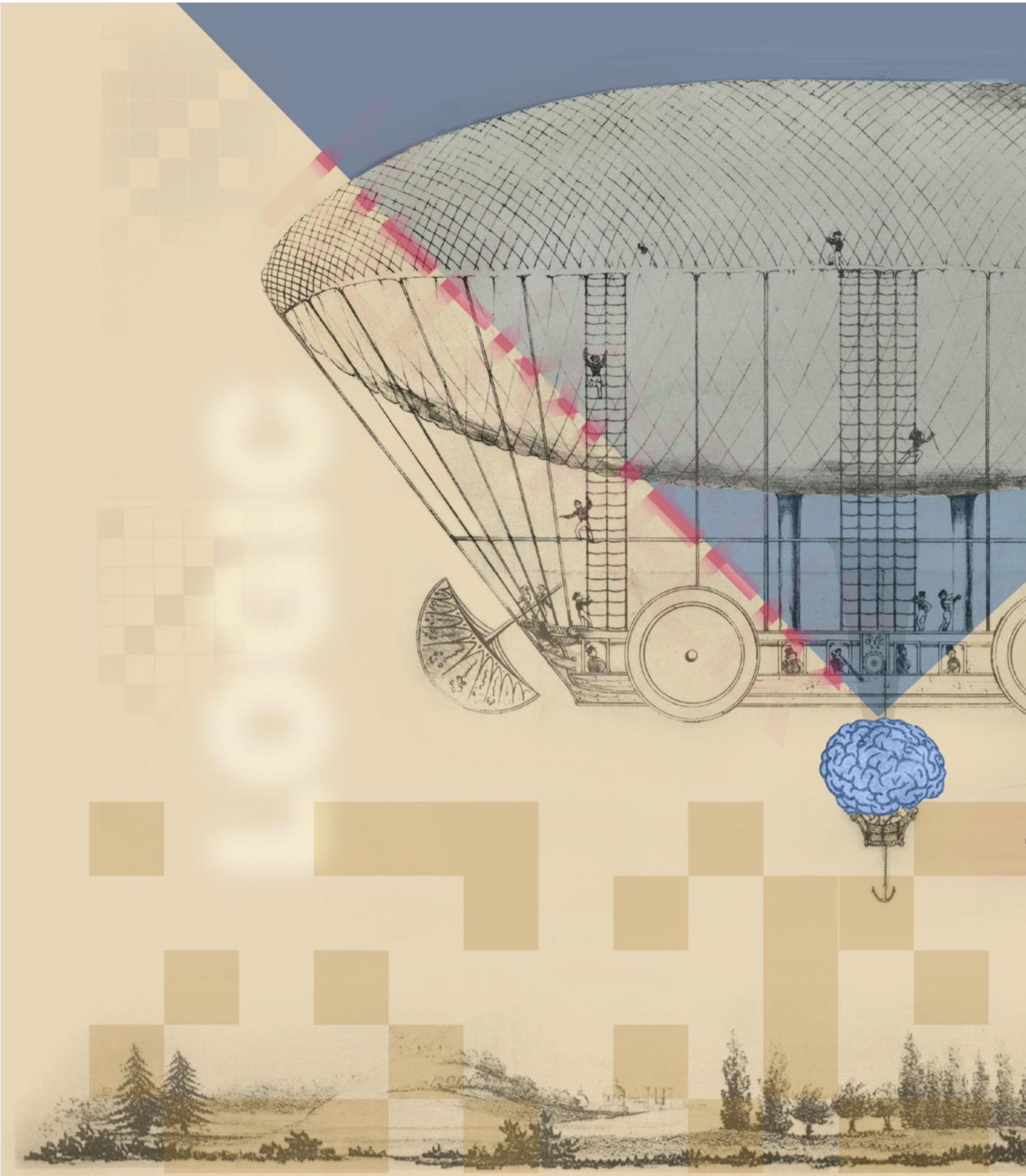
SUBSCRIPTIONS
In the U.S., $29.95 for one year; in Canada, $39.95 for one year (U.S. funds only), includes GST, BN 12271 3209RT; other foreign countries, $44.95 for one year (U.S. funds only).

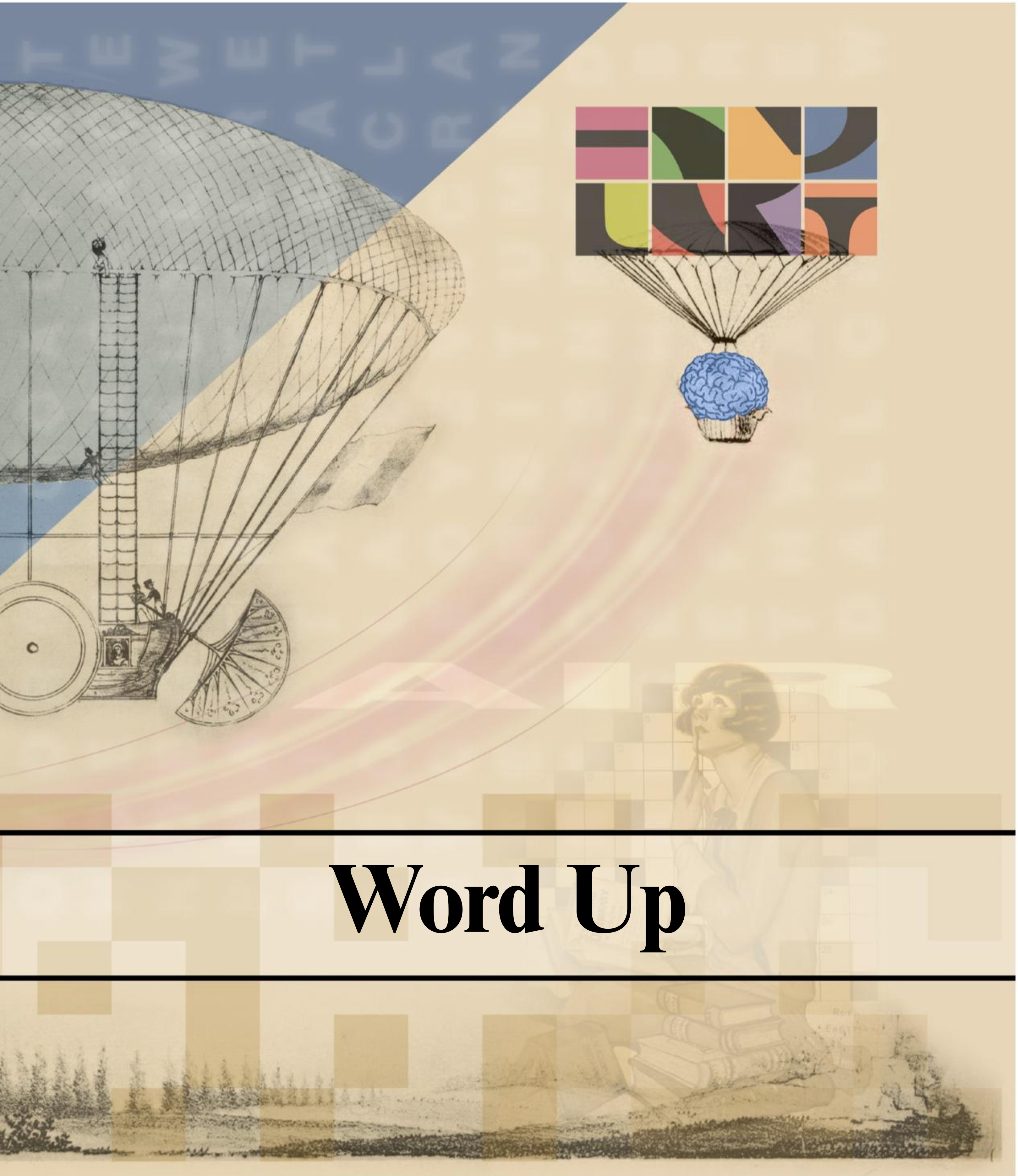
CUSTOMER SALES & SERVICE
800 829 9132
Outside the U.S. and Canada: 813 910 3616
Customer Service: Discover@customersvc.com
Digital: Discover.Digital@customersvc.com
Back Issues: Discover.SingleCopy@customersvc.com

EDITORIAL INQUIRIES
editorial@discovermagazine.com
21027 Crossroads Circle, Waukesha, WI 53186

www.DiscoverMagazine.com

Alliance for Audited Media
KALMBACH PUBLISHING CO.


LOGIC

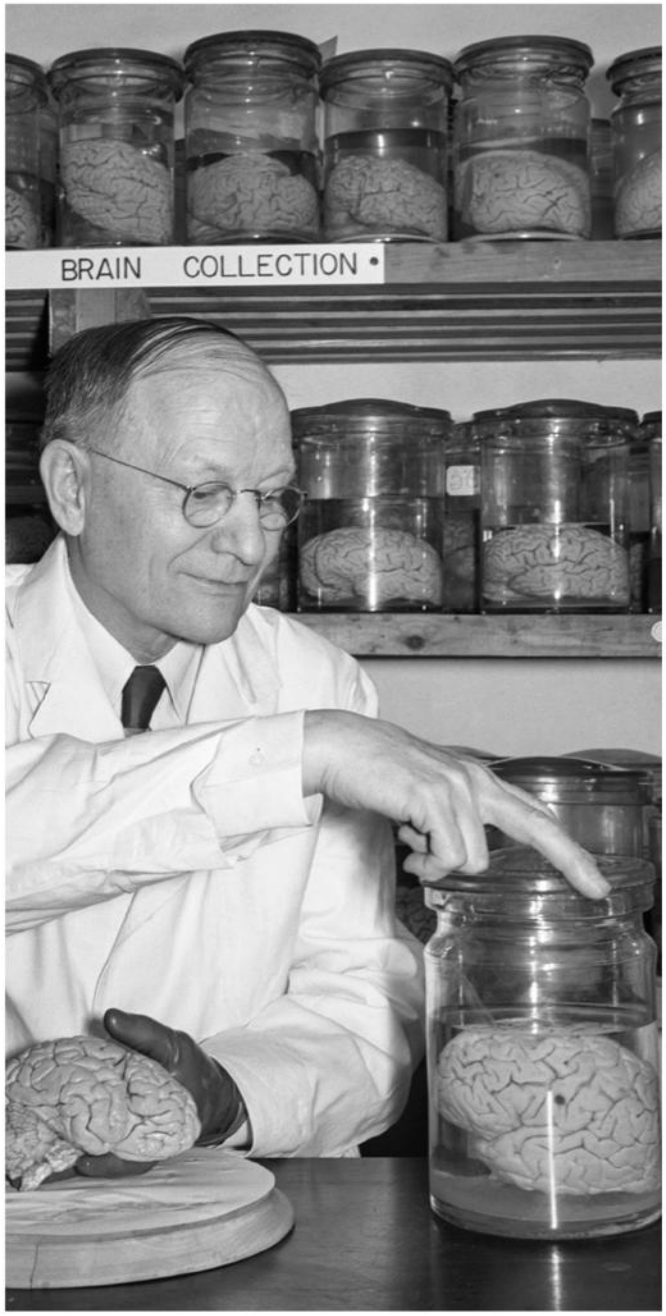


Word Up

KELLIE JAEGER/DISCOVER

Does Your Brain Measure Up?

When it comes to smarts, size matters.



ARTHUR ROTHSTEIN/LOOK MAGAZINE COLLECTION/LIBRARY OF CONGRESS

To the untrained eye, one human brain seems pretty much like another. But if you look as closely as a brain surgeon does, you find striking variations in size, shape and structure.

Could these differences account for behavioral and cognitive variations among people? In the 18th and 19th centuries, investigators such as the German physiologist Franz-Joseph Gall concluded that the answer was a firm yes. They developed the "science" of phrenology: predicting intelligence and personality from the shape of one's head, which was said to indicate the shape of one's brain. Sir Arthur Conan Doyle, an avid proponent of phrenology, endowed both Sherlock Holmes and the evil genius Moriarty with high foreheads in keeping with his belief that the feature connotes intelligence. But later research discredited phrenology; after all, Einstein didn't have a particularly high forehead.

Then in the 1960s, American neuroscientist Norman Geschwind found positive correlations between verbal ability and the size of a region of the brain called the planum temporale. With new techniques, such as magnetic resonance imaging, that can form detailed pictures of living brains, scientists have been able to demonstrate a relationship between cerebral structure and a wide range of cognitive functions, including social skills and spatial reasoning.

Even without a brain imager handy, it's possible to get a crude idea of how brain structure varies by administering cognitive tests associated with particular regions of the brain. For example, studies by P. Thomas Schoenemann of the University of Pennsylvania compared women with large prefrontal cortices and women with smaller prefrontal cortices. When asked to do specific cognitive tasks that required them to filter out information previously learned but extraneous to the job at hand, the women with larger prefrontal cortices tended to show greater proficiency than those in the other group. This finding is consistent with studies of brain damage that indicate the prefrontal cortex plays an important role in executive functions such as extracting meaningful information from complex environments.

So how big is your prefrontal cortex? Take these tests to find out.

EXPERIMENT 1 Cover the colors below with a sheet of paper. Then remove the sheet completely, and say the name of each color, scanning row by row from left to right. Record how many seconds it takes you to correctly name the colors of all 50 rectangles.

EXPERIMENT 2 Repeat the procedure with the words below. Say the name of the color of ink each word is printed in — not the words themselves.

Red	Green	Brown	Blue	Purple	Red	Blue	Brown	Green	Purple
Green	Blue	Purple	Red	Brown	Green	Red	Blue	Purple	Brown
Purple	Red	Green	Brown	Green	Blue	Green	Brown	Blue	Red
Blue	Green	Purple	Red	Blue	Brown	Purple	Green	Red	Brown
Brown	Purple	Green	Purple	Red	Red	Brown	Blue	Green	Blue

It takes longer to get through this second sequence because in order to identify the colors, you have to inhibit a learned tendency to read the words. The average score on this test for people from 20 to 59 years old is about 55 seconds; if you are in that age group, a time below or above that suggests that your prefrontal cortex is respectively larger or smaller than average. A normal score for individuals 60 to 74 years old is 71 seconds; 78 seconds is average for those over 75. Don't be discouraged if your score was subpar. This is a simple test, and it predicts less than a fifth of the variation in size of prefrontal tissue from one person to the next. Also, the brain is in some ways similar to a muscle: Practice and exercise will improve its performance. Finally, most people are mediocre at some cognitive skills yet excel at others.

LINGO MANIA

RECOMBINANT WORDS

Complete each sentence below with two words that are anagrams of each other — words that contain exactly the same letters, just in a different order. The dashes indicate the number of letters in each word. For example, the missing words in puzzle 3 are *reef* and *free*. The final puzzle requires that you come up with three words that are anagrams of one another.

1. _ _ _   _ _ _ RNA are blueprints for making proteins.

2. Of all the elements, _ _ _ _ is as useful as _ _ _ _ for making brightly lit signs.

3. The coral _ _ _ _ was _ _ _ _ of pollution.

4. Because the telescope was out of focus, the astronomer was _ _ _ _ _ _ to see the _ _ _ _ _ _ clearly.

5. The brilliant _ _ _ _ _ _ scientist could count in both _ _ _ _ _ _ and decimal systems.

6. When ophthalmologists _ _ _ _ _ _ a patient's eyes, they can see more _ _ _ _ _ _ in the retina.

7. The computer used a fast _ _ _ _ _ _ _ _ _ to compute the _ _ _ _ _ _ _ _ _ of a number.

8. You can turn a _ _ _ _ _ _ _ _ into a square by _ _ _ _ _ _ _ _ the number of sides.

9. The doctor had to _ _ _ _ _ _ _ _ _ his instruments to look for a _ _ _ _ _ _ _ _ _ infection.

10. Despite the pregnant woman's _ _ _ _ _ _ _ _ care and her husband's obvious _ _ _ _ _ _ _ _ feelings, the couple shared certain _ _ _ _ _ _ _ _ concerns.

MISSING LINKS

Fill in the missing word in each group below so the first two words and the last two words form two different scientific terms. For instance, the missing word in the first puzzle is *ice* ("dry ice" and "ice age").

1. DRY ICE AGE

2. PERPETUAL _____ SICKNESS

3. STROBE _____ WAVE

4. CLEAN _____ TEMPERATURE

5. BINARY _____ FISH

6. FUEL _____ DIVISION

7. FOOD _____ REACTION

8. COMMON _____ FUSION

KIOSEA39/DREAMSTIME.COM

FINDING A CONNECTION

I'M LOOKING FOR MY MISSING LINK

Any two "root" words in a thesaurus can be linked, on average, by two other related words. Fill in the missing links to connect the eight pairs of words that appear below. Each pair of adjacent words must be strongly related in some obvious way. These puzzles have multiple answers — the connections are limited only by your imagination.

1. NEEDLE EYE LIGHT LIGHTBULB

2. CLOCK _____ _____ LOBSTER

3. STYROFOAM _____ _____ PRAYER

4. TREE _____ _____ PIPE

5. EGG _____ _____ TUNNEL

6. CEMENT _____ _____ STAR

7. LICENSE _____ _____ CABBAGE

8. PEPPER _____ _____ PIANO

WORD SCRAMBLE

Use the clues below to deduce six words taken from different branches of science. Hint: None of the secret words has any repeated letters.

1. [EASY]
What five-letter word associated with forensics shares four letters with COMER and four letters with MEDIC?

2. [TRICKY]
What five-letter word associated with physics shares four letters with FROCK and three letters with CHAFE?

3. [TRICKY]
What five-letter word associated with archaeology shares four letters with VIRUS and two letters with BUNCH?

4. [TRICKY]
What five-letter word associated with mathematics shares four letters with CLOGS and no letters with AMUSE?

5. [DIFFICULT]
What six-letter word associated with chemistry shares five letters with HUMBLE and one letter with ABOUND?

6. [DIFFICULT]
What six-letter word associated with anatomy shares three letters with EXPIRY and no letters with BICEPS?

PURE DEDUCTION

ASSEMBLING CLUES

When scientists can't observe a phenomenon directly, they rely on a process of deduction to infer what's happening. In each puzzle below, your challenge is to deduce a secret five-letter English word from a series of clues. Each clue states how many letters a given word shares with the secret word. For example, if a clue states that *guess* shares two letters with the secret word, the secret word could be *seven* (because the two words share the letter *s* and the letter *e*) or *grout* (because the two words share the letters *g* and *u*) or *sassy* (because the two words share two *s*'s). You will need all of the clues in each puzzle to deduce the secret word, and there is only one correct answer to each puzzle.

1. [EASY]
3 letters of SUETS
4 letters of SUITE
4 letters of GUESS
occur in the secret word _ _ _ _ _

2. [TRICKY]
1 letter of NANNY
2 letters of SASSY
3 letters of GEESE
4 letters of GENES
occur in the secret word _ _ _ _ _

FINDING PATTERNS

To learn how our world works, scientists look for patterns in data. Seventeenth-century astronomer Johannes Kepler spent years puzzling over data assembled by Tycho Brahe before discovering that the planets move in elliptical orbits. This pattern-finding puzzle should take you much less time. In each figure, a simple rule distinguishes the letters on the left from the letters on the right. For instance, all the letters on the left in puzzle 1 are made up of only straight lines, while the letters on the right contain curved lines. Can you figure out the rule for each of the other puzzles? *Hint: Think shape, except for puzzle 4.*

MA	CO
NT	RP
LE	US

1. Straight   Curved

HA	FP
NK	VI
RW	TY

2. ______ ______

PR	CH
OB	IL
AD	ES

3. ______ ______

BL	UP
AM	TO
ED	WN

4. ______ ______

WA	PR
YO	JG
UT	QF

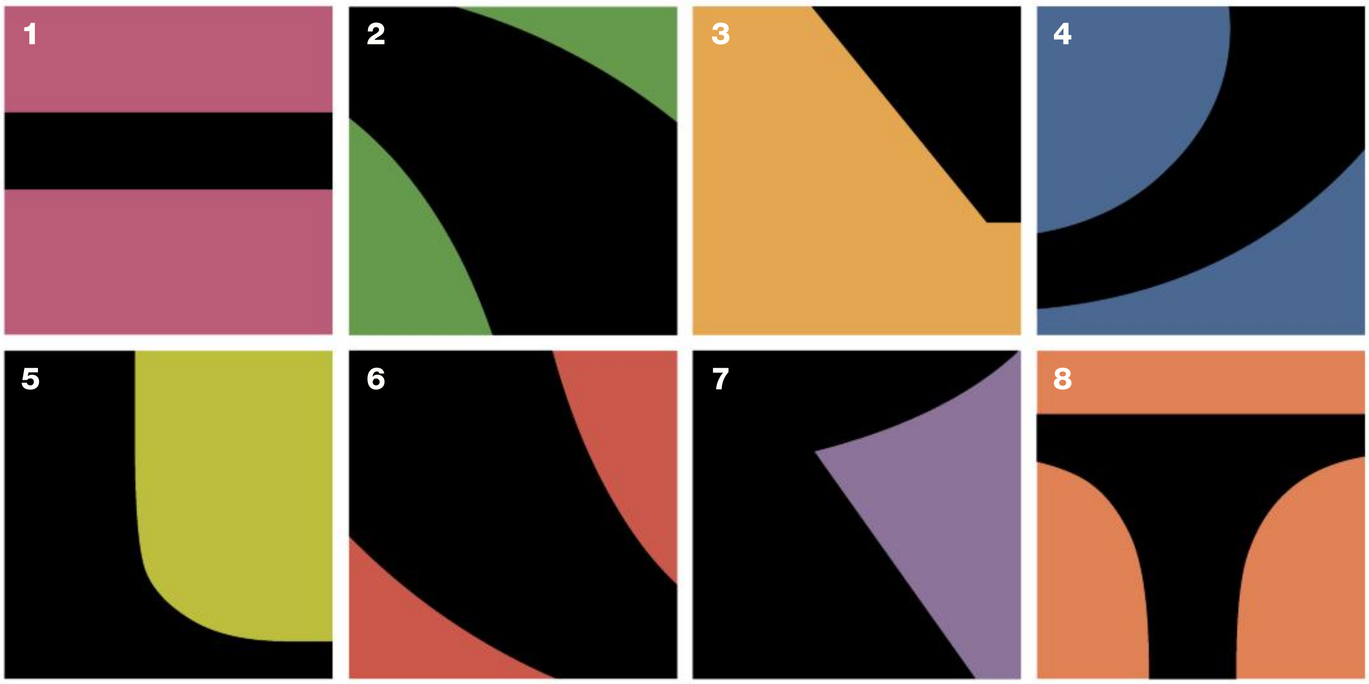
5. ______ ______

HU	OP
NK	TI
YW	FA

6. ______ ______

FOCUS ON FRAGMENTS

Paleontologists painstakingly reconstruct dinosaur skeletons from fragments of fossilized bone. Similarly, this puzzle works with fragments of letters. Try to match each letter fragment below to a different letter from the word *DINOSAUR*, as shown at the bottom of the page. We've given you one answer: Fragment 1 is taken from the letter *A*. While some fragments match more than one letter (fragment 2 could match *D*, *O*, or *R*), there is only one way to match every fragment to a different letter. All fragments are in the same orientation in which they appear in the original letter, and all are magnified the same amount.

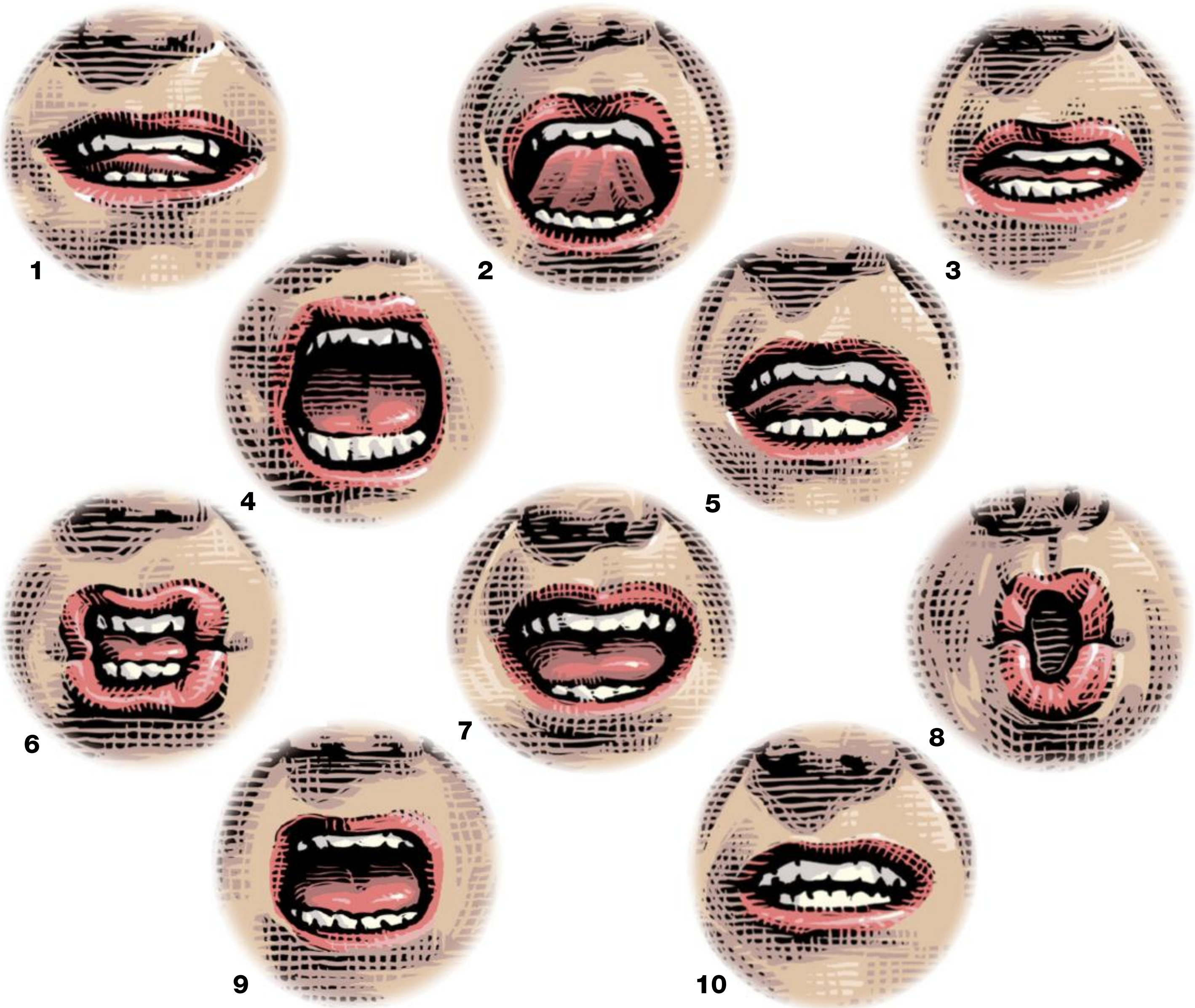


TOP: KELLIE JAEGER/DISCOVER. BOTTOM: NEILLD/DREAMSTIME.COM

The Hungry Eye

How your brain gobbles up visual clues.

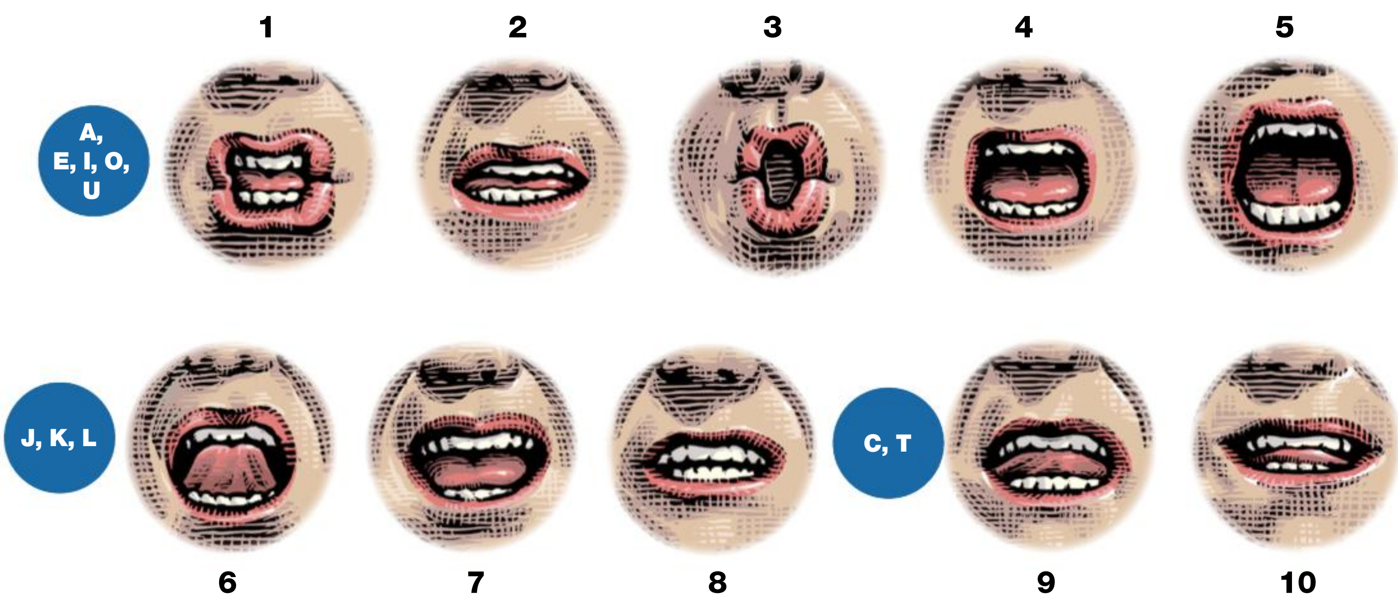
Always ravenous for information, the brain acts like a forager that never knows where its next meal is coming from. So it gorges when it finds digestible data. Witness the way snacking on visual hors d'oeuvres helps your brain process speech.



BILL RUSSELL

EXPERIMENT 1 Jot down which letter you think is mouthed in each of the 10 pictures at left (no fair peeking at the second set of pictures below). You should easily identify at least one letter: *O*. If you don't know precisely which letter is mouthed, guess whether it is a vowel or a consonant. *Hint: Mouth 4 is a vowel and mouth 2 a consonant.* You can make these reasonable guesses because your brain has learned how to gobble up visual information relevant to speech, even when it's consuming more than enough acoustic information to understand spoken words.

EXPERIMENT 2 To see just how useful redundant visual information can be, watch a TV program with the volume turned so low that you can barely hear what the actors are saying. Then close your eyes, noticing how you miss words without the visual information.



EXPERIMENT 3 In addition to using visual information, your brain uses context to understand speech. The 10 mouths from the first experiment are sorted into three groups, above. Guess which mouths correspond to the letters next to each group (the answers to both experiments are in the margin). Your performance should improve considerably over that for Experiment 1.

EXPERIMENT 4 Stand directly behind a partner, facing a wall mirror. Fix your gaze on the reflected image of your partner's mouth. Then have your partner mouth — but not say aloud — *gah* while you simultaneously softly utter *bah*. If you synchronize your quiet *bah* with your partner's silent *gah* (counting down from three will help), both of you may very well hear *dah*. This illusion occurs because your brain relies so much on vision that you eyes influence your ears. Harry McGurk, the late British psychologist who discovered this effect, theorized that when the brain is confronted with conflicting acoustic and visual information, it interpolates (ergo *dah* from *bah* and *gah*). Test the theory by standing in front of your friend. Now mouth *gah* into the mirror while your friend says *bah*. Repeat the procedure with your eyes closed and hear the *dah* turn back into a *bah*.

EXPERIMENT 1. 1-C, 2-L, 3-E, 4-I, 5-T, 6-U, 7-K, 8-O, 9-A, 10-J **EXPERIMENT 3.** 1-U, 2-E, 3-O, 4-A, 5-I, 6-L, 7-K, 8-J, 9-T, 10-C

GRIDLOCK

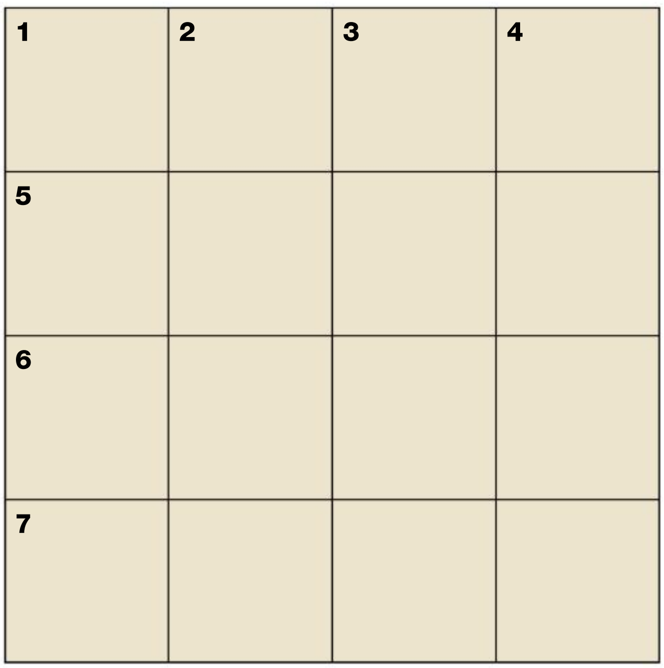
More than 50 million Americans do a crossword puzzle at least occasionally, which makes solving crosswords possibly the most popular intellectual sport in the country. It's a pastime of considerable beauty and depth, and one that the sport's elite practice with passion and intimidating speed.

ACROSS

1. Surgeon's tools
5. Mouse catcher
6. Relating to air or atmosphere (prefix)
7. Ecstatic

DOWN

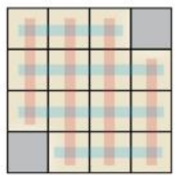
1. Alpha Eridani, e.g.
2. πr^2 or ½*bh*
3. To bend through a lens
4. Jupiter has a great red one

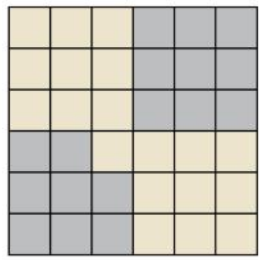


PLAY BY THE RULES

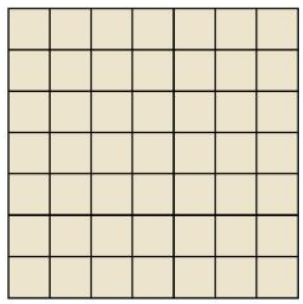
American crossword grids obey at minimum the following rules:
1. Every word in the grid must share at least one letter with an intersecting word.
2. All words must be at least three letters long.
3. All the white squares in the grid must interlock: There can't be islands of white squares that aren't connected to the rest of the white squares.

Below is a valid 4x4 grid with two black squares. There is room for eight words, four across (shown in blue) and four down (in pink), and every word is at least three letters long. Similarly, the 6x6 grid fits 12 words, and every word is at least three letters long. Both grids follow American crossword conventions.
1. Why is it impossible to make a 6x6 grid with room for more than 12 words, with every word at least three letters long?

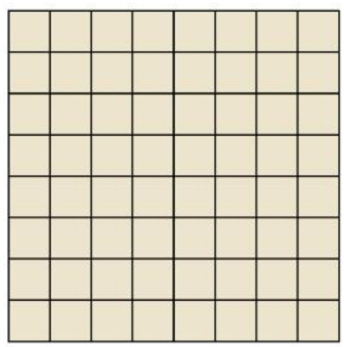




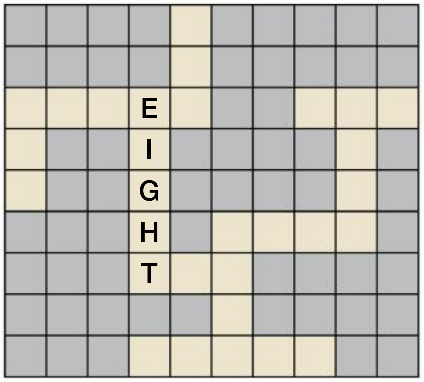
2. Make some of the squares black in the 7x7 grid at right to create a valid crossword grid with room for 14 words, each three or four letters long.



3. Make some of the squares black in the 8x8 grid at right to create a crossword grid with room for 28 words, each three or four letters long.



NUMBER CRUNCHING



1. Put the names of the numbers 1 through 10 in the crossword grid above. There is just one solution. (The first word is filled in.)

E								
I								
G								
H		F	I	V	E			
T								

2. Put the names of the numbers 1 through 10 in the grid above. You will have to figure out where the black squares go. Words can read across or down, and you may not use any extra words — just the 10 number names. The first two are filled in.

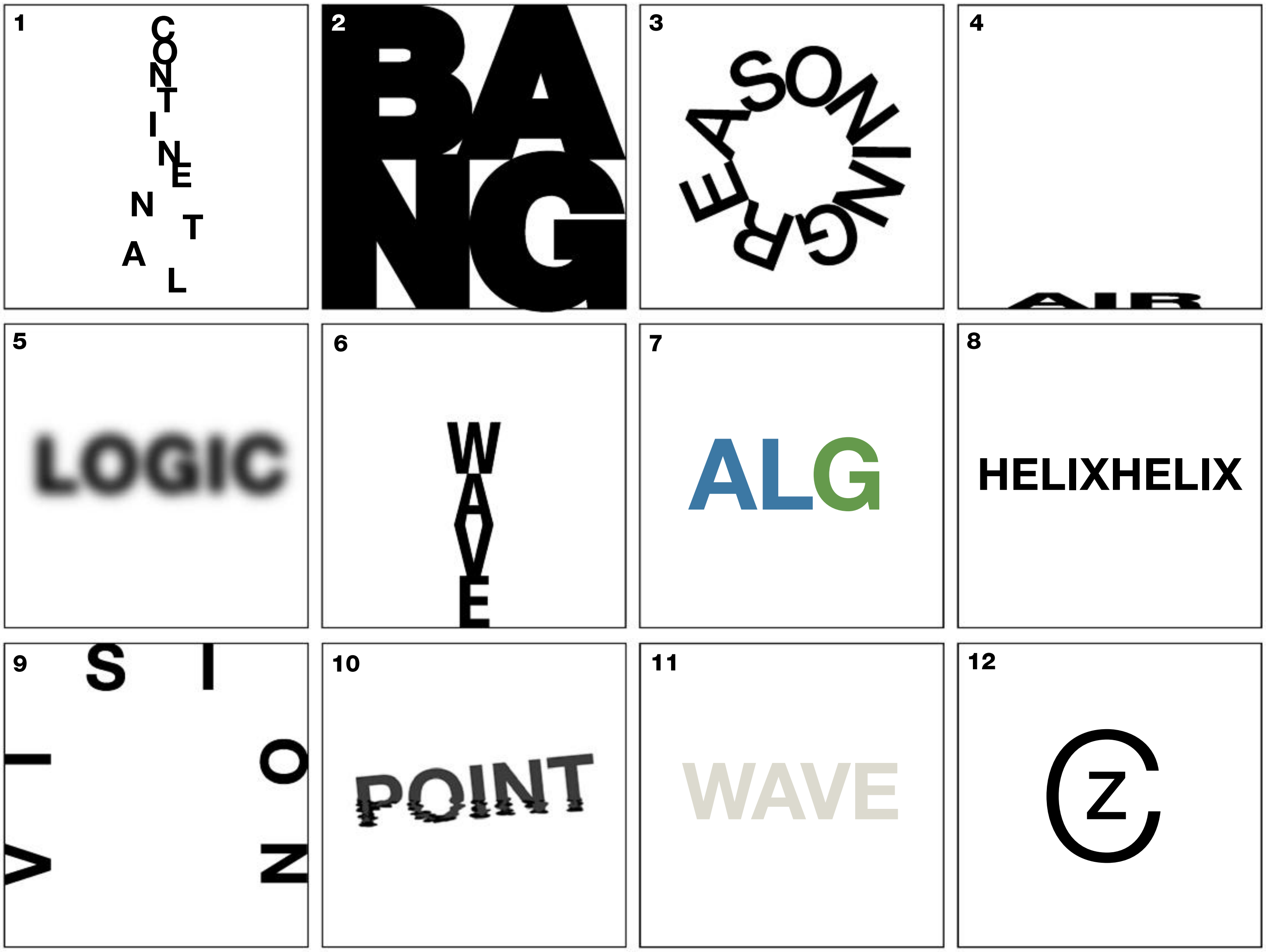
	S		F		
	E	I			
	V				
E	E				
	N				

3. Put the names of the numbers 1 through 10 in the word-search grid above. Words may read in any direction: horizontal, vertical or diagonal, and forward or backward. You must include all 10 numbers, and every square of the grid must include a letter of one of the number names — you can't leave empty squares or use "filler" letters.

TUPUNGATO/DREAMSTIME.COM

FRIEZE FRAMES

The 12 word pictures below represent common phrases or terms in science. The first box, for example, yields "continental drift." Can you decipher the rest of the mystery phrases? *Hint: For number 12, try writing down possible solutions.*



STRATIFIED LEXICON

Dig into the colorful matrix below to uncover 23 words related to geology. Words may be spelled horizontally, vertically or diagonally, and either forward or backward. Letters may appear in more than one word. When all 23 words have been crossed out, the letters remaining in the grid can be entered in sequence into the matching colored boxes below to spell a quotation about our planet. To get you started, we've already unearthed the word *CRYSTAL*.

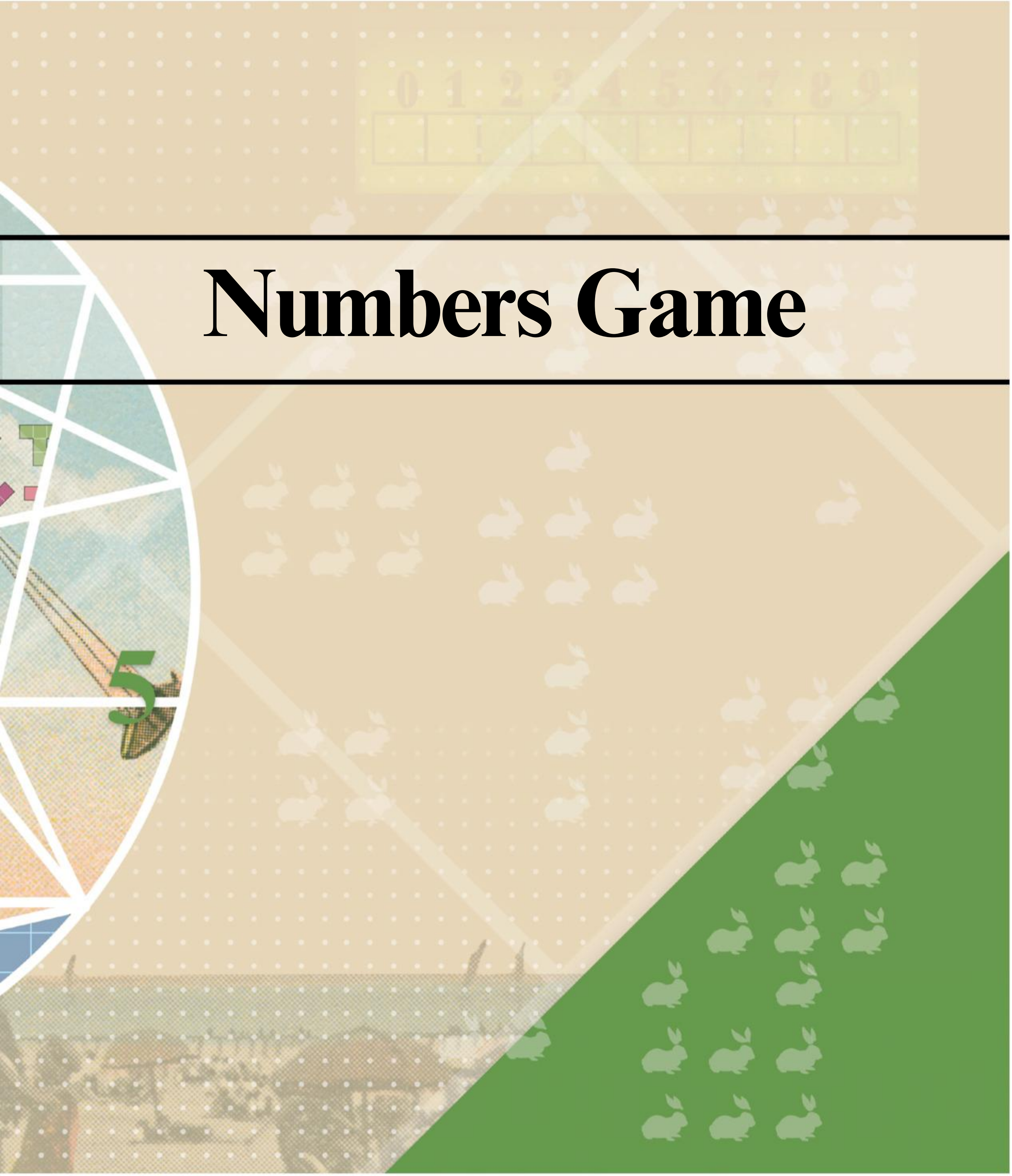
O	Y	O	R	R	A	C	O	A	L	F	N	T
H	D	E	R	M	E	N	A	R	A	A	O	E
N	O	E	G	L	A	V	A	U	Y	L	B	W
P	M	A	L	C	A	C	L	T	A	L	R	E
S	M	I	L	T	A	T	N	T	L	O	A	T
S	E	O	N	L	A	U	S	N	P	Y	C	L
B	V	G	D	E	O	Y	E	V	A	C	R	A
A	E	E	R	M	R	B	I	T	U	M	E	N
S	R	S	A	C	O	A	S	N	S	P	S	D
A	A	E	C	E	S	H	L	H	I	P	Y	S
L	S	E	R	E	F	I	U	Q	A	A	E	R
T	A	E	P	T	H	W	E	A	R	L	G	E
F	J	O	R	D	A	L	L	C	R	E	E	W

HIDDEN IDENTITIES

Unscramble the letters in the first phrase of each anagram below to reveal the name of a famous scientist or inventor. The subsequent phrase in each anagram unscrambles to reveal a clue to the scientist's identity — a discovery, field of study or other relevant scientific terms. For example, HANDRAIL SCREW—NO EVIL OUT forms CHARLES DARWIN—EVOLUTION.

1. HANDRAIL SCREW—NO EVIL OUT (one word)
2. RASCAL NAG—COY GLOOMS (one word)
3. LUNAR GIANT—TIGER STUNT (two words)
4. WOMAN AS JEST—BOLLIXED HUE (two words)
5. INSULIN A PLUG—MOUSE CELL (one word)
6. AROUSE TULIPS—VIATIC CANON (one word)
7. MOTION SHADES—HAG POP HORN (one word)
8. HORSECAR CLAN—CLOY EGO (one word)
9. GOLDEN MERGER—THIRD EYE (one word)

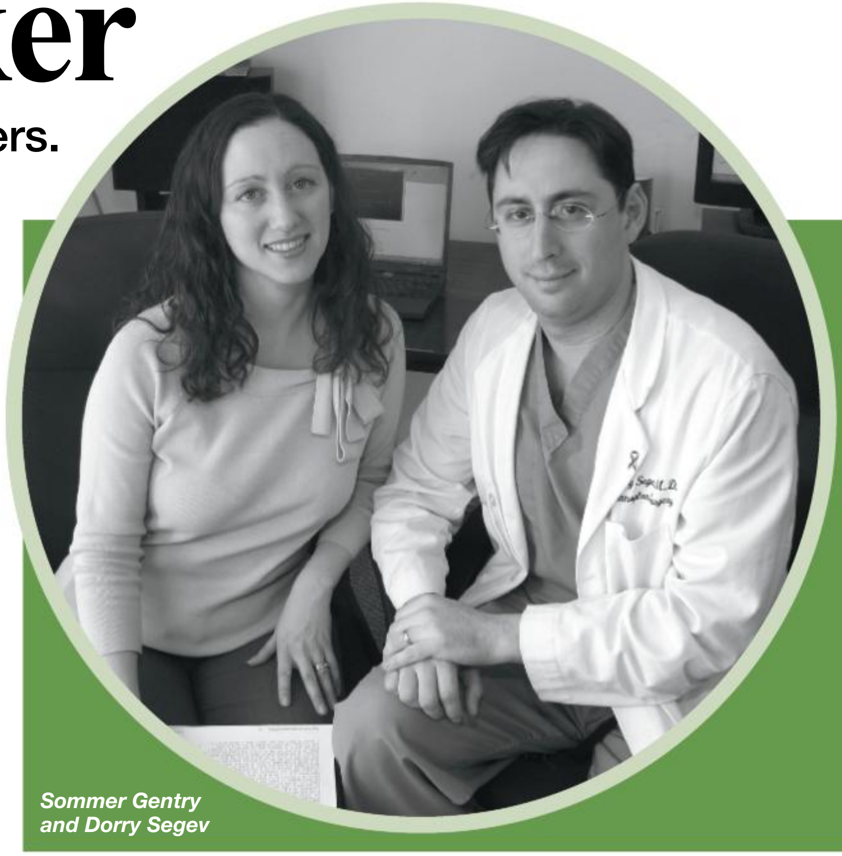
Numbers Game



ILLUSTRATIONS BY KELLIE JAEGER/DISCOVER UNLESS NOTED

Matchmaker

How to do surgery by the numbers.

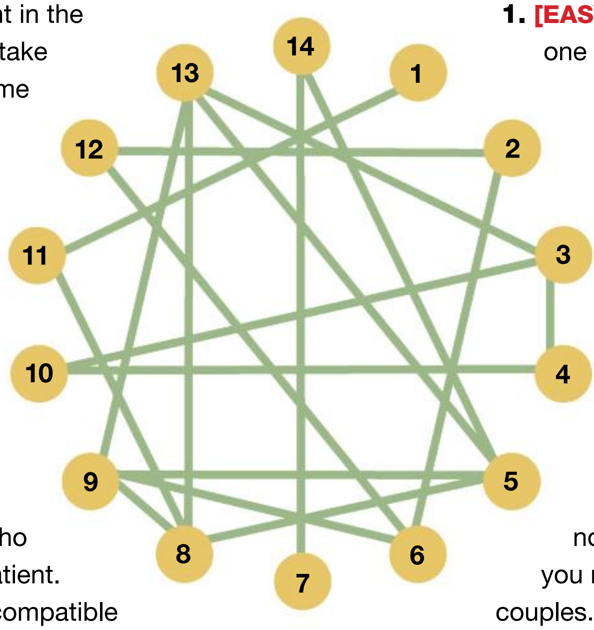

Sommer Gentry and Dorry Segev

Optimized Match is a technique developed by mathematician Sommer Gentry and transplant surgeon Dorry Segev to increase the odds that a patient in need of an organ transplant will find a suitable donor. It is based on graph theory, a branch of mathematics used to analyze diagrams made of dots connected by lines.

ORGAN SWAP

A problem in organ transplants is that someone who wants to donate to a loved one often can't because their blood types are incompatible. The solution is to match such a couple with another couple who have the right blood types and swap organs, the donor from each couple giving a kidney to the patient in the other couple. The operations must take place simultaneously and at the same facility. Johns Hopkins and several other institutions have performed over 100 such procedures, a few of which have involved swaps among more than two couples. Gentry and Segev now advocate a nationwide registry to spread the practice.

In the diagram, an example of graph theory, each circle represents two people: a patient who needs a kidney and a donor who wants to donate a kidney to that patient. The people in each couple have incompatible blood types, so the donor cannot give a kidney to his or her partner. Each line between two couples represents a potential swap: The donor from each pair is compatible with the patient in the other couple.



1. [EASY] Which couples have only one potential match?

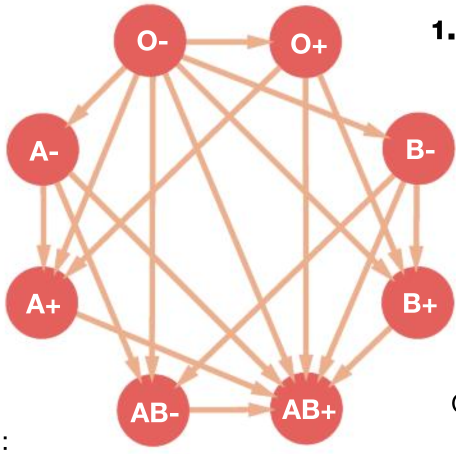
2. [DIFFICULT] Optimized Match finds the best swapping scheme for a pool of available donors. Maximize the number of matches by choosing seven lines that connect all 14 couples. *Hint: The solution is unique.*

3. [DIFFICULT] If you do not choose swaps carefully, you may end up stranding some couples. Find the worst possible matching scheme so that no more than five lines can be chosen. You are not allowed to choose two lines that end at the same couple. *Hint: The solution is not unique.*

COURTESY OF SOMMER GENTRY AND DORRY SEGEV

BLOOD TYPES

Graph theory can also be used to model things like the structure of molecules, the strength of buildings and the connectivity of the internet. Here is another medical application. The diagram shows the eight major blood types. An arrow from one to another, say A– to A+, indicates that the first can donate to the second. Notice that compatibility is not always mutual: A– can donate to A+, but not vice versa. (All blood is compatible with itself, but here we are interested only in donations between different types.)



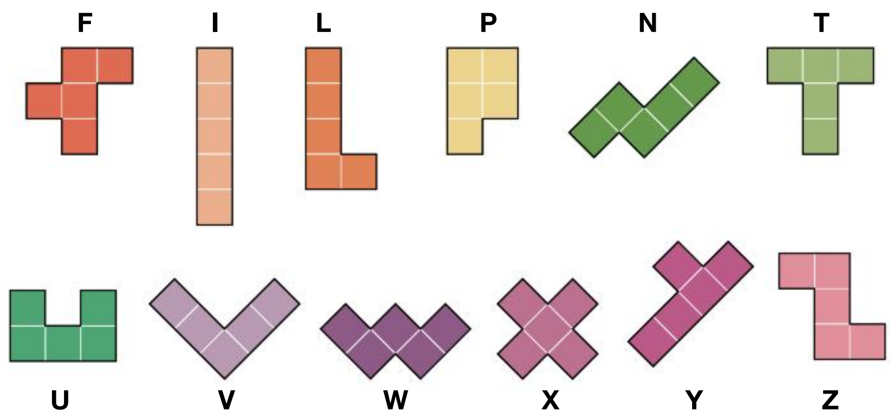
1. [EASY] Which type can donate to the largest number of other blood types? Which type can receive the largest number of other types of blood?

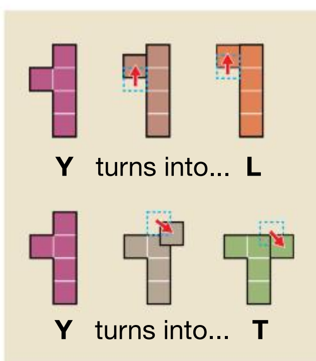
2. [TRICKY] How many ways are there to make a chain of four blood types so that the first can donate to the second, the second to the third and the third to the fourth? For instance, one solution is O– to B– to B+ to AB+.

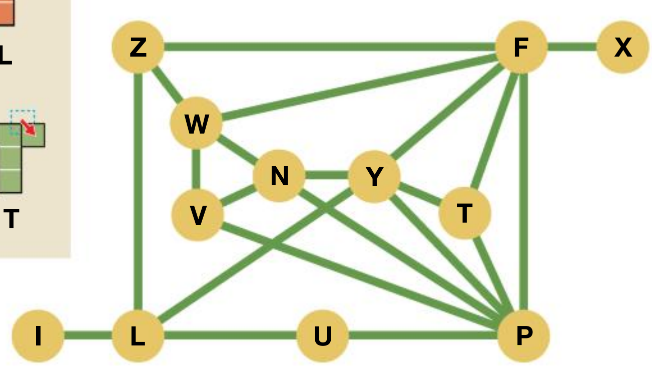
3. [DIFFICULT] Make a group of three blood types, none of which can donate to either of the other two. Can you find both possible solutions?

SHAPE COUSINS

Here is a puzzle that looks very different from organ donation but uses the same underlying mathematics. The 12 shapes at right are each made of five squares. For convenience, they're labeled with letters that look like the shapes. Suppose that two shapes are "cousins" if you can change one shape into the other by sliding one of the squares one space horizontally, vertically or diagonally. (After sliding one square, you may also rotate or flip the whole shape.) For instance, Y is a cousin of L and T, but not of X.







1. [EASY] Y is a cousin of three other shapes. What are they?

2. [TRICKY] Which shapes have only one cousin?

3. [DIFFICULT] Can you divide the 12 shapes into six pairs of cousins? *Hint: Study the diagram at far right.*

CONNECTING THE DOTS

GAUSS' SHORTCUT

When the great German mathematician and astronomer Carl Friedrich Gauss was a schoolboy, his teacher asked the class to add together all the whole numbers from 1 to 100. To the teacher's astonishment, young Gauss answered immediately.

1. Can you figure out Gauss' clever shortcut? *Hint: Don't add the numbers in their original order. Find a pattern that will make your job easier, starting from both ends and working your way toward the middle.*
2. Using the same method, add the whole numbers from 1 to 1,000.
3. Add the even numbers from 2 to 2,000.
4. Add the odd numbers from 1 to 1,001.

Carl Friedrich Gauss

ADDING BACKWARD

In school we learn to add numbers from right to left, carrying digits to the left as necessary. This method certainly works, but it's prone to error, requires confusing reversals and can lead to shaky mathematical confidence.

A better method is to add left to right. For instance, to compute the sum in the large green box at right, start with the hundreds place. In the left column, we have 1, 3 and 5, which stand for 100, 300 and 500. Add these up, and we get 900. Already we know the final answer is at least 900, probably closer to 1,000.

In the middle column we have 2, 0 and 4, which stand for 20, 0 and 40. Add these to our running total and we get 960. So far, so good.

In the right column we have 7, 1 and 6, which total 14. Add that number to 960 and we get our answer: 974. Working left to right gets you the same answer as working right to left, but left to right makes more sense.

100	20	7	127
300	0	1	301
+500	+40	+6	+546
900 +	60 +	14 =	

241	150	130
130	222	522
+427	+318	+834

1. Without using paper or a calculator, add the three sets of numbers shown at left in your head, working from left to right.

2. There are many other shortcuts for working with numbers. Multiplying by 10 is easy: Just tack on a zero. Want to divide by 5? Multiply by 10 and divide by 2. Now, without using paper or a calculator, adapt these tricks to compute to the penny the standard 15 percent restaurant tip on a bill of $26.14.

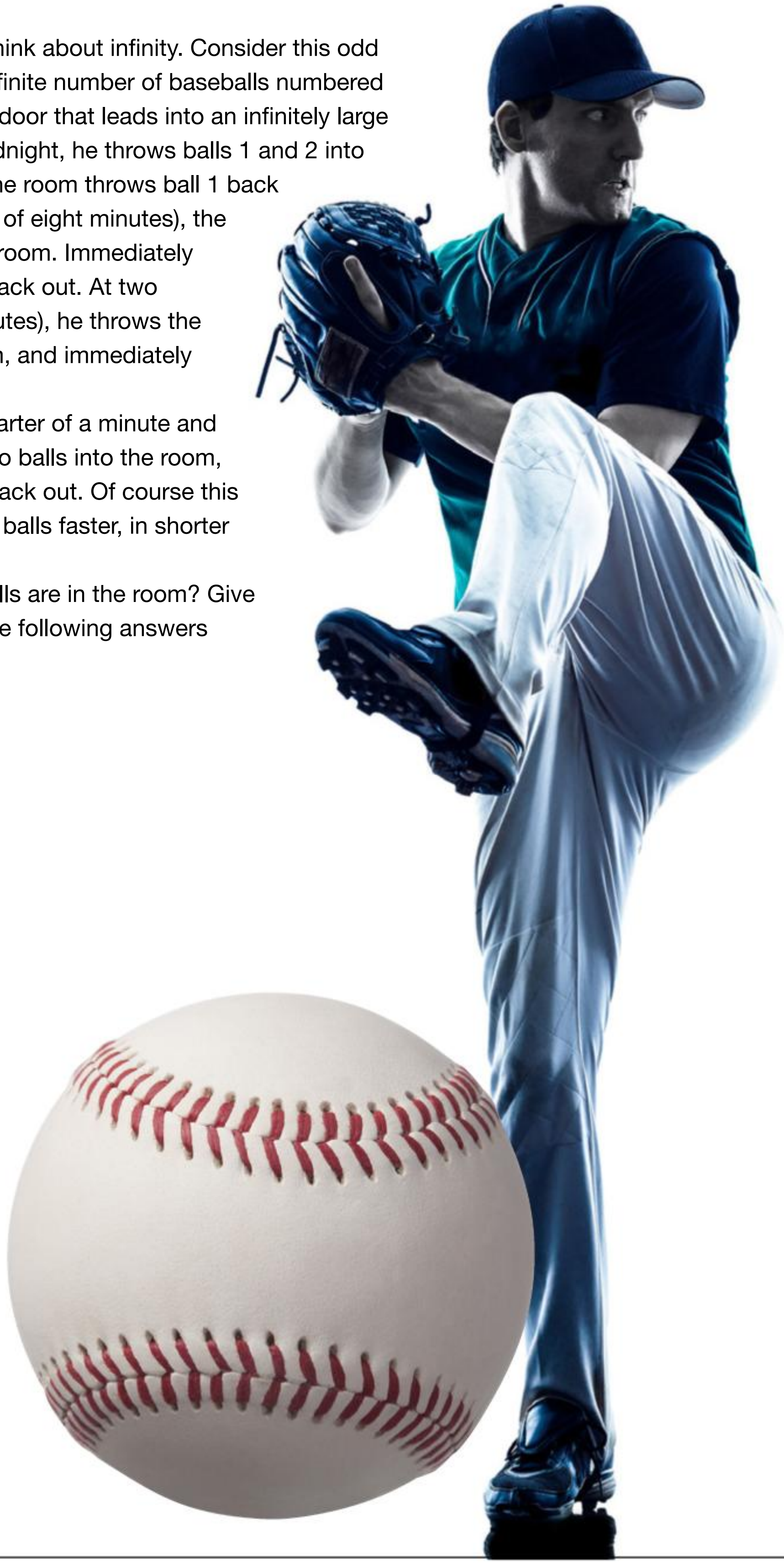
OUT OF THE BALLPARK

Things get strange when you try to think about infinity. Consider this odd situation. At a pitcher's feet are an infinite number of baseballs numbered 1, 2, 3 and so on. In front of him is a door that leads into an infinitely large room. At exactly eight minutes to midnight, he throws balls 1 and 2 into the room. Immediately someone in the room throws ball 1 back out. At four minutes to midnight (half of eight minutes), the pitcher throws balls 3 and 4 into the room. Immediately someone in the room throws ball 2 back out. At two minutes to midnight (half of four minutes), he throws the next two balls, 5 and 6, into the room, and immediately ball 3 is thrown back out.

At one minute, half a minute, a quarter of a minute and so on, the pitcher throws the next two balls into the room, and immediately one ball is thrown back out. Of course this presumes that he can keep throwing balls faster, in shorter amounts of time.

At exactly midnight, how many balls are in the room? Give arguments explaining why each of the following answers could be true.

1. An infinite number
2. Half of infinity
3. Zero
4. None of the above



PITCHER: OSTILL/123RF. BASEBALL: ALDODI/DREAMSTIME.COM

COUNTING HOUSES

You are in charge of ordering big brass street address numbers for houses. To do that, you must figure out how many of each numeral you need. For instance, to make the street number 587585 you would need three 5s, one 7 and two 8s. You would fill in the order form like this:

ORDER FORM

0	1	2	3	4	5	6	7	8	9
0	0	0	0	0	3	0	1	2	0

1. How would you complete the form to order digits for houses numbered consecutively from 1 to 99?

ORDER FORM

0	1	2	3	4	5	6	7	8	9

2. How would you complete the form to order digits for houses numbered consecutively from 1 to 999?

ORDER FORM

0	1	2	3	4	5	6	7	8	9

3. Below is a form for purchasing only the numerals 0, 1, 2 and 3. You are ordering digits for a house with the street number 1210. Oddly enough, the numbers you've filled in are exactly the same as the street number itself: one 0, two 1s, one 2 and zero 3s.

ORDER FORM

0	1	2	3
1	2	1	0

What other four-digit street number counts its own digits?

ORDER FORM

0	1	2	3

4. Here is another form for ordering all 10 digits. What 10-digit number counts its own digits? There is only one correct answer. *Hint: The number contains many zeros.*

ORDER FORM

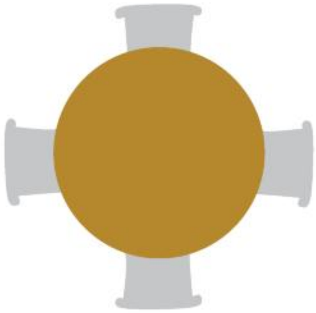
0	1	2	3	4	5	6	7	8	9

HOMES: RUDMER ZWERVER/123RF. NUMBERS: DEFOTOBERG/123RF

PERMUTATIONS

MUSICAL CHAIRS

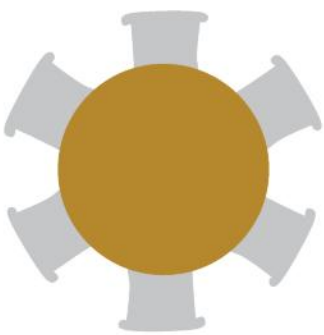
Combinatorics is the study of the different ways in which collections of objects can be grouped, ordered and counted. One of the oldest branches of mathematics, it is fundamental to many fields, including thermodynamics, probability theory and economics.



1. **[TRICKY]** Two couples — the Reds and the Blues — have dinner together every Sunday, seated around a table with four chairs. To keep things fresh, they like to switch chairs. How many weeks can they have dinner together and sit in a different arrangement each time?

2. **[TRICKY]** How many weeks can they have dinner together in different combinations if the members of each couple always sit across from each other?

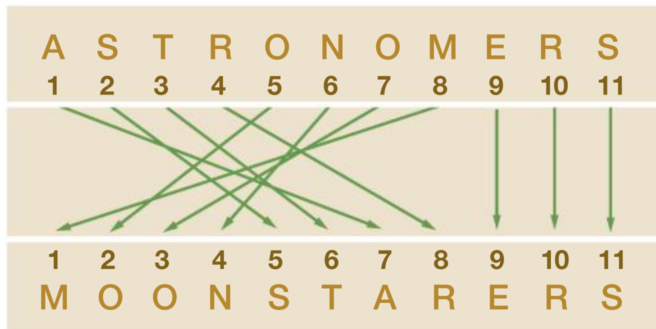
3. **[TRICKY]** How many weeks can they have dinner together in different combinations if the members of each couple always sit next to each other?



4. **[DIFFICULT]** Suppose the Reds and the Blues are joined by the Grays to make six people sitting in six chairs. Now answer the three previous questions.

ANAGRAMS

If you rearrange the letters in ASTRONOMERS, you can make the appropriate anagram MOON STARERS. Mathematicians call such a rearrangement pattern a permutation. This particular permutation is written as (7 5 6 8 2 4 3 1 9 10 11). Each number in the permutation tells you the new position of each successive letter: In ASTRONOMERS the first letter (A) moves to position 7 in MOON STARERS, the second letter (S) moves to position 5, the third to position 6 and so on.



1. **[EASY]** What appropriate anagram do you get from ASTRONOMERS by using the permutation (9 7 8 10 2 1 4 3 6 5 11)? *Hint: The answer has three words.*

2. **[TRICKY]** Can you match the scientific anagrams below with the correct permutation?

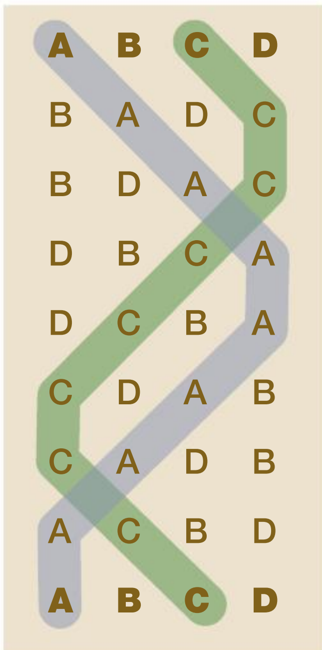
Anagrams	Permutations
A L B E D O / D O A B L E	1 2 3 5 6 4
S I L V E R / L I V E R S	3 5 4 6 1 2
P R O T O N / P R O N T O	6 2 1 3 4 5

RINGING IN THE CHANGES

Change ringing is music that is made by bells in mathematical patterns. A group of people stands in a tight circle in a bell tower. Each person pulls on the rope of one bell. Typically, there might be six to eight bells.

The bell ringers play a pattern that is made by sounding all the bells one at a time in a sequence, followed by another sequence that differs from the first only in that one or more adjacent notes have been swapped. A series of such sequences is called a peal. By convention, every sequence in a peal must be different, so with four bells a peal can be at most 24 sequences long. Peals with more bells can take hours to play.

Many pleasing peals have been composed over the centuries. Shown is a peal called "Plain Hint Minimus." Each letter stands for one of four bells. Notice how the position of each bell weaves its way through the pattern like a strand in a braid.



1. **[EASY]** Follow the paths of bells B and D in the sequence above. How are they related to the positions of bells A and C?

2. **[TRICKY]** The sequence of bells in this peal starts A B C D B A D C B D A C.

3. **[DIFFICULT]** Suppose you make a peal by using the permutations (2 1 3 4), (1 3 2 4) and (1 2 4 3) in order, over and over. How many sequences must you play until you return to the original sequence?

FIBONACCI'S RABBITS

In 1202, Leonardo Pisano, better known as Fibonacci, wrote a book containing the following problem: A man puts a pair of rabbits in a pen. How many pairs of rabbits will be produced from that pair over a year if each pair gives birth to a new pair (one male and one female) once a month, starting two months after birth? The diagram shows the family tree for the first six months. Each rabbit pair takes two months to mature before starting to spawn more rabbits. The monthly totals (1, 1, 2, 3, 5, 8 . . .) are known as the Fibonacci sequence, one of the most intriguing sequences in mathematics.

Fibonacci

1. Notice that each number in the Fibonacci sequence is the sum of the previous two numbers: 1 + 1 = 2, 1 + 2 = 3, 2 + 3 = 5 and so on. There are eight pairs of rabbits in month 6. How many rabbit pairs will there be in month 12?

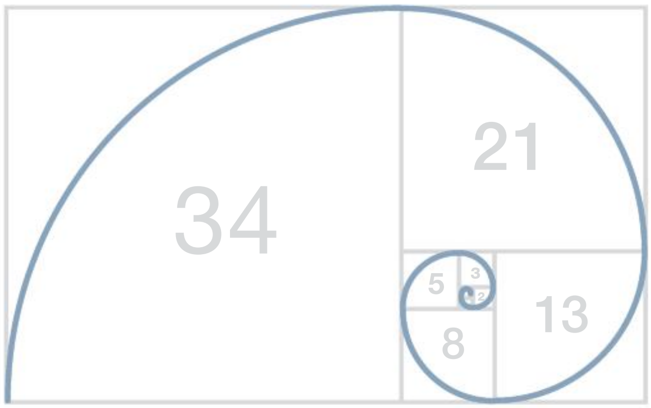
2. If each pair of rabbits started reproducing after one month instead of two, how many pairs of rabbits would there be in month 12? *Hint: Draw the family tree for the first few generations, count the rabbit pairs in each generation, and look for a pattern in the numbers.*

3. How many pairs of rabbits would there be in month 12 if each pair took three months to start reproducing instead of two?

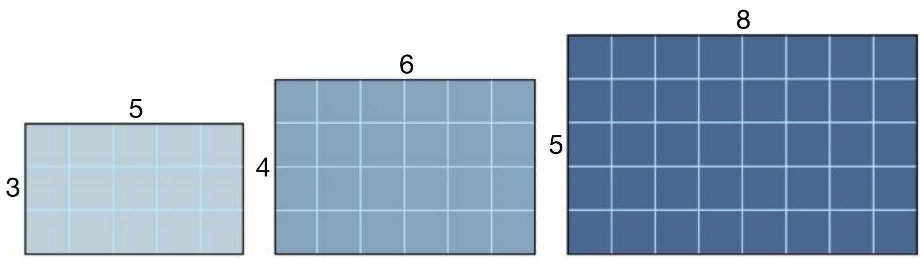
4. How many pairs of rabbits would there be in month 12 if each pair of rabbits spawned a new pair after one month and a second pair after two months, then stopped reproducing?

THE GOLDEN RATIO

If you divide a Fibonacci number by the previous one in the sequence, you get an approximation of a famous number called the golden ratio (1.61803399...). The further you go in the sequence, the more accurate the approximation. For instance, 5 divided by 3 is 1.666 . . . but 13 divided by 8 is 1.625. The golden ratio appears in the Parthenon, Leonardo da Vinci's paintings, Frank Lloyd Wright's architecture, even office supplies. American index cards come in three common sizes: 5x3, 6x4 and 8x5 inches. Notice that 5/3 and 8/5 are ratios of consecutive Fibonacci numbers, while 6/4 (1.5) is the best fractional approximation of the golden ratio with 4 in the denominator.



The golden ratio



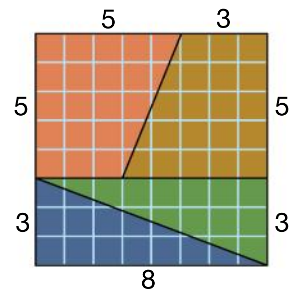
1. Suppose index cards came in other sizes that approximated the golden ratio and that the dimensions must always be whole numbers of inches. If the short dimension of an index card were 2 inches, what should the long dimension be to best approximate the golden ratio? What if the short dimension of an index card were 6, 7 or 8 inches?

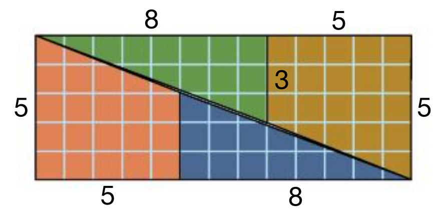
2. American stationery (11x8½ inches) deviates considerably from the golden ratio. Is this rectangular proportion more skinny or more squat than the golden ratio?

3. How do the proportions of European stationery (297x210 millimeters) compare with the golden ratio? American business cards (3½x2 inches)? The aspect ratio of traditional television sets (4x3)? High-definition televisions (16x9)?

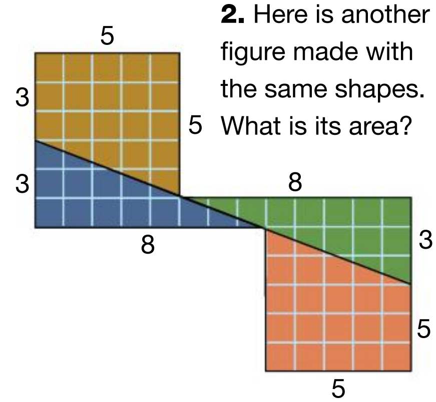
AREA PARADOX

1. The Fibonacci sequence is the basis of this tantalizing paradox. The figure below has an area of 8 x 8 = 64 squares. If you cut it up into four pieces as shown in the diagram, you can make another figure that has an area of 5 x 13 = 65 squares. Where did the extra area come from?





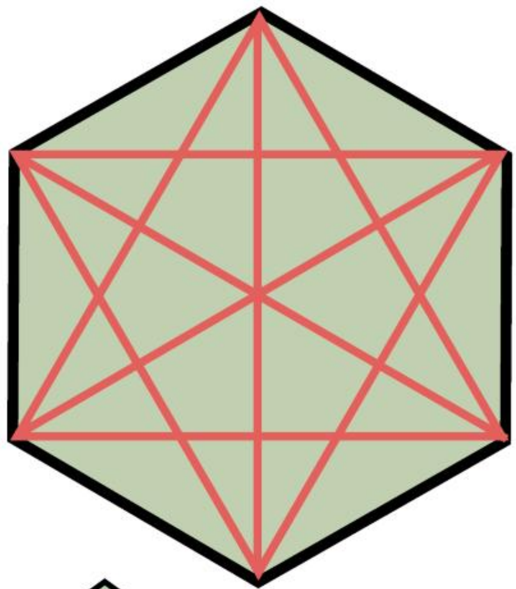
2. Here is another figure made with the same shapes. What is its area?

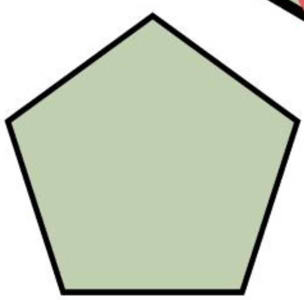


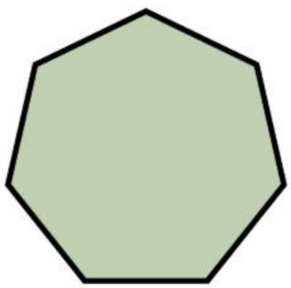
3. Notice that all the numbered lengths here are Fibonacci numbers. What happens if you replace every number with the next number in the Fibonacci sequence? Does the paradox still work?

DRAW THE LINE

Let’s start things off small and simple, with a hexagon. A diagonal is a line that joins two nonadjacent corners of a polygon. The nine diagonals of a hexagon appear in red.





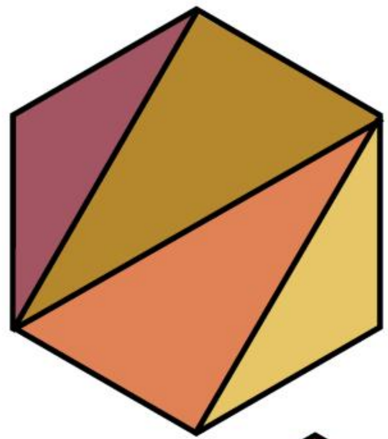


1. How many different diagonals can you draw in the pentagon? In the heptagon?

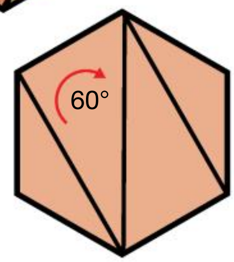
2. To get a handle on abstract problems, mathematicians examine specific examples and look for general patterns. Without drawing anything, can you predict how many diagonals you can draw in a nonagon? A decagon? *Hint: Look at the number of diagonals in a square, a pentagon, a hexagon and so on, and try to find a pattern.*

HOW YOU SLICE IT

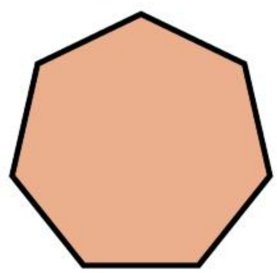
To dissect a figure is to cut it into pieces, like the parts of a jigsaw puzzle. The hexagon below has been dissected into four triangles by three diagonals. Note that the diagonals do not intersect.

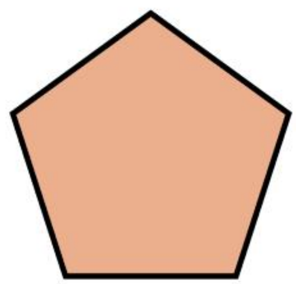


1. How many different ways are there to dissect a hexagon into triangles using only nonintersecting diagonals? (Dissections that differ by rotation or reflection are considered different. For instance, the hexagon above rotated by 60° or 120° would constitute a different dissection. If rotated by 180°, however, it yields the same configuration as the one shown, so that would not be considered a different dissection.)



2. Now go further: How many triangles can you cut a pentagon into using nonintersecting diagonals? How many for a heptagon?

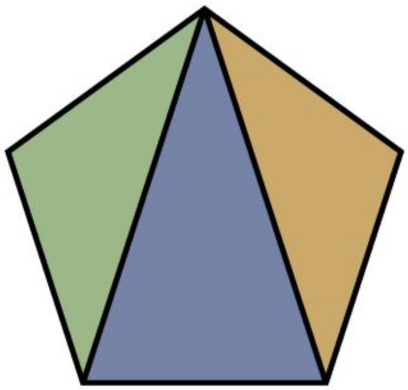




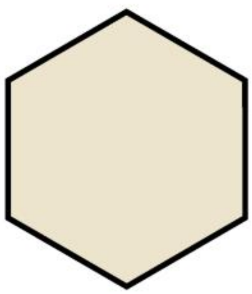
3. Without drawing anything, can you predict how many triangles you can cut an octagon into, using only nonintersecting diagonals? A nonagon? *Hint: Again, look at the pattern in the number of triangles for a square, a pentagon, a hexagon and so on.*

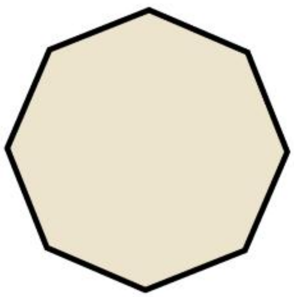
PEAK PERFORMANCE

An isosceles triangle is a triangle that has at least two sides of equal length. (An equilateral triangle, which has three sides of equal length, also counts as an isosceles.) This pentagon is dissected into three isosceles triangles with nonintersecting diagonals.

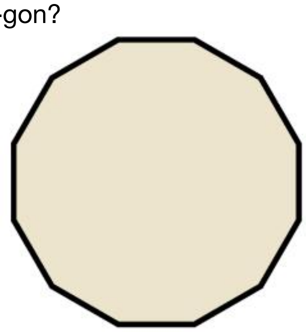


1. Can you dissect the hexagon and the octagon into isosceles triangles using only nonintersecting diagonals?





2. Go further. Can you dissect a dodecagon (a 12-sided polygon) into isosceles triangles using only nonintersecting diagonals? Without drawing anything, can you imagine how to do the same for a 24-gon or a 48-gon? How about an 80-gon?



ALISON MACKEY/DISCOVER

MISSING NUMBERS

1. [EASY]

Fill each yellow square with an operation (+, –, x, /) so that each row and column makes a true equation. You may add parentheses as needed — for instance, to make the middle row true, you must interpret it as (5 – 4) x 2 = 2, which is correct, rather than, say, 5 – (4 x 2) = 2, which is false.

10		9		1	=	1
5	–	4	x	2	=	2
3		8		7	=	3
=		=		=		
6		5		-4		

2. [TRICKY]

Fill each green square with a positive single-digit number so that each row and column makes a true equation. Again, add parentheses as you wish.

4	x		/		=	6
+		–		–		
	+		–		=	2
+		x		+		
	x		/	10	=	½
=		=		=		
8		10		8		

3. [DIFFICULT]

Fill each yellow square with an operation (+, –, x, /) and each green square with a different number (from 1 to 9) so that each row and column makes a true equation. Every number 1 to 9 will appear just once. Use parentheses when needed.

	/		x		=	1
–						
					=	22
+						
	+		–		=	3
=		=		=		
6		-5		4		

The Shape of Things

ILLUSTRATIONS BY KELLIE JAEGER/DISCOVER UNLESS NOTED

Cover-Up

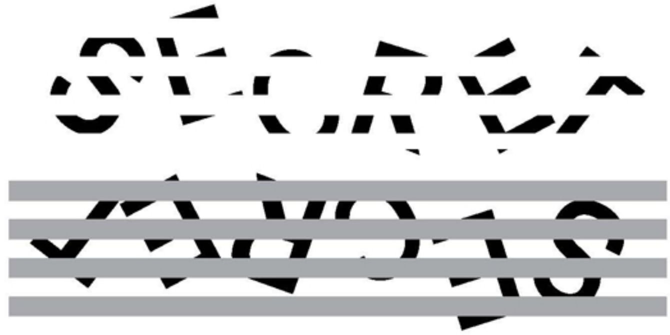
Why the brain gets tricked by optical illusions.

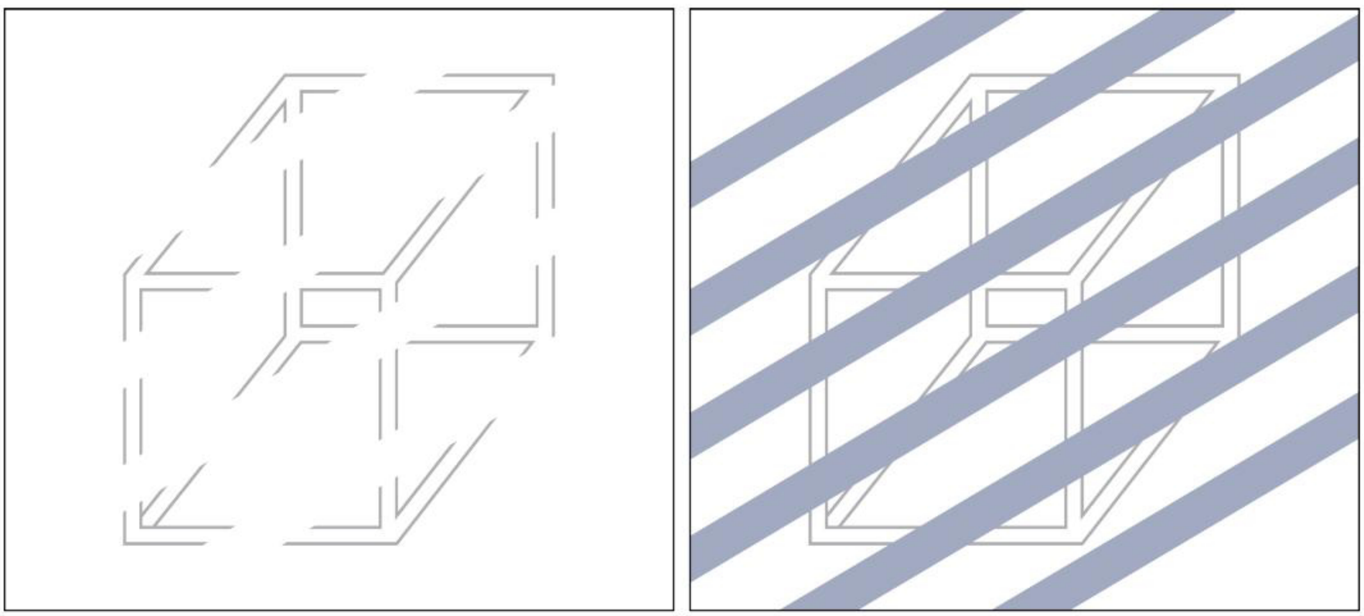
The page you are reading now looks flat and feels flat, but your brain isn't so certain. That's because when the brain evolved into its current form about 30,000 years ago, it was programmed for interpreting 3-D objects — especially predators — not images on flat surfaces. As a result, your brain plays tricks on you. For example, the dimensions of the two tabletops above look different, but they are actually identical. The front edge of the table on the left is the same length as the left edge of the table on the right, but it looks shorter because perspective makes it appear closer and therefore smaller. Similarly, the front and rear edges of the right-hand table are actually the same length as the apparently receding long edges of the left-hand table. Although many optical illusions depend upon erroneous transformations of two dimensions into three, your brain's tendency to project depth onto flat surfaces can occasionally help it correctly interpret what it sees.

ROEN KELLY/DISCOVER

EXPERIMENT 1

Examine the figure on the top, then rotate the page 180 degrees and study the figure below it. The letter fragments in both figures are identical, but those covered by the gray bars are easier to read. This is because your brain interprets the bars as being in front of the letters, and so they “fill in” the blanks to create the perception of a single word as opposed to isolated, fragmented letters.





EXPERIMENT 2

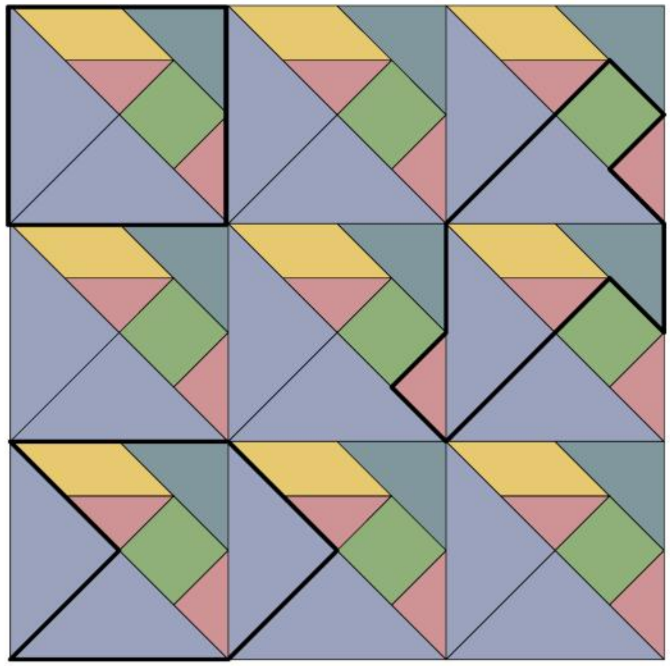
Your brain’s ability to fill in gaps behind obstructions is not restricted to letters and words. Notice how much more “together” the cube on the right seems than its neighbor, even though it contains no more information.

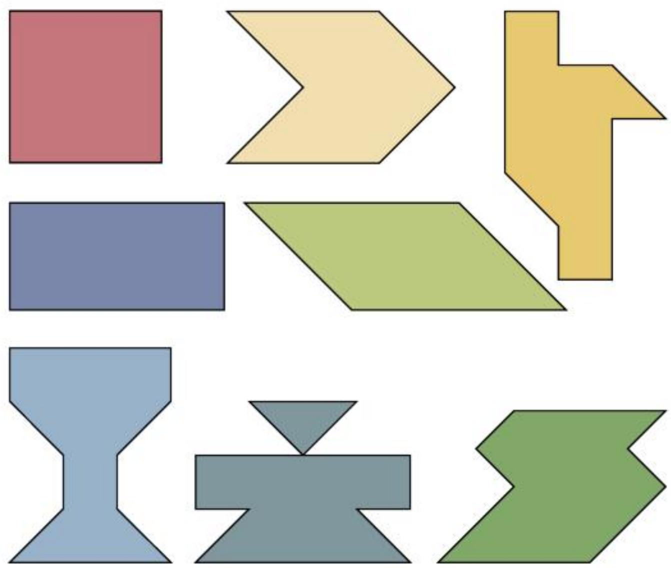
Such perceptual anomalies, known as occlusion effects, provide neuroscientists with clues about how the brain processes information. For example, by studying electrical responses of visual neurons to fragmented visual stimuli, a research team at MIT discovered that the filling in of missing information occurs in the tiniest building blocks of our nervous systems: individual nerve cells.

Given that our brains happen to be wired this way, it appears that we are doomed forever to read not just between the lines, but behind them as well.

TANGLED TANGRAMS

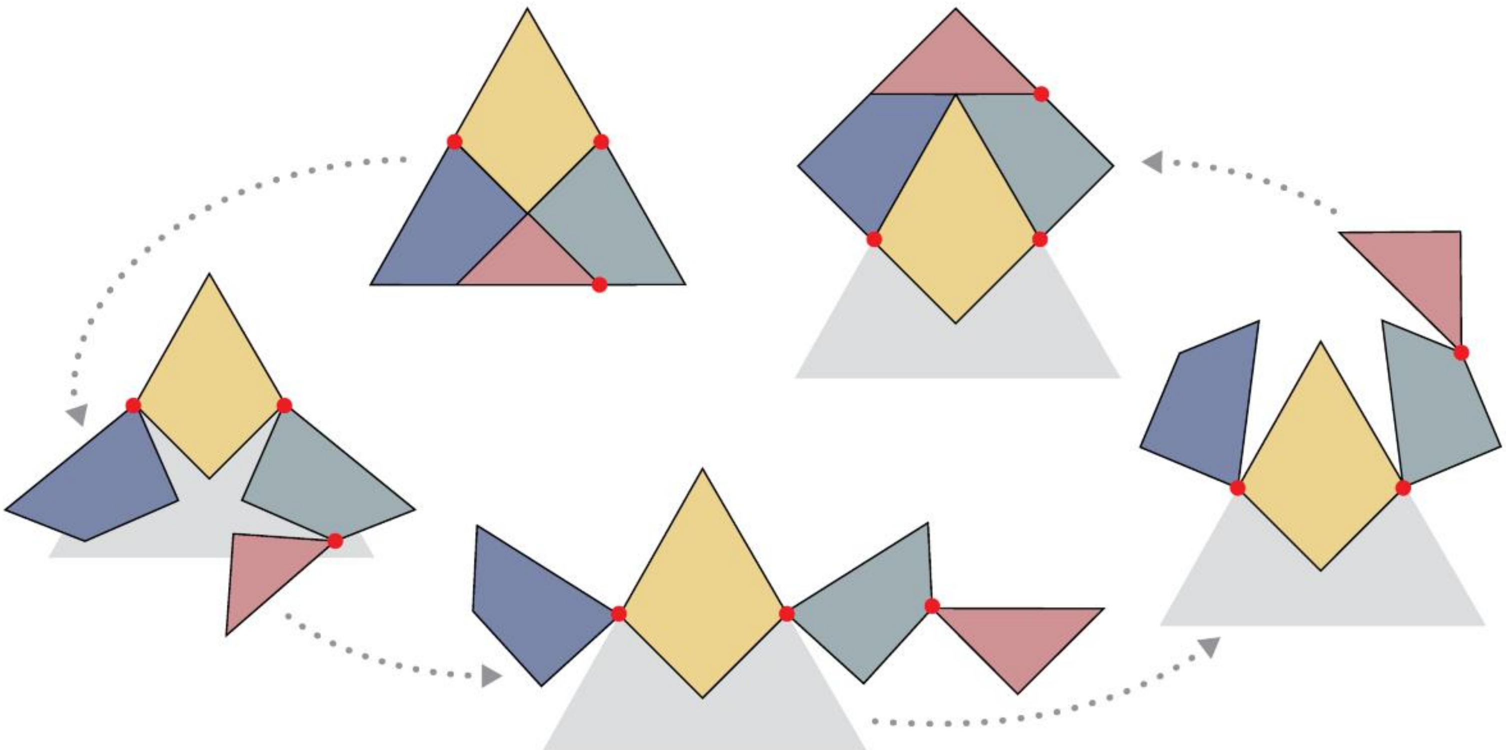
A tangram is a puzzle formed by cutting a square into seven simple geometric pieces — five isosceles right triangles, one rhomboid and one square. These pieces can be reassembled to make other geometric shapes as well as playful, stylized figures of humans and animals. Tangrams were invented in China hundreds of years ago. The oldest known set, carved from ivory in 1802, is shown below. Tangram books published in China in 1858 include 789 figures, each one made using all seven tangram pieces. Today tangrams are commonly used in elementary school classrooms to teach geometry, fractions and spatial reasoning.





A grid of nine tangram squares appears above. Eight geometric figures are shown below the grid. Each figure comprises all seven tangram pieces. Three of these eight figures are outlined in the grid. Can you find the outlines of the other five figures? Hints: Figures may be rotated and may appear more than once. Some may overlap.

TANGRAM: THE SLOCUM PUZZLE FOUNDATION



HINGED DISSECTIONS

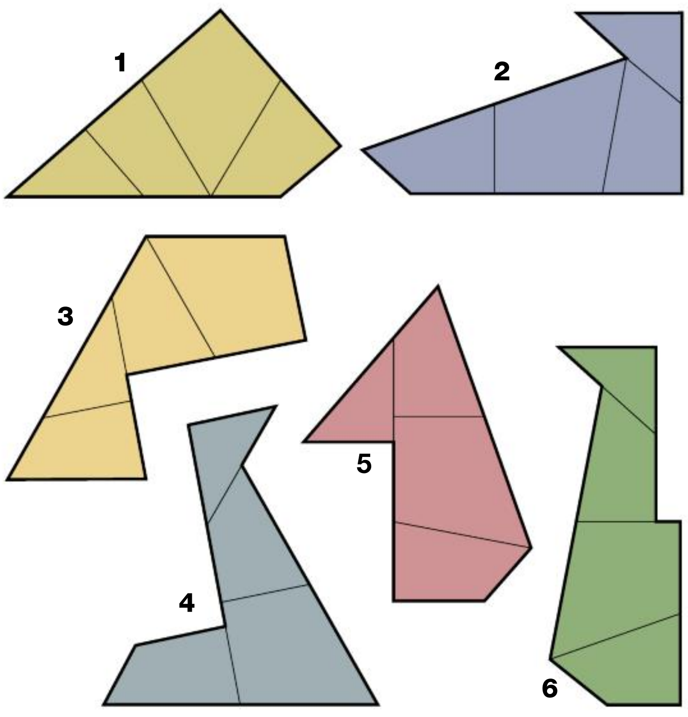
Tangrams are just one of a large class known as dissection puzzles. Another variety makes use of "hinges" to transform the pieces of one shape into another. As you can see above, pieces of this triangle can swing around hinges at corners as the triangle turns into a square.

By swinging individual pieces, you can transform the hinged construction into a variety of shapes.

1. In each figure at right, identify a single piece you could swing to turn either into a triangle or a square.

2. Which figure requires swinging two pieces of the hinged construction to form a triangle or a square?

3. In which figure would the swinging piece collide with another piece before it reached its destination?

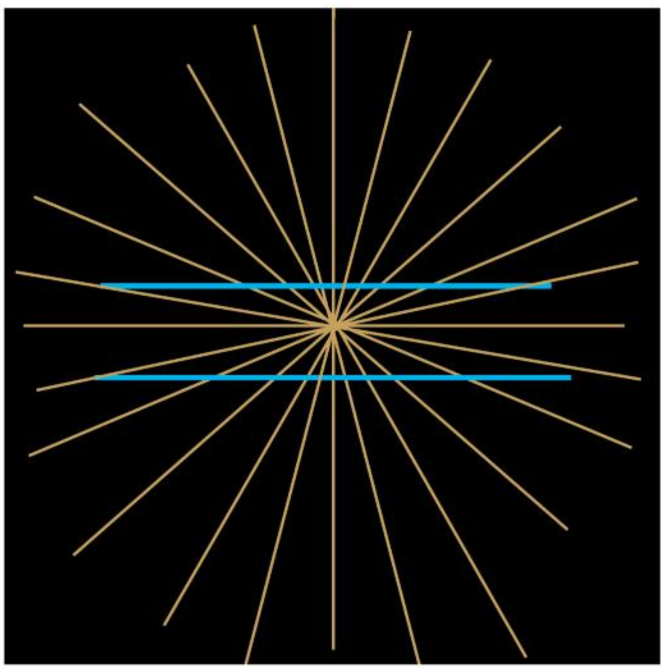


Bugs in the Brain

Find glitches in your neural software.

Anyone whose laptop has crashed in the middle of a project has come face to face with a computer bug. Software engineers sometimes inadvertently create these defects by taking shortcuts to reduce the amount of memory or processing power needed for a particular application. Despite causing occasional hiccups, such economies make computers more affordable.

Our brains also must occupy a limited space and resort to shortcuts to conserve computational resources. A few of these little cheats are revealed in the following experiments.



EXPERIMENT 1

Take a quarter, place it on the floor, and walk away slowly while keeping your eye fixed on the coin. The image of the quarter shrinks on your retinas as the distance between the coin and you grows. Still, you don't perceive the coin as smaller; it's just farther away. That's because your brain magnifies images of distant objects to compensate for their small size on your retina. The phenomenon is called size constancy, and it helps you accurately estimate the dimensions of things in everyday life — most of the time. But in some circumstances, defects in the size constancy "program" can be misleading.

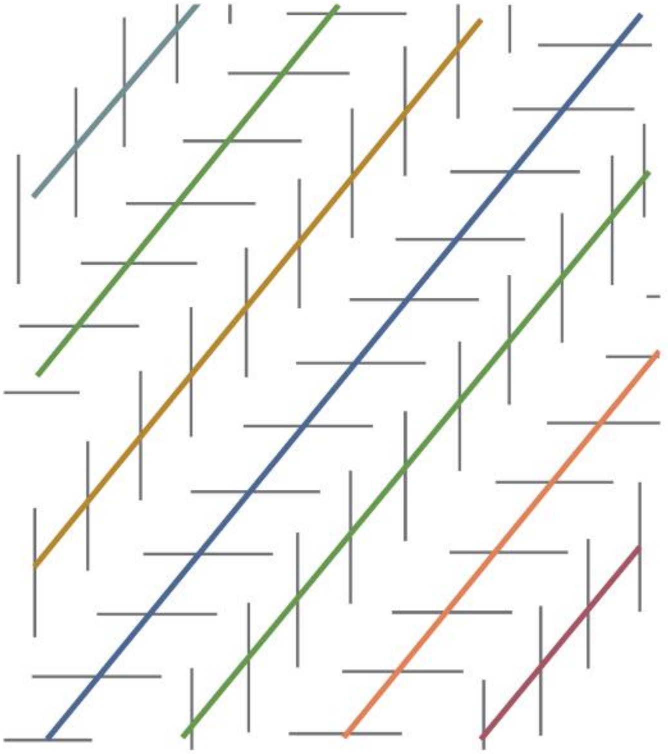
For example, take a ruler and examine the starburst figure at left. The turquoise lines look curved, but if you measure the space between them, you'll find that your brain is deceiving you. Its software assumes that the center of the image, where the yellow spokes converge, is farther away than the periphery of the figure and so magnifies the space between the turquoise bars.

EXPERIMENT 2

Errors in estimating distances also cause the tilt of the colored parallel lines, atop the opposite page. (If you don't believe they're parallel, get out the ruler again.)

Notice that the gray hash marks between the purple and green lines angle toward each other, as though forming arrows, and point toward the upper ends of these two colored lines. Also note that the purple and green lines seem farthest apart at these ends. In all likelihood, the brain interprets the upward progression of the hash marks, from the bottoms of the lines to the tops, as a gradual increase in their distance from the eye. In response, it magnifies the space between the purple and green lines at their uppermost, or "farthest," points.

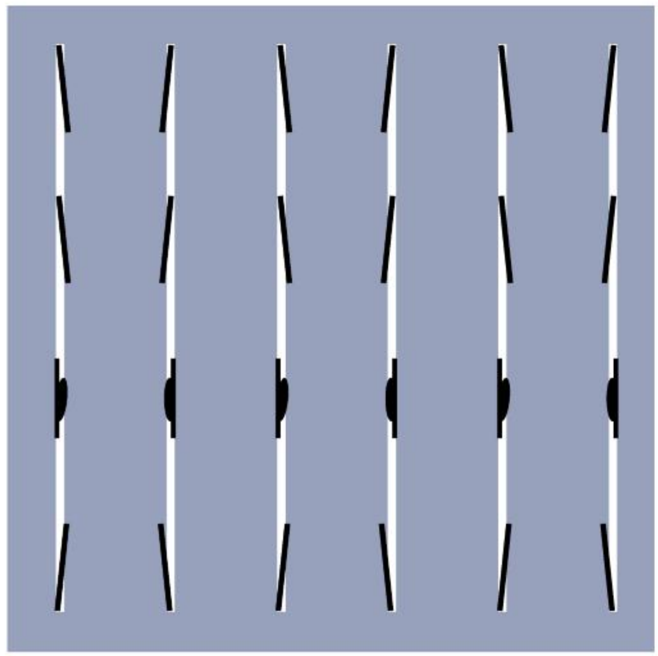
ROEN KELLY/DISCOVER

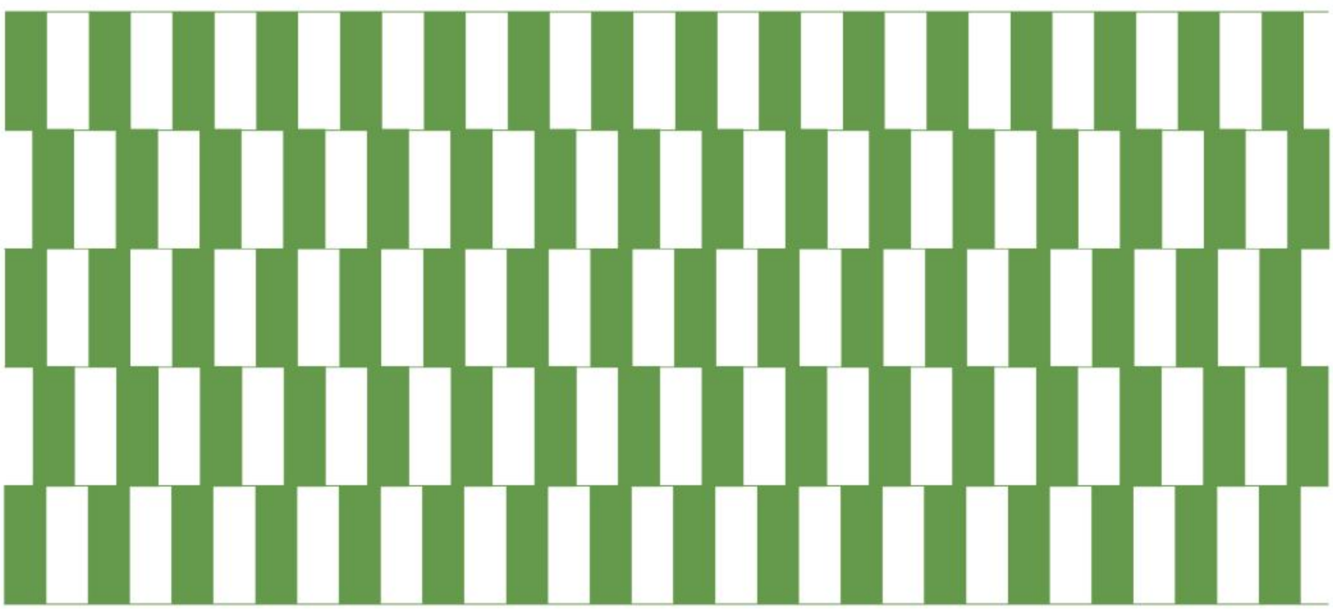


Although definitive explanations for these two illusions haven't been found, brain scientists keep searching. A deeper understanding of neural miscalculations will yield valuable insights into how the nervous system processes information. Despite its bugs, the brain is still the supreme computing machine, so figuring out how it works will help scientists design ever more powerful computers — perhaps ones that think as we do.

EXPERIMENT 3

Researchers, however, do not believe that size constancy causes the thin horizontal lines in the green image below to tilt in on each other (note that the bars are all the same size) or that it makes the straight white lines in the purple image at right bow in and out. In these illustrations, there are no cues, such as converging lines, to suggest increasing depth or distance.





BLOCK PARTY

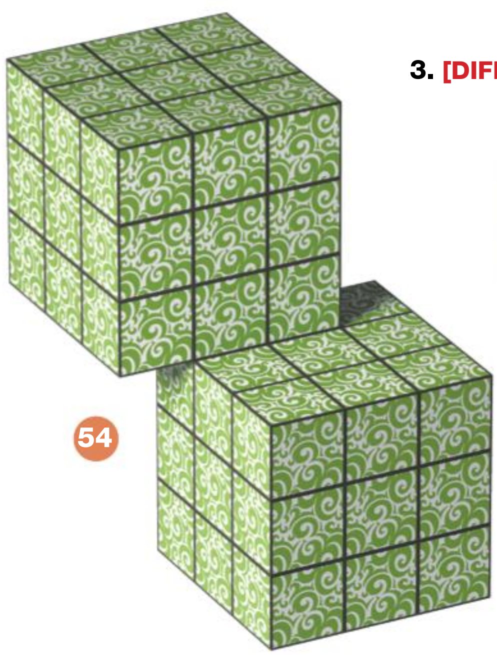
BUILDING OUT

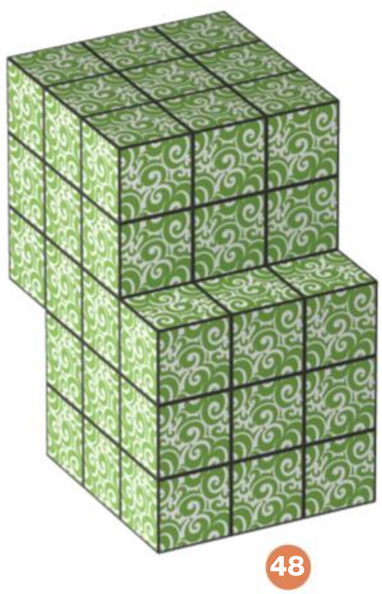
Each series shows the first three shapes in a progressive sequence. For instance, in series 1 the shapes increase from one to six and then to 18 cubes. How many cubes are in the next shape in each sequence? You may assume that hidden cubes are where you expect them to be.

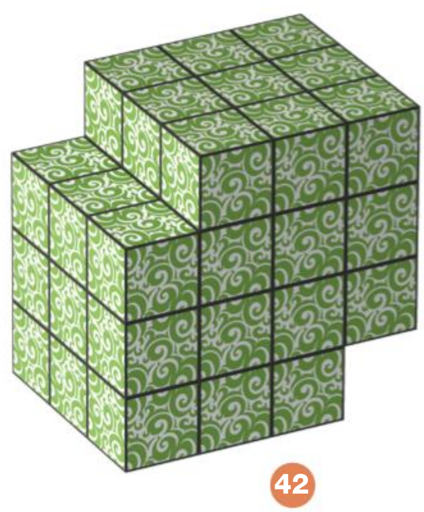
1. [EASY]

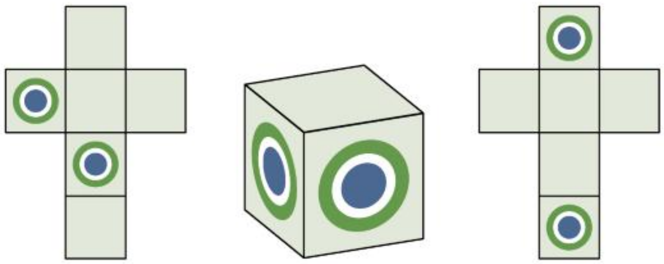
2. [TRICKY]

3. [DIFFICULT]



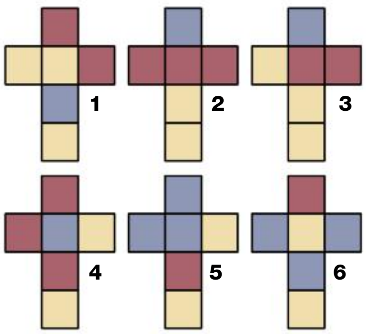




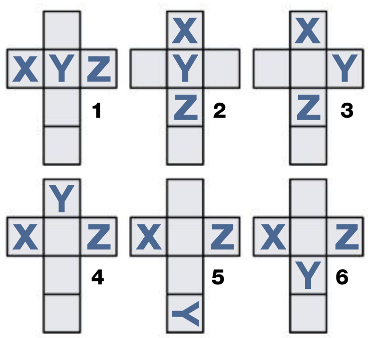


FOLDING IN

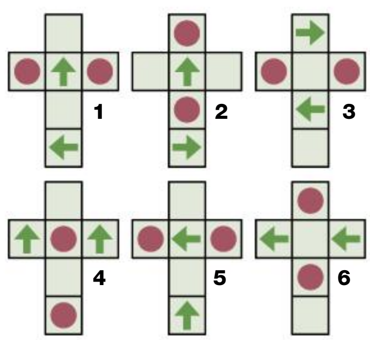
Find a pair of patterns in each set below that could be folded to create identical cubes. For instance, the two patterns above could both be folded into a cube with targets on adjacent faces.



1. [EASY]
Hint: Count the squares of each color.



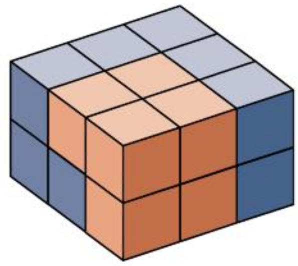
2. [TRICKY]
Hint: Some letters look the same no matter how they're rotated.



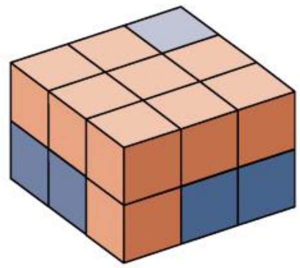
3. [DIFFICULT]
Hint: The red dots are always on opposite faces.

STACKING UP

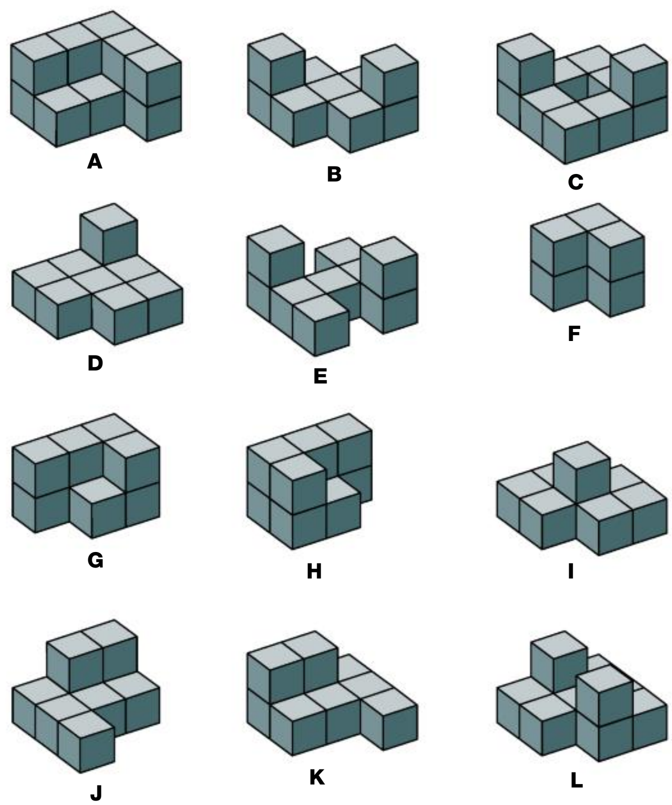
Fit each figure below with another figure to complete a solid 3x3x2 block. You can rotate figures — for example, figure *F* can be rotated to fit into figure *A* — but you can't use mirror reflections to complete a figure. In some cases a figure can fit with a copy of itself to form a block. *Hint: Think of each figure in terms of a top layer of cubes and a bottom layer of cubes.*



A + F = BLOCK



D + D = BLOCK



RUBIK'S CUBISM

Ernő Rubik, a lecturer at the Academy of Applied Arts and Design in Budapest, made the prototype of his famous cube in 1974 as an exercise in design and structural problem-solving. In the process, he created a puzzle of almost limitless possibilities. This array of small cubes, known as cubies, can be twisted and turned into 43 quintillion different configurations.

THE CUBIES

Fresh out of the package, all nine cubie faces on each side of a Rubik's Cube are the same color. An internal mechanism lets you twist any 3x3 slice of cubies by 90 degrees. After just a few twists, the colors become hopelessly mixed up. The challenge is to twist the scrambled cubies back to their original positions.

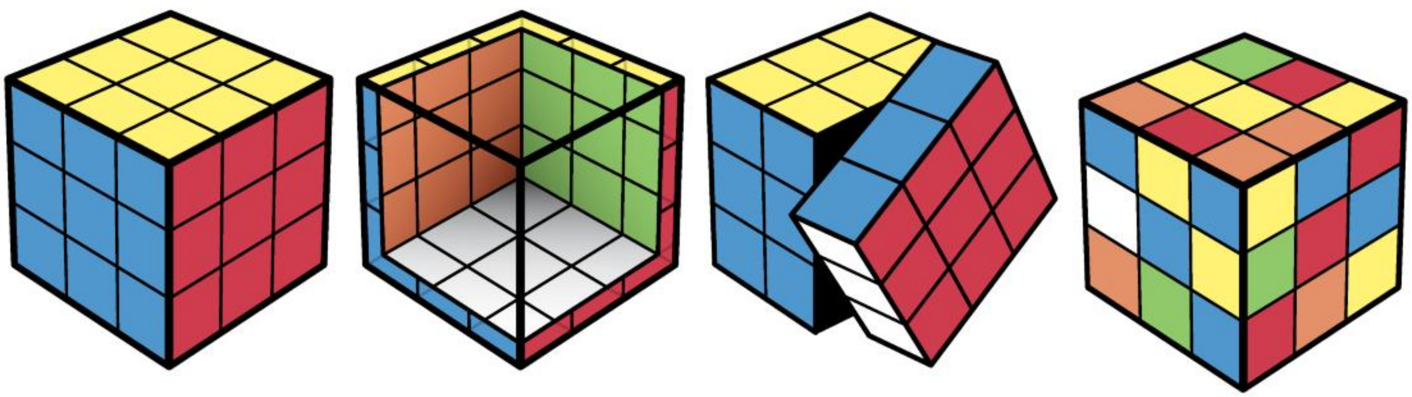
1. [TRICKY] Imagine that a Rubik's Cube is composed of 27 (3x3x3) cubies. (In an actual Rubik's Cube, the cubies are not full cubes, and there's no center cube.) Only the outside faces of the cube are colored; all inside faces are black. How many of the cubies are colored on one side? On two sides? On three sides? Four? Five? Six? No sides?

2. [EASY] Which pairs of colors never appear together on the same cubie?

3. [EASY] How many different ways are there to twist a face of a Rubik's Cube by 90 degrees?

4. [TRICKY] When you twist one face, which of the 27 cubies stay in the same position?

5. [TRICKY] Suppose you are trying to twist a mixed-up cube back to its original position. How can you tell which face should be which color?



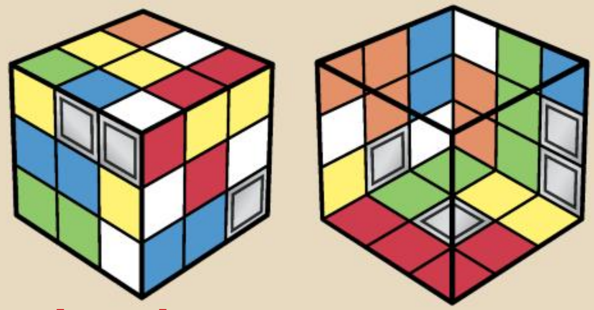
Starting position (front and inside) Twisting Scrambled

TOP: WILLIAM ZUBACK/DISCOVER. BOTTOM: ROEN KELLY/DISCOVER

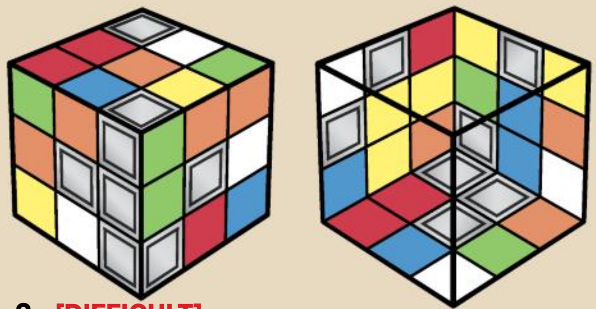
THE COLORS

The colors on a Rubik's Cube are stickers that have been applied to the black plastic cubies. You can even cheat by pulling off the stickers and gluing them back on in the right places. (If you want to indulge in such self-trickery, the official Rubik's site, www.rubiks.com, sells blank cubes and stickers.)

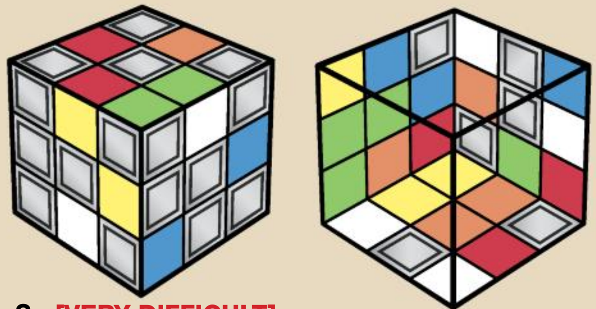
Each pair of diagrams at right shows a mixed-up cube. The diagrams on the left show the front faces of a cube; the diagrams on the right show the back faces of the cube as if the front were transparent. The light gray faces are missing their stickers. Can you deduce the missing colors?



1. [TRICKY]



2. [DIFFICULT]

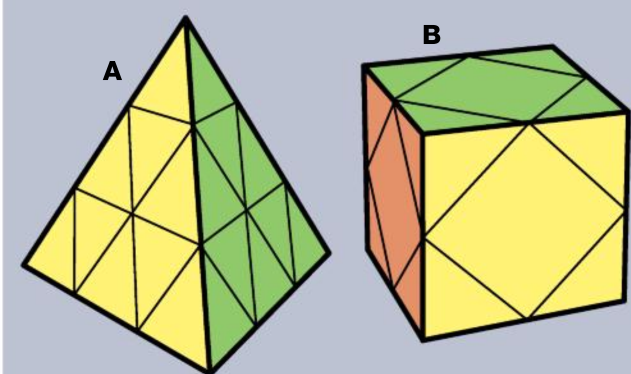


3. [VERY DIFFICULT]

THE VARIATIONS

Like all popular toys, the Rubik's Cube has given rise to a host of competitors. Puzzle inventor Uwe Meffert of Hong Kong (www.mefferts.com) has devised more than a hundred riffs on Rubik's theme, including the Pyraminx (A), which has four triangular faces, and the charmingly eccentric Skewb Cube (B).

As with the Rubik's Cube, you start out by twisting the initially solid-colored faces of the Skewb Cube and the Pyraminx to mix up the colors. The goal is then to unscramble the colors back to their original order.



1. [EASY] How many stickers of how many shapes and colors do you need to cover the surface of the Pyraminx? And of the Skewb Cube?

2. [EASY] A Rubik's Cube has six different faces that can be twisted around three perpendicular axes. How many different twists and how many axes are there for the Pyraminx and the Skewb Cube? *Hint: Each axis for the Pyraminx is perpendicular to a face.*

3. [TRICKY] The faces of the Rubik's Cube are made up of three types of small cubies: eight corner cubies colored on three sides, 12 edge cubies colored on two sides and six center cubies colored on one side. How many types of pieces are in the Pyraminx and the Skewb Cube, and how many of each type?

How Old Is Your Brain?

Neurology doesn't always obey chronology.

If you are 30-something or older, your brain is shrinking. After age 30, the brain loses about a quarter of a percent of its mass every year. Many factors, such as gender (men's brains shrink faster than women's) and alcohol consumption (excess is toxic to brain cells), influence the rate of shrinkage. Edward Coffey and his colleagues at the Henry Ford Health Center have shown, contrary to intuition, that the brains of well-educated people lose tissue faster than the brains of individuals with little education. Two tests of sensory-motor skill can help you determine how fast your brain is shrinking. As preparation, reproduce enlarged versions of Figure 1 and Figure 2 on separate 8½-by-11 sheets of paper, using a pencil and dime to outline the circles. Then turn the sheets over. Take a five-minute break to help you forget where you put the numbers and letters.

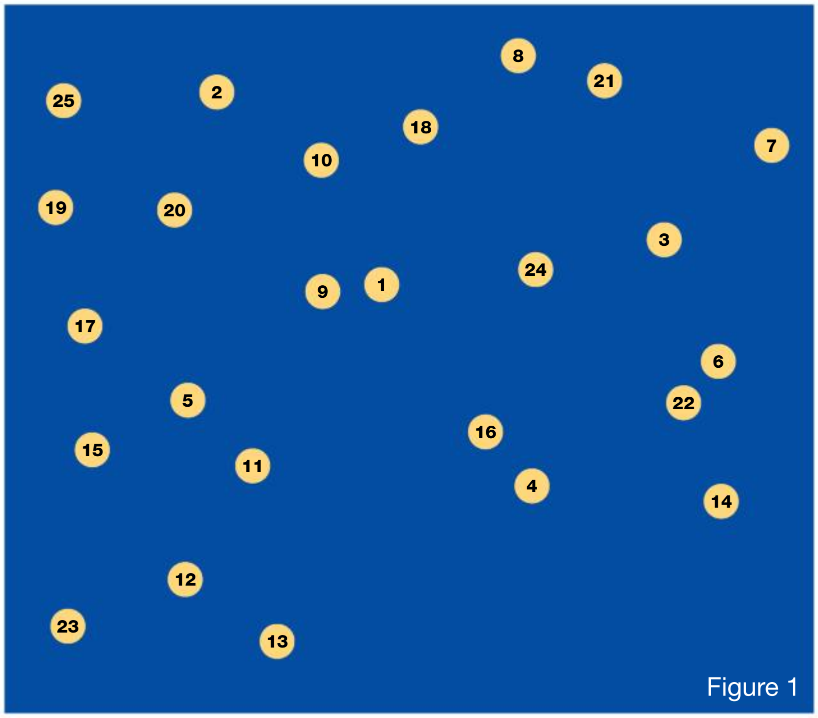


Figure 1

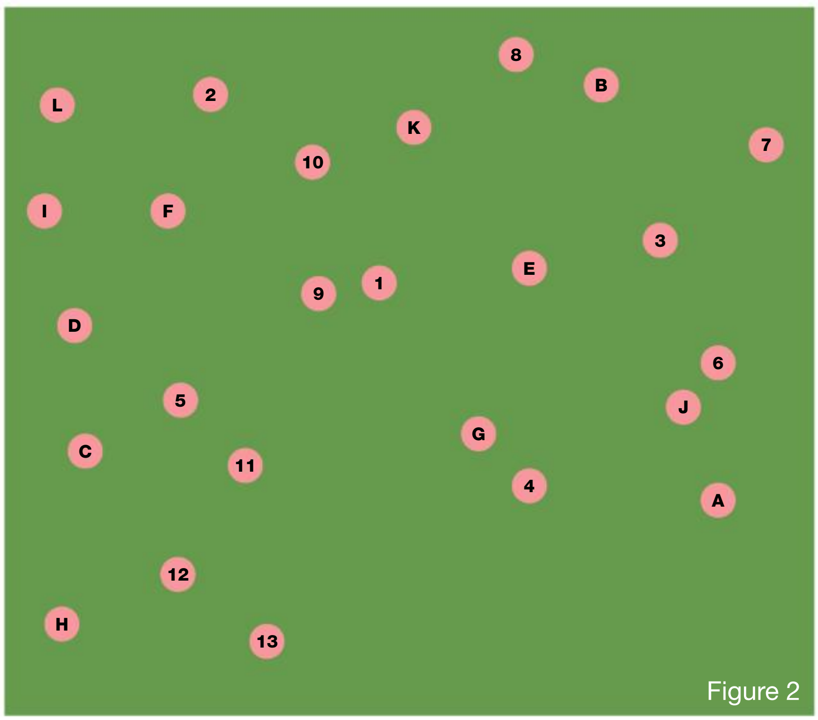
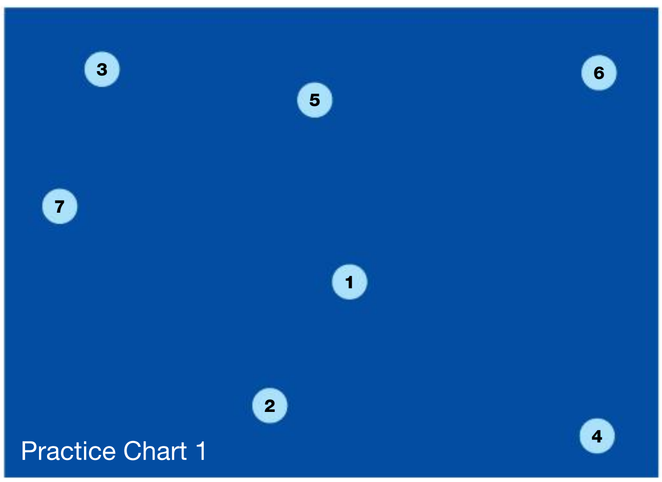


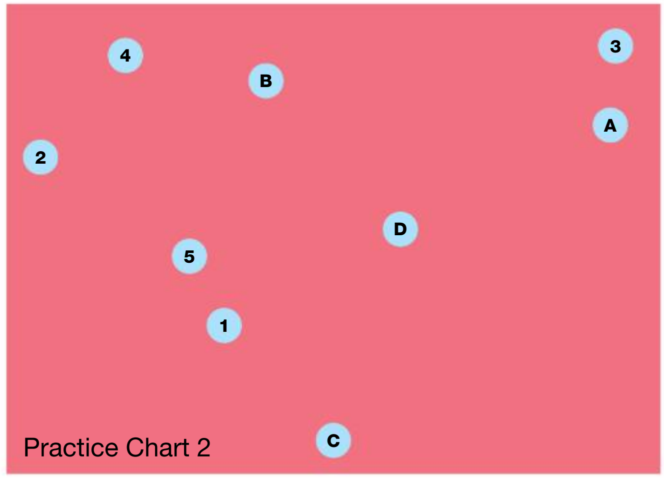
Figure 2

EXPERIMENT 1

Make an enlarged version of Practice Chart 1. As a warmup, connect the numbers on the chart with straight lines without lifting your pencil. Go from 1 to 2 to 3 and so on. Don't worry about circles that get in your way. Then flip over Figure 1. Record how many seconds it takes to trace the sequence from 1 to 25.



Practice Chart 1



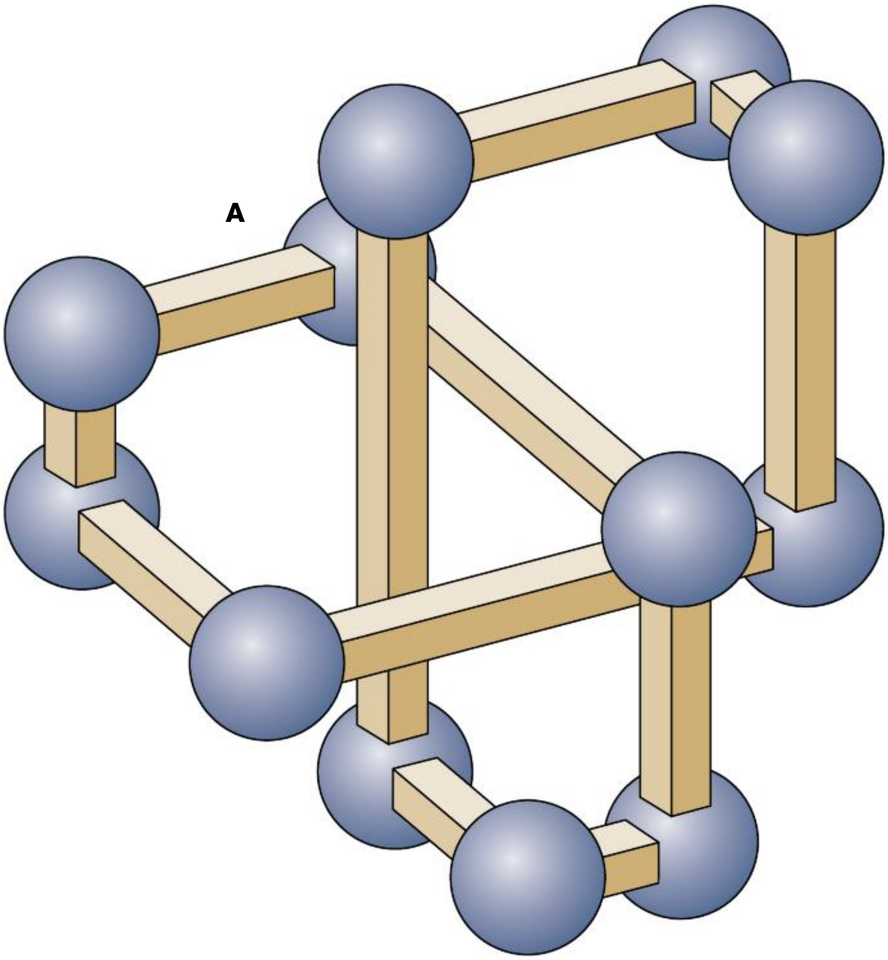
Practice Chart 2

EXPERIMENT 2

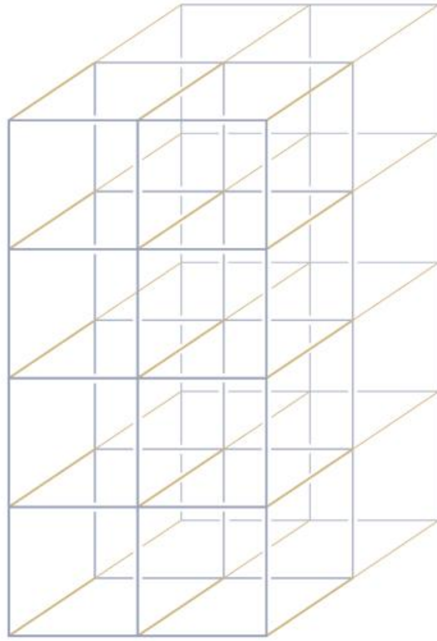
Connect the circles on an enlarged version of Practice Chart 2, jumping from numbers to letters in sequence: 1 to A, A to 2, 2 to B, B to 3 and so forth. When you're ready, turn over Figure 2 and record how long it takes to connect numbers to letters, ending with 13. Add your times for experiments 1 and 2, and consult the table to see what performance is normal for your age. Disappointed with the results? Don't despair. Our brains slow down as we age, but some skills, such as verbal fluency (e.g., recalling six-letter words that begin with the letter S), actually improve throughout most of our lives. And although education may (for unknown reasons) correlate with accelerated brain shrinkage, the more active you keep your brain, the more likely you'll preserve youthful cognitive skills. This principle will come in handy if discovering that your brain is shrinking has aged you a few years.

COMBINED TIMES FOR TESTS 1 AND 2	
Age 20-29	122 Seconds
Age 30-39	114 Seconds
Age 40-49	145 Seconds
Age 50-59	148 Seconds
Age 60-69	228 Seconds

A



B



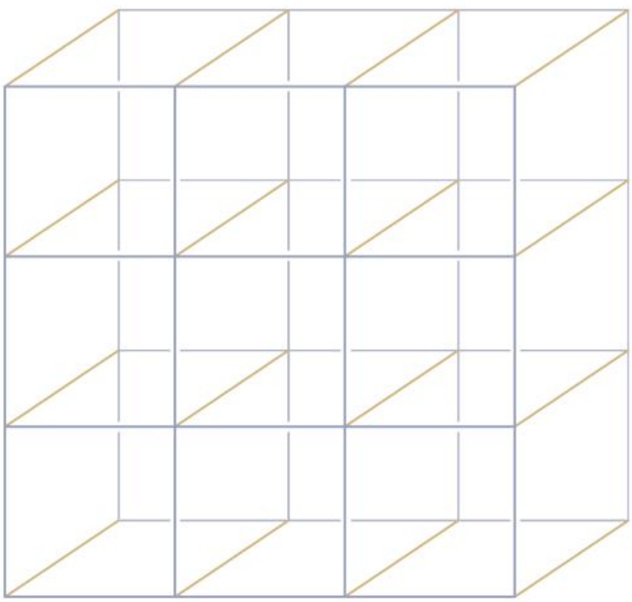
STICK KNOTS

1. **[EASY]** Figure A is a knotted loop made up of 12 straight sticks joined at right angles. If the sticks didn't have to meet at right angles, how could you make a knotted loop with just six straight sticks?

2. **[TRICKY]** Framework B is composed of 96 sticks of equal size. Your challenge is to remove enough sticks from the framework to leave a knotted loop.

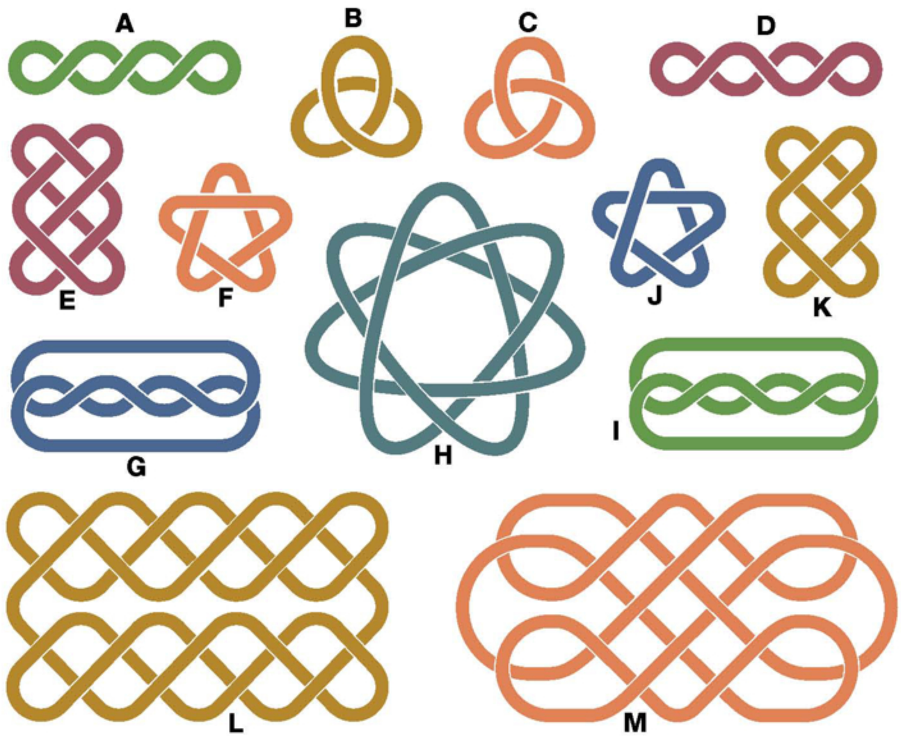
3. **[TRICKY]** Remove some of the 64 sticks from framework C to leave a knotted loop.

C



TRICK KNOTS

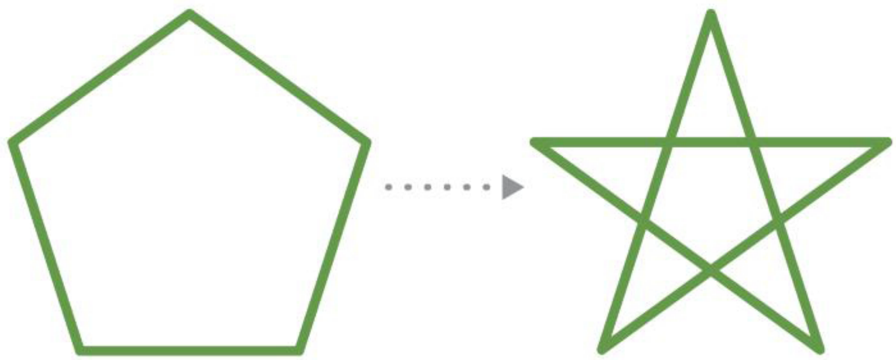
1. [VARYING DIFFICULTY] Which of these loops are knotted? You may bend and stretch the loops, but you may not cut and rejoin them.



STAR FORMATION

1. [TRICKY] Tie together the ends of a 10-foot length of string to make a loop. Find a way for five people to hold the loop at five different points to make a five-pointed star.

2. [TRICKY] Have five people hold five points of the loop of string to form a pentagon, making sure the string is taut. Find a way to smoothly transform the pentagon into a five-pointed star, keeping the string taut throughout the process. Note: You can do this with three or four people if some use both hands.



3. [DIFFICULT] Have five people hold the loop at five points to make a pentagon. Find a way to smoothly transform this pentagon into a five-pointed star inside the pentagon, as shown at right. *Hint: All five people will do the same thing.*

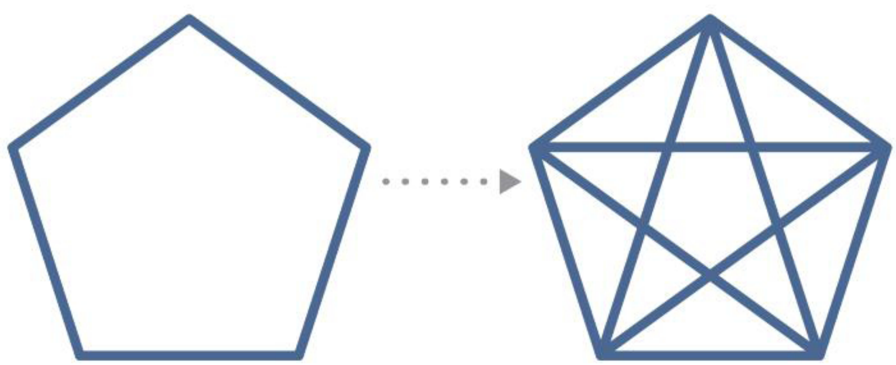
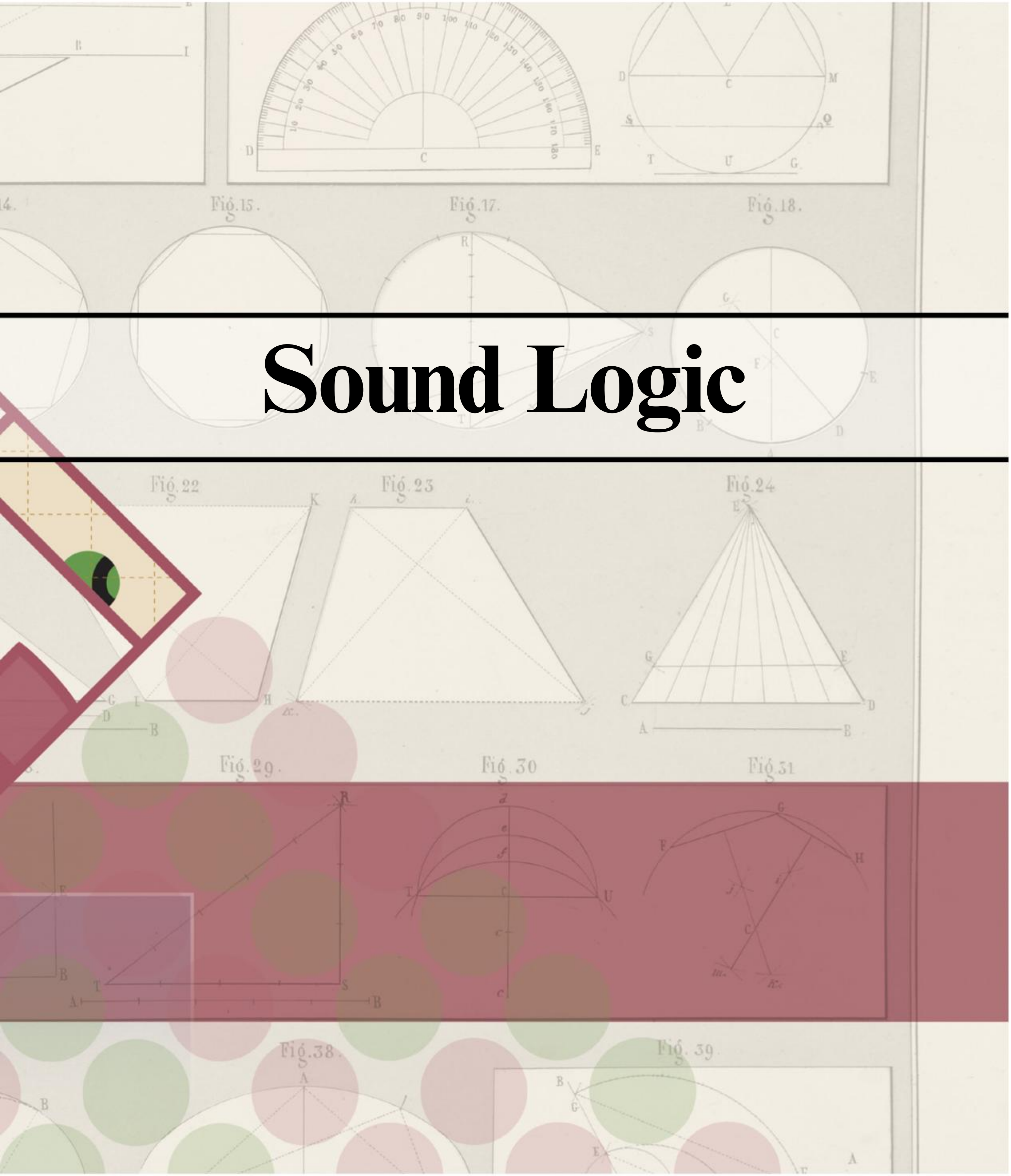



Fig. 9.
Fig. 11.
Fig. 13
Fig. 25.
Fig. 26.
Fig. 27.
Fig. 32.
Fig. 33.
Fig. 37.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Sound Logic



ILLUSTRATIONS BY KELLIE JAEGER/DISCOVER UNLESS NOTED

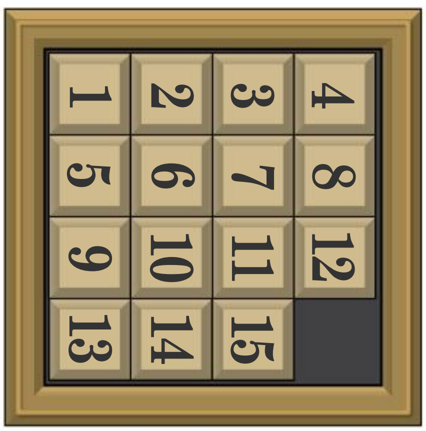
The 15 Puzzle

How do you solve an impossible puzzle?

Long before the Rubik's Cube and a century before Sudoku, mental gymnasts were seized by a different craze: the 15 Puzzle. A mechanical brainteaser, the 15 Puzzle consisted of a frame surrounding wooden blocks numbered 1 through 15. The sequence of blocks read like lines of text, from left to right, except that the last numbers, 14 and 15, were reversed. The challenge was to get the numbers in the correct numerical sequence by sliding the blocks around without taking them out of the frame. This seemingly simple game became an international mania, inspiring songs, contests and even newspaper editorials. Long after the craze ended, America's great puzzle crafter Sam Loyd, who claimed to have invented the 15 Puzzle, offered a $1,000 prize to the first person who solved it. In fact, he didn't have anything to do with the puzzle's creation, though he managed to fool the world for the next 115 years.

BENDING THE RULES

The 15 Puzzle is so maddening because it is, in fact, impossible to solve. But that doesn't stop people from trying. Here are some solutions that bend the rules. All puzzles began with the blocks in the order described, with 14 and 15 reversed. Can you explain how each solution bent the rules?



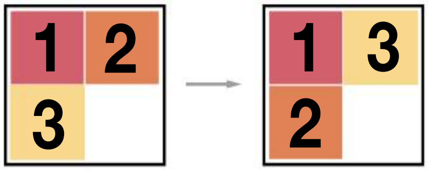
1. **[EASY]** This solution has the blocks in the correct numerical order, reading left to right. How did the solver achieve this?

2. **[TRICKY]** The person who devised this solution removed at least one block from the tray but put it back in the same position before moving any other blocks. The blocks are printed only on the top surface. How did the solver bend the rules?

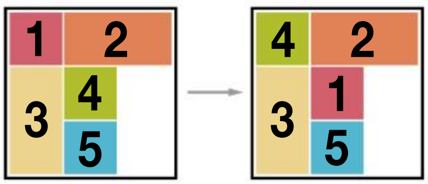
3. **[TRICKY]** In this clever solution, the solver never removed a block from the tray. All blocks are in the correct order. How did the solver bend the rules?

THE IMPOSSIBLE PUZZLE

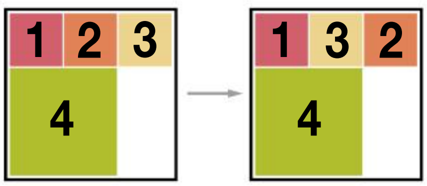
The first mathematical proof that the 15 Puzzle cannot be solved was published in 1880, a few months after the puzzle made its debut. The proof is too tricky to explain here, but these simpler challenges will give you a sense of why such a puzzle is impossible to solve. In the following problems, imagine trying to turn the first tray into the second tray by sliding the blocks within the frame. You may slide pieces horizontally or vertically, but you can't rotate them. Can you explain why these can't be solved?



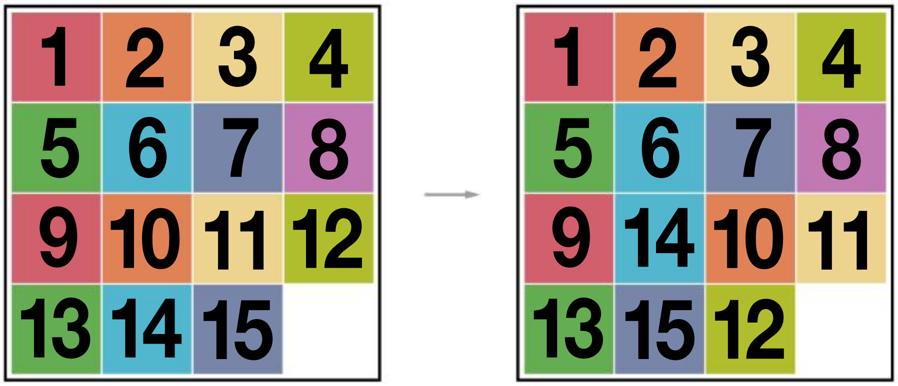
1. [EASY]



2. [TRICKY]



3. [TRICKY]

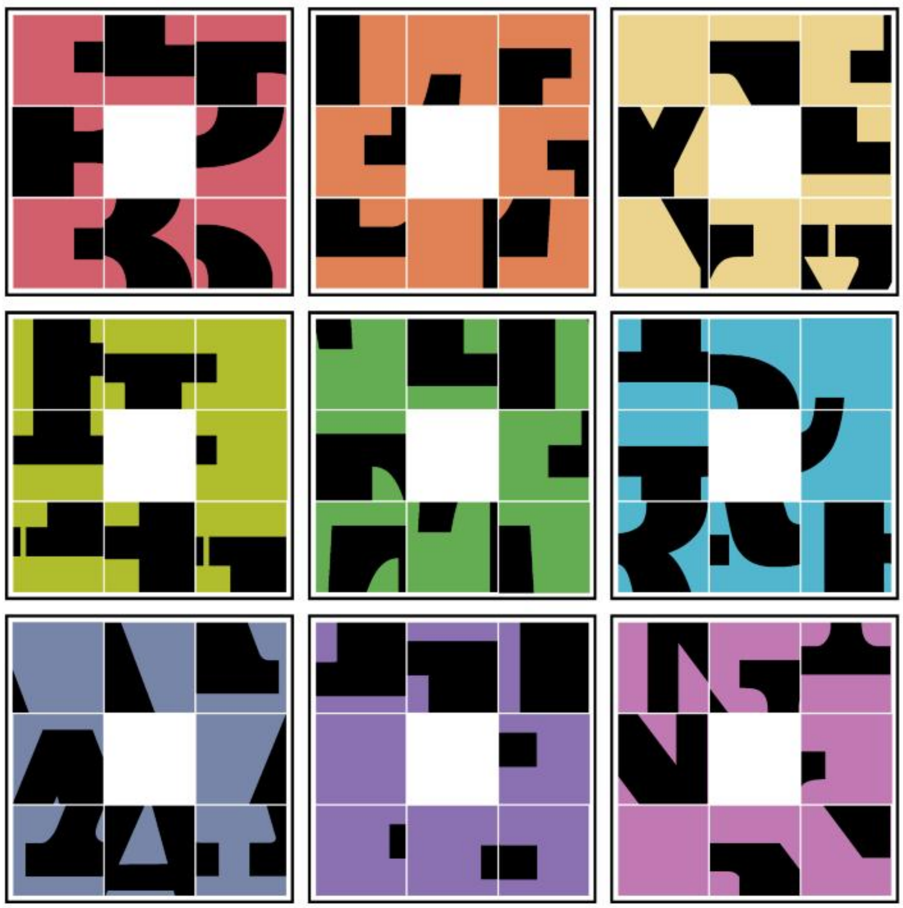


4. [DIFFICULT] How can you transform the first tray into the second tray in exactly six moves? (You may slide only one block on each move.) How can you do it in eight moves? Why can't you do it in exactly 99 moves?

ALPHABET SOUP

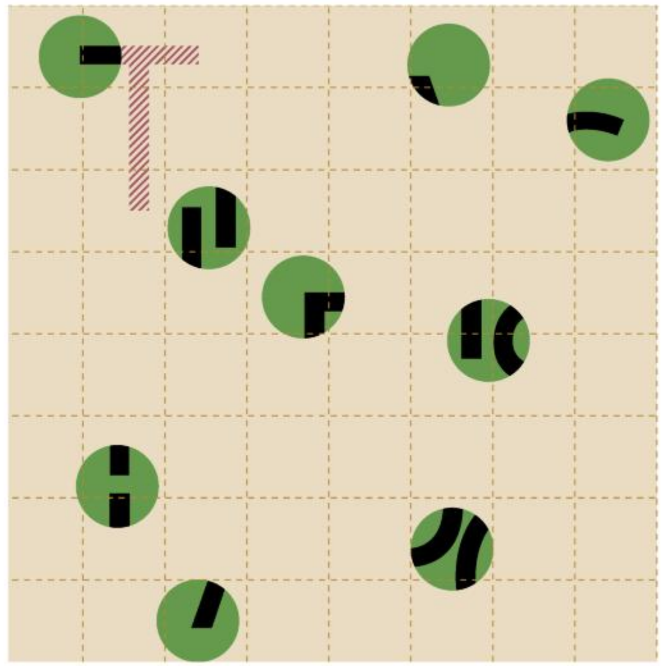
1. [EASY] Each tray at right unscrambles to become a different letter of the alphabet. Figure out the nine letters, then rearrange them to make a word that describes a type of real world puzzle.

2. [TRICKY] When you unscramble each letter, where will the empty square end up? All but one of the trays have a single possible location for the empty square.



TYRANNOSAURUS REX REDUX

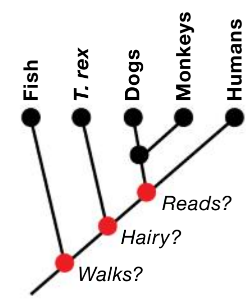
The 13 letters of TYRANNOSAURUS are buried at a partially excavated fossil site. The green areas in the matrix show where one small portion of each letter has been uncovered. Can you reconstruct the positions of the complete original letters? Each is two grid squares tall and sits right-side up. Letters do not touch each other or overlap. To get you started, the complete T is shown in red. Some of the letters are easy to deduce; others require detective work.



CRYPTO CLADISTICS

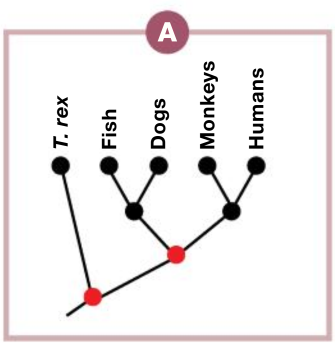
Paleontologists study fossils to reconstruct not just individual creatures but the history of life on Earth. To help figure out how species are related, scientists use a method called cladistics, invented by Willi Hennig in 1950. For example, suppose you want to draw an evolutionary tree that includes fish, *T. rex*, dogs, monkeys and humans. You might classify those animals based on a few characteristics: Do they walk? Have hair? Read? The results are tabulated below. Note: Using just these criteria, dogs aren't distinguished from monkeys. Cladistics assumes that organisms that share a particular characteristic most likely evolved from a common ancestor. Organisms that do not have that characteristic belong on a different evolutionary branch, as shown in the simplified cladogram at right. The red dots show where the tree splits based on the presence (or absence) of a given characteristic. For instance, *T. rex*, dogs, monkeys and humans all walk, while fish do not. All five animals could have shared a common ancestor before fish branched off.

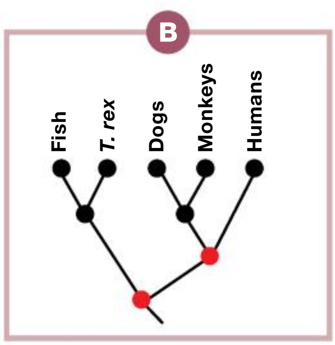
Animal	Walks	Hairy	Reads
Fish	–	–	–
T. rex	YES	–	–
Dog	YES	YES	–
Monkeys	YES	YES	–
Humans	YES	YES	YES

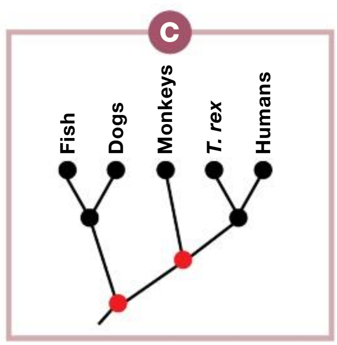


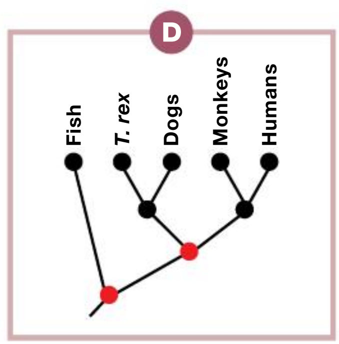
Can you match each set of characteristics with the corresponding cladogram?

1. Has four limbs. Has opposable thumbs.
2. Common household pet. Can be found in dinosaur museums.
3. Still alive today. Common household pet.
4. Hairy. Has a tail.









IT'S CHEMISTRY, BABY

EXPOSED TO THE ELEMENTS

Atoms bond together to form molecules, and letters bond, in an admittedly looser fashion, to form words. In the following "equations," we've added letters to the names of 15 chemical elements. These letters can be recombined to make a synonym of the clue word(s) to the right of the equal sign. For instance, in no. 1, IRON + SP = PRISON.

1. IRON + SP = jail
2. ZINC + TIE = resident
3. ARGON + AL = crunchy cereal
4. COPPER + ISE = submarine spyglass
5. COBALT + KU = power loss
6. ARSENIC + E = augment
7. BROMINE + ST = Satan's sulfur
8. HYDROGEN + U = kind of dog
9. CHLORINE + C = history
10. POTASSIUM + N = postulate

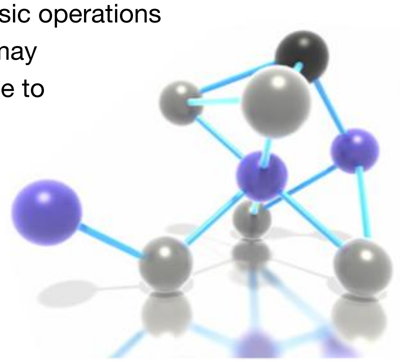
MATERIAL DIFFERENCE

The same elements can sometimes bond together in different ways to make different materials. For instance, depending on the structure of their bonds, carbon atoms can form both soft graphite and hard diamond. In this puzzle, your challenge is to "bond" together four 4s using four operations (+, –, x, /) and square root (√); you may use parentheses to control the order of operations.

1. Make each number from 1 to 10 with four 4s. For instance, 1 = 4 – 4 + (4/4).

2. Make each number from 11 to 15 with four 4s. In addition to the four basic operations and square root, you may also put 4s side by side to make 44 or 444.

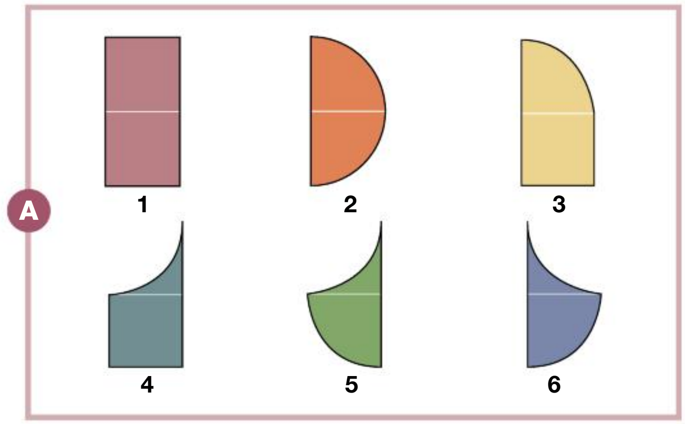
3. One of the numbers between 16 and 20 cannot be made this way. Which number is it?

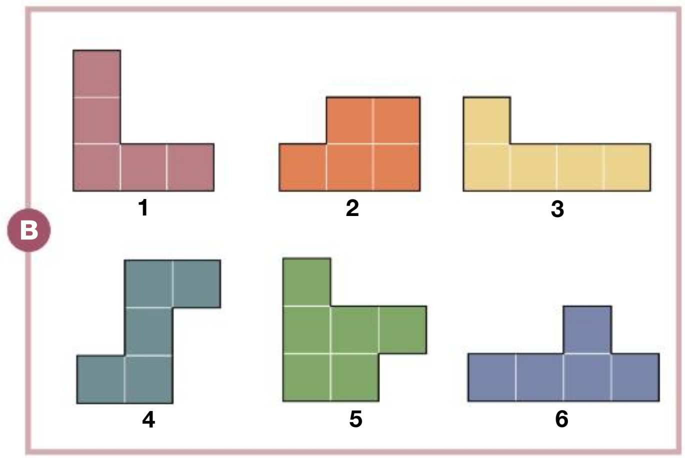


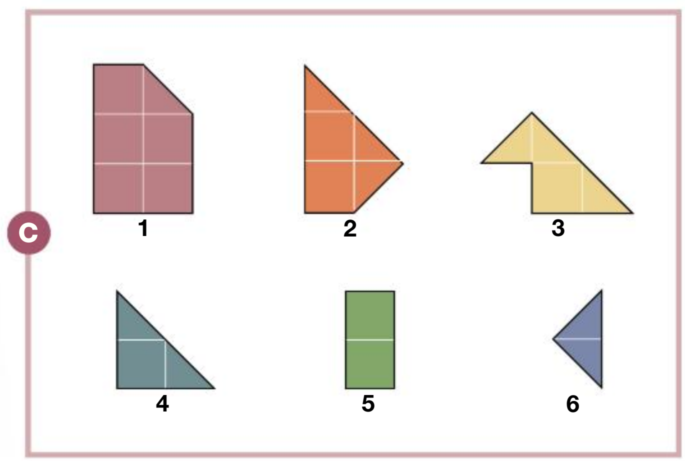
MOLECULE: ECLIPSE DIGITAL IMAGING, INC/DREAMSTIME.COM

COMBINED FORMS

When proteins bind to other molecules, they fit together like pieces of a complex three-dimensional jigsaw puzzle. In each set of merely two-dimensional figures below, find three pieces that fit together to make a square. You may rotate pieces, but you may not overlap them or flip them over.







HERO'S JOURNEY

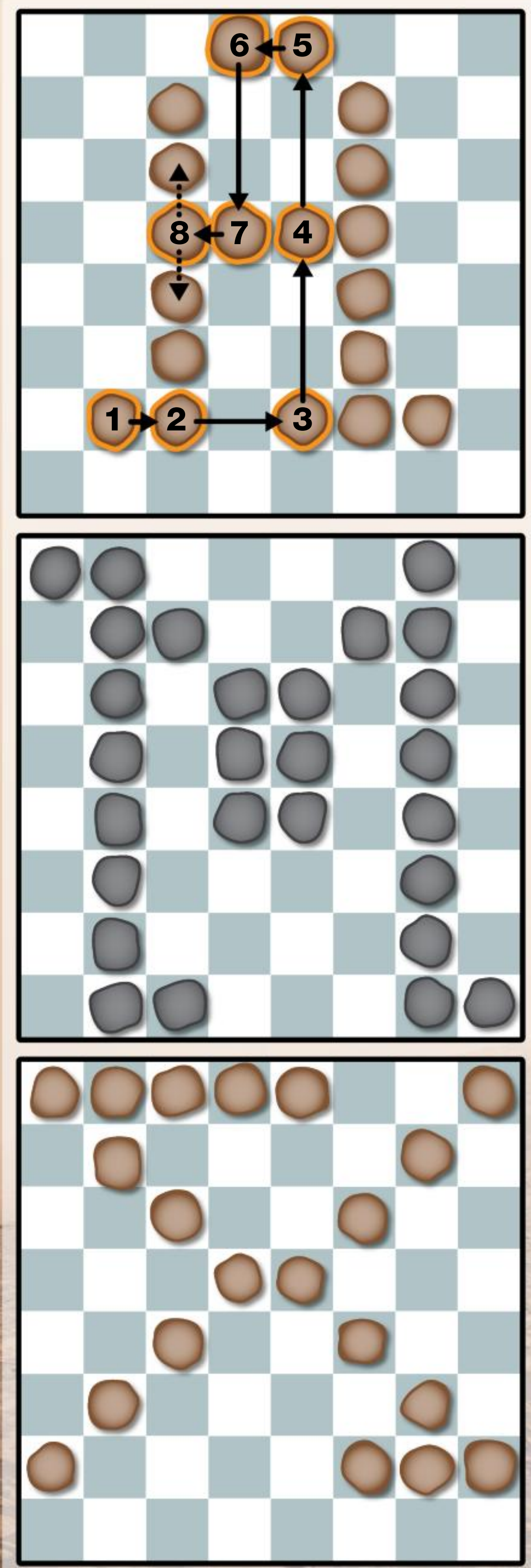
A robot named Hero was sent to Mars to investigate rock formations that look curiously like letters. A rough landing damaged Hero's sensors, and now his movements are limited. Your mission is to plan Hero's journey so he picks up all the rocks on the boards shown at right.

HERE ARE THE RULES

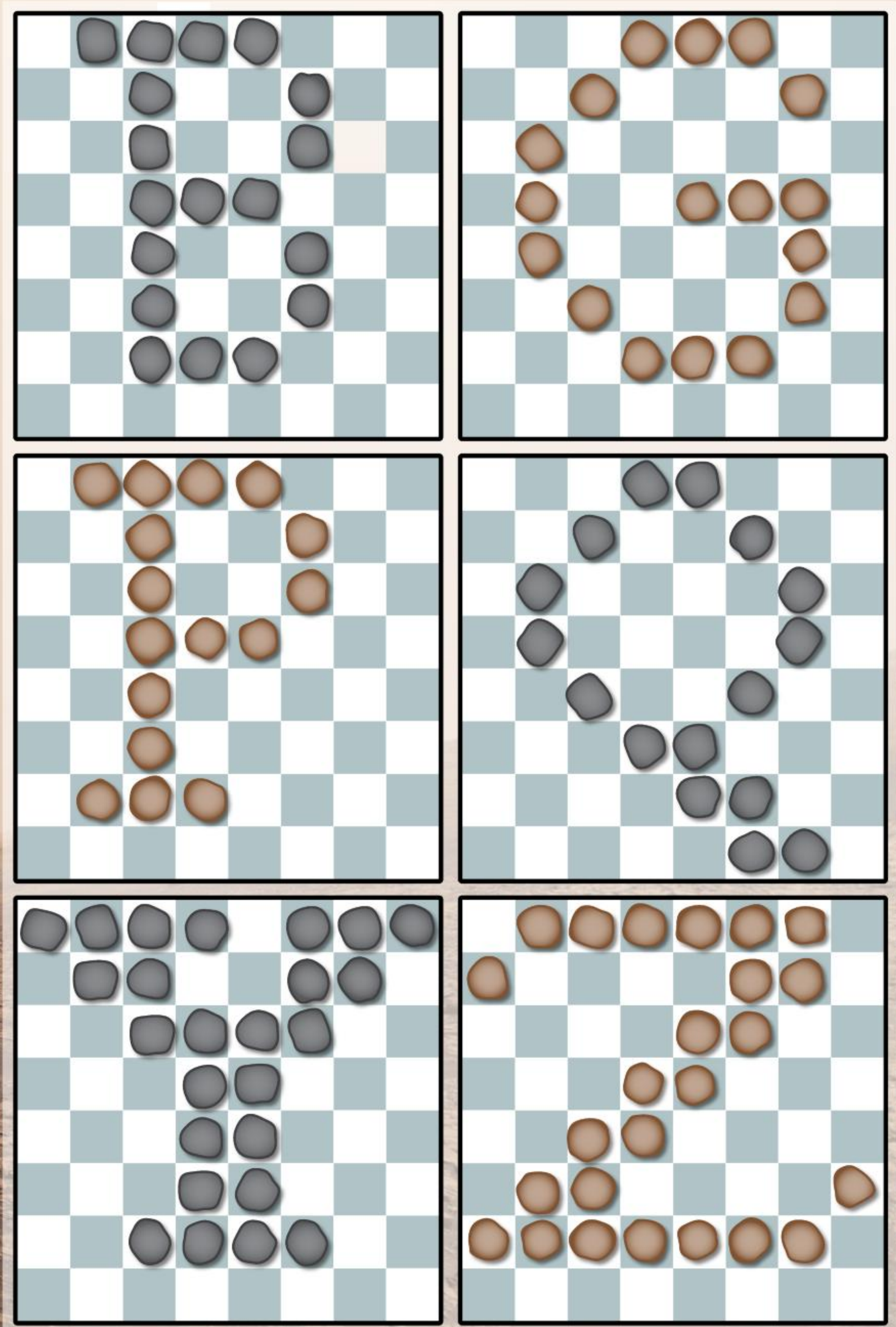
Start by placing Hero on any square that contains a rock. Hero will promptly remove that rock from the board. For instance, on the first board, Hero starts by removing rock 1. After picking up a rock, the robot must move directly left, right, up or down any distance until he lands on another rock. On that board, Hero moves right from rock 1 to pick up rock 2, then right again to rock 3, then up to rock 4. If there is no rock in a particular direction, then Hero cannot move that way. He cannot, for instance, move to the right from rock 5 because there is no rock in that direction.

One last rule: Because his camera can swivel no more than 90°, Hero cannot turn 180° and go back in the direction from which he came. For instance, from rock 8 Hero can pick up the rocks above or below, but he cannot reverse course and move to the right, even though there is a remaining rock in that direction.

Can you draw a solution path on each board? Remember that each move must end at a rock, so you cannot stop at a rock again after it has been picked up.



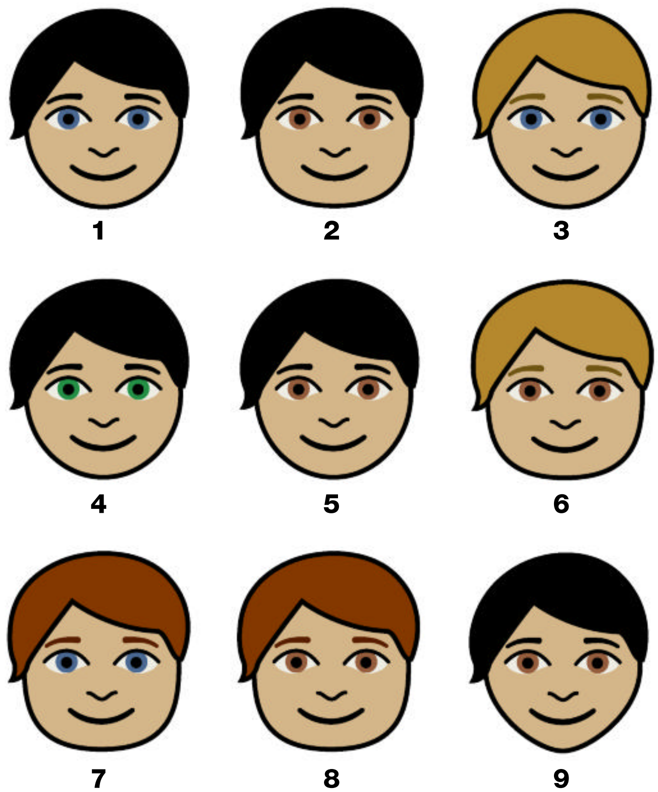
PUZZLES: ROEN KELLY/DISCOVER. BACKGROUND: NASA/JPL-CALTECH/MSSS



PARLOR GENOMICS

INHERITED TRAITS

In Muggsville, home base for the fruitful Mugg family, it's easy to tell which residents are cousins. If two Muggsvillers are cousins, their faces share two of three identifying characteristics: eye color, hair color and head shape. For example, in the nine "Mugg shots" below, Muggsvillers 4 and 5 are cousins because their faces are identical except for eye color. Muggsvillers 1 and 2 are not cousins because their faces differ both in shape and eye color.



1. **[EASY]** Which of the Muggsvillers have just one cousin in the group?

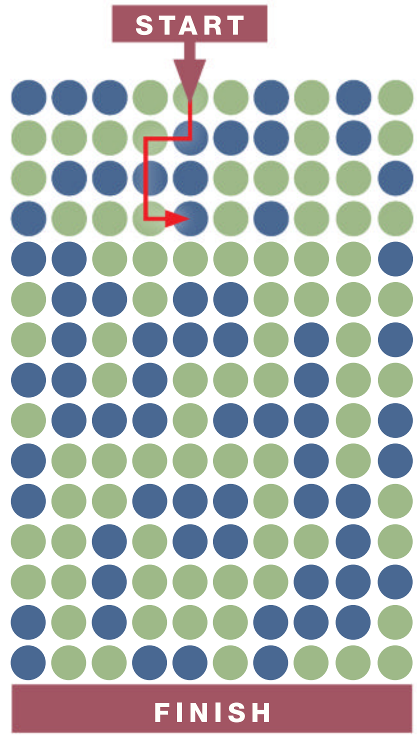
2. **[TRICKY]** Who has the most cousins? *Hint: None of the Muggsvillers has more than four cousins in the group.*

3. **[DIFFICULT]** How can you arrange these nine Muggsvillers in a row so that each is placed only next to cousins? *Hint: What must be true of the first and the last Muggsvillers in the row?*

GENETIC TRANSCRIPTION

The body stores instructions for making a human in DNA, a long molecule that consists of a sequence of base pairs — adenine and thymine, guanine and cytosine — that are represented by the symbols A, T, G and C. The DNA inside a human cell nucleus would be about 6 feet long if you could stretch it out. To fit in the cell, DNA folds itself in a tightly coiled tangle.

The matrix at right has just two symbols, 🟢 and 🔵, which are packed in a 10-by-15 grid. These symbols form twisted paths through the matrix. Can you find the routes described below?



1. **[EASY]** Travel from the green start dot to any of the dots in the bottom row by following a path formed by the repeating pattern 🟢🔵🟢🔵. You may move only left, right, up or down (not diagonally) from one symbol to the next. The first few steps are shown.

2. **[TRICKY]** Find the shortest possible path that follows the repeating pattern 🟢🟢🔵🔵🟢🟢🔵🔵 from the green start dot to any of the dots in the bottom row. *Hint: The shortest path uses 23 dots, and the first five moves are right, right, down, down, left.*

3. **[DIFFICULT]** Find the shortest possible path that follows the repeating pattern 🟢🟢🔵🟢🟢🔵 from the green start dot to any of the dots in the bottom row. *Hint: The shortest path has 26 dots, and the first three moves are right, down, down.*

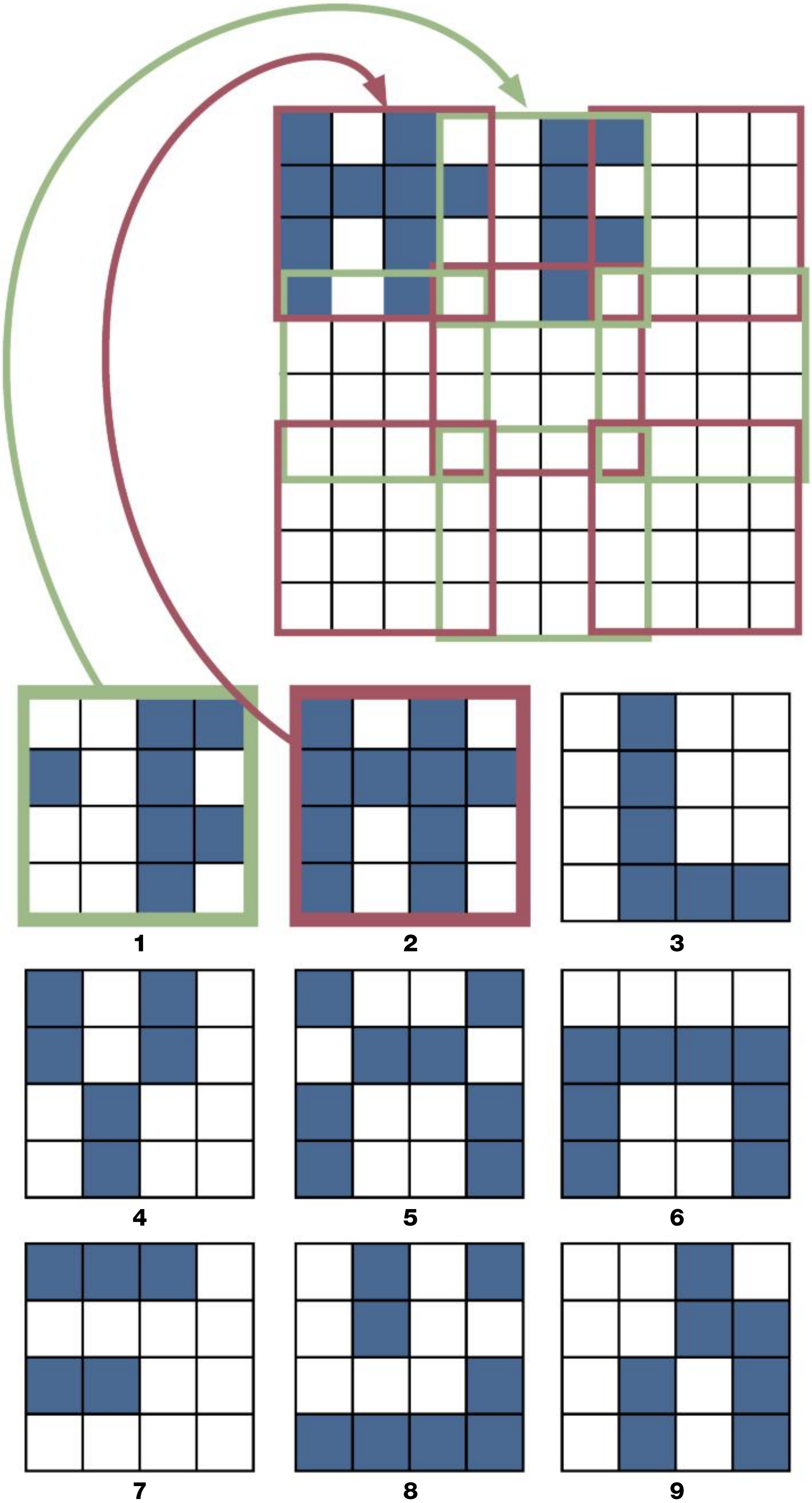
LEFT: ROEN KELLY/DISCOVER. RIGHT: ALISON MACKEY/DISCOVER

JIGSAW SEQUENCING

The human genome is about 3 billion pairs long. To decode this mass of information, researchers cloned segments of DNA and cut them into shorter pieces. About 500 bases on each piece of DNA were decoded using a gene-sequencing machine. Then the millions of segments were put back into their original order, like pieces of a jigsaw puzzle.

How do you assemble a million-piece jigsaw puzzle when you don't even know what the final picture looks like? The solution was ingenious: Search for a sequence at the end of one segment that matches the sequence at the beginning of another segment. If the two sequences match, you can guess that the two segments fit together with a common overlapping sequence.

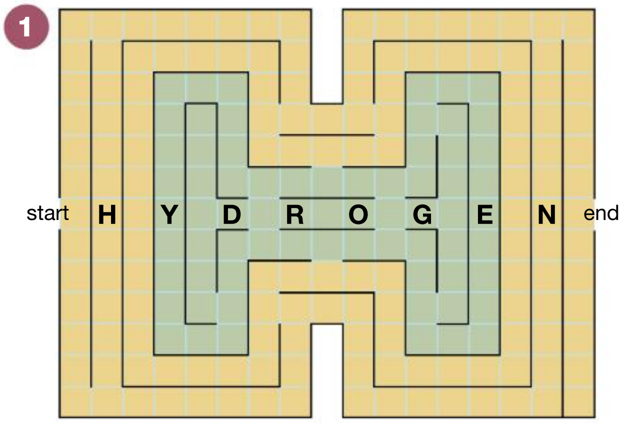
Use a similar approach to assemble the puzzle at right. Fit the nine pieces into the 10-by-10 grid so that adjacent pieces overlap by one column or one row of squares that match exactly. (Pieces may not be rotated.) When the puzzle has been finished, the shaded squares will spell a five-letter word that's related to DNA. The first two pieces have been filled in. Note how the right edge of piece 2 overlaps and matches the left edge of piece 1.



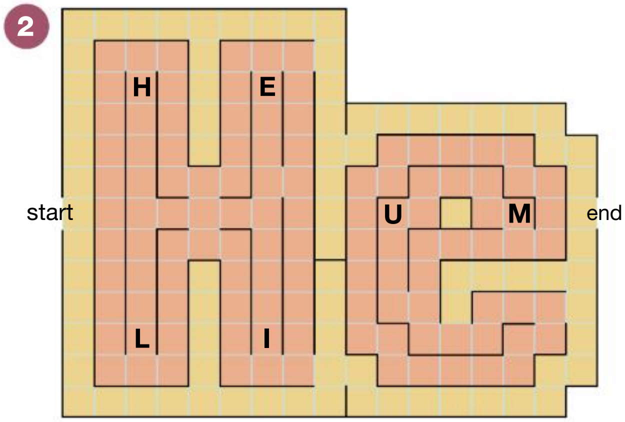
ELEMENT OF SURPRISE

The names of the first six elements of the periodic table — hydrogen, helium, lithium, beryllium, boron and carbon — inspired the mazes that follow. The challenge in each maze is to draw a path from START to END that passes through every letter of an element's name just once and does not pass through any square of the maze more than once. The path does not need to go through the letters in the correct order, though a few paths do. Some mazes have more than one solution. Notice that the shaded areas show the symbol for each element.

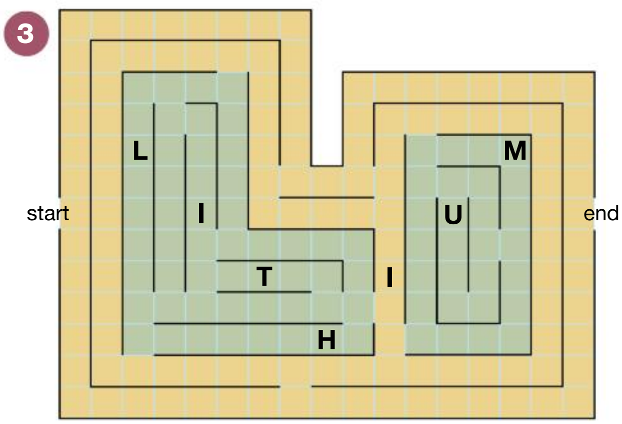
1



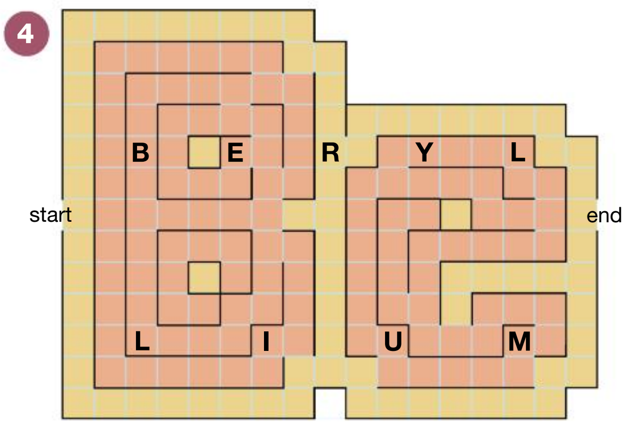
2



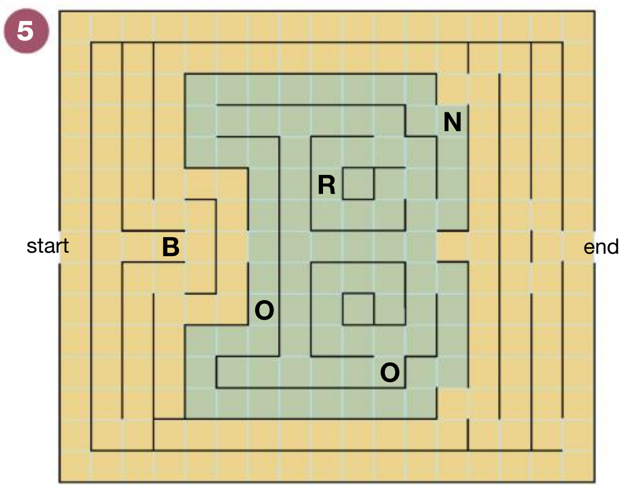
3



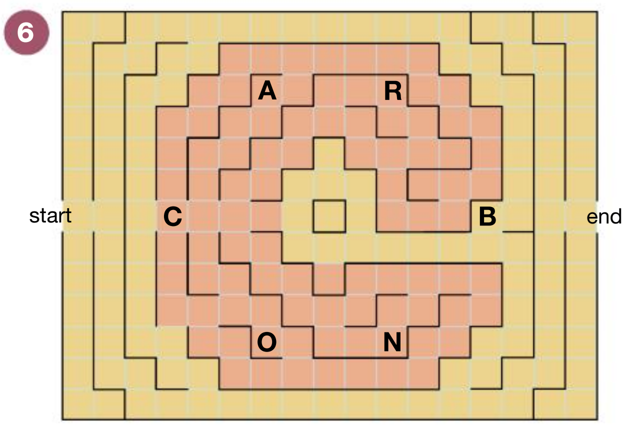
4



5



6



MIX, MAP AND MATCH

MUSICAL CHAIRS

Six scientists attended a three-day conference where they gathered at a round table. Each day they sat in different chairs. Use the following clues to figure out where each person sat each day.

1. MONDAY [EASY]

Abe sat opposite Barb, Carl sat opposite Deb, and Ed sat opposite Fay. Abe sat next to the red chair and immediately to Carl's right. Ed did not sit next to Barb, nor did he sit in the red chair. Where did Fay sit?

2. TUESDAY [TRICKY]

Abe, Barb and Carl were all separated from each other at the table. Deb sat in the chair opposite Abe, and Barb sat in the red chair. Ed sat just to Barb's right. Where did Fay sit?

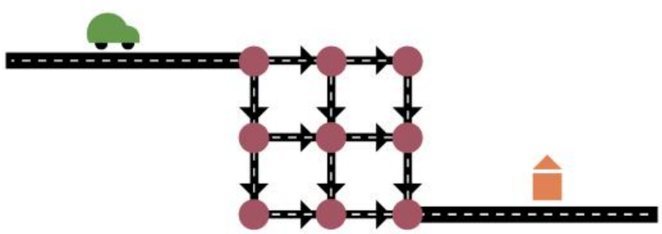
3. WEDNESDAY [TRICKY]

Abe and Barb paired off in adjacent seats, as did Carl and Deb and Ed and Fay. Deb also sat next to Abe, and Barb sat immediately to Ed's right. Carl sat in the red chair. Where did Fay sit?

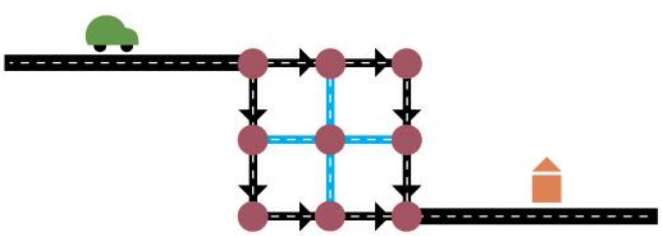
HOMEWARD BOUND

Count the number of ways to drive the green car home in each figure below. You may turn only when you reach a dot, and you may not pass over any dot or road twice. Roads with arrows are one-way; blue roads are two-way.

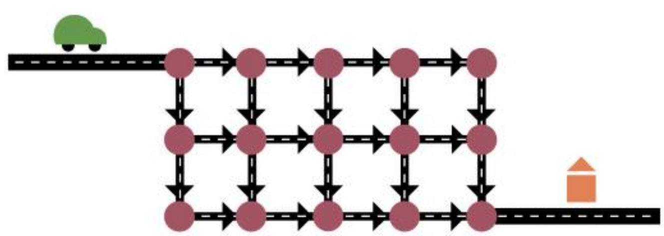
A. [EASY]



B. [TRICKY]



C. [TRICKY]



A BETTER MOUSETRAP

ACCIDENTAL TECHNOLOGY

Here are the surprising circumstances that led to eight famous inventions. Can you match each invention with its backstory?

1. In the early 1800s, **Jean-Baptiste Jolly** spilled an oil lamp containing distilled turpentine on his wife's tablecloth.

2. In the mid-1800s, **Alfred Nobel** was transporting a sensitive material in glass flasks packed in soil when one of the flasks broke.

3. Robert Chesebrough watched oil field workers scrubbing a waxy substance off their machinery in 1859.

4. In the early 1700s, French scientist **René-Antoine Ferchault de Réaumur** paused to study an empty wasp nest.

5. DuPont chemist **Roy Plunkett** was surprised in 1938 when an experimental refrigerant turned from a gas into an oily white powder.

6. Percy L. Spencer was working with radar equipment at Raytheon in the 1940s when he pulled a melted candy bar from his pocket.

7. Also in the 1940s, **Georges de Mestral** went out for a walk and came home to find his clothing covered with cockleburs.

8. In 1965, **James Schlatter** was developing a new drug to treat ulcers when he spilled some of it on his fingers.

A. Velcro

B. Teflon

C. Vaseline

D. Dynamite

E. NutraSweet

F. Dry cleaning

G. Modern paper

H. Microwave oven

ISTOCK PHOTOS, CLOCKWISE FROM TOP LEFT: THIRADECH; ZOOMSTUDIO; BOB_EASTMAN; TOMBAKY; TURK_STOCK_PHOTOGRAPHER; SAMOHIN; BIGREDCURLYGUY; LLEEROGERS

EVOLUTION OF THE PAPER CLIP

Many people have tried to improve on the classic Gem paper clip, which has been around for more than a century. Can you match each clip with its description?

1. The classic Gem paper clip

2. Somewhat similar to the Gem but holds more and is easier to affix

3. Patented around the time of the Gem clip's introduction

4. Gem-like but uses less wire

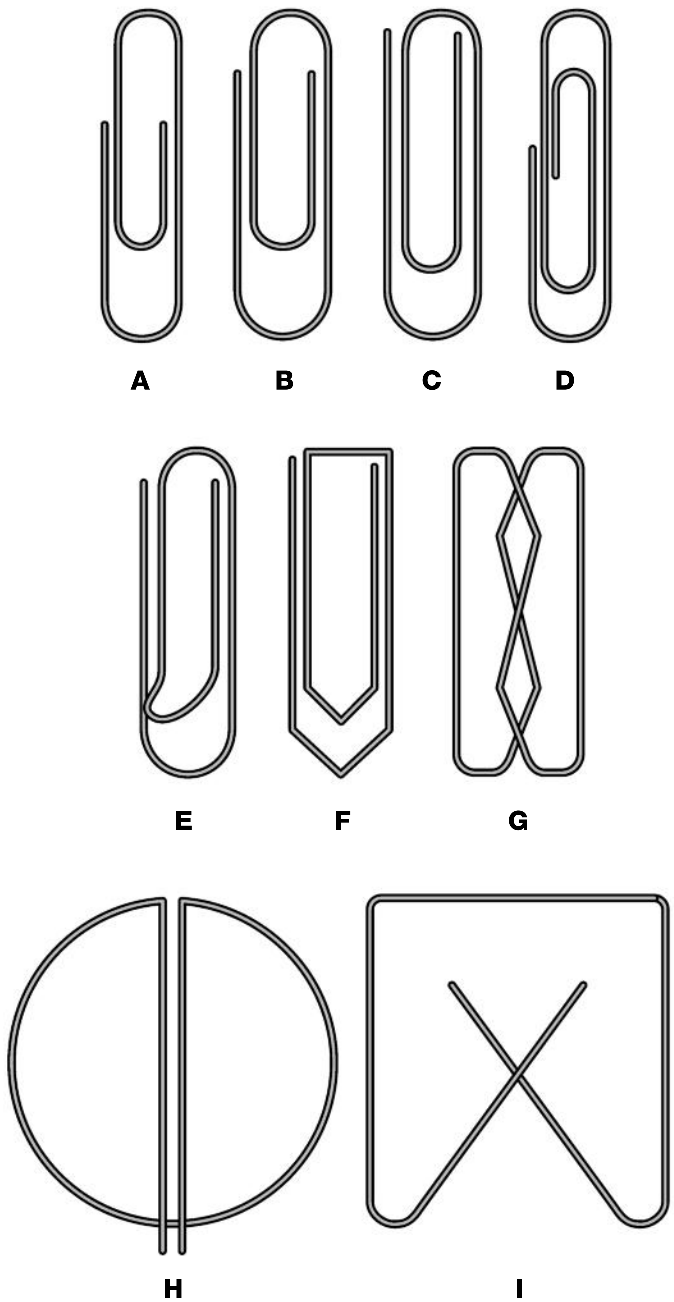
5. Popular among librarians because its long legs reduce tearing

6. Slides onto paper without the user having to spread the loops first

7. Goes on from either end; endless wire eliminates tearing

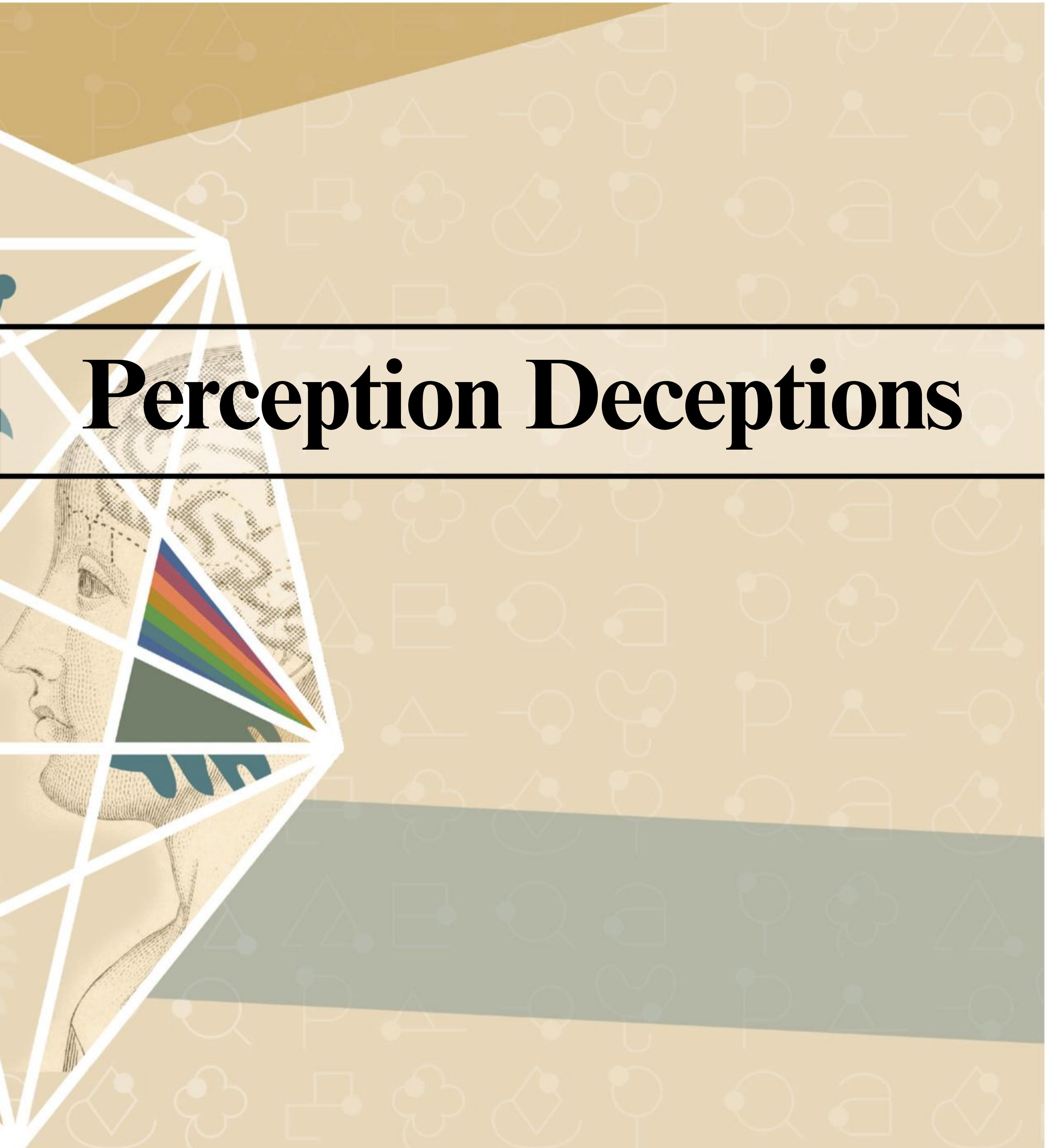
8. Similar to the Gem but has lengthened legs that eliminate tearing

9. Slides on from either end; always protrudes beyond edge of paper



TOP: ROEN KELLY/DISCOVER (A -I). BOTTOM: LJUPCO/DREAMSTIME.COM

Perception Deceptions



ALL ILLUSTRATIONS BY KELLIE JAEGER/DISCOVER UNLESS NOTED

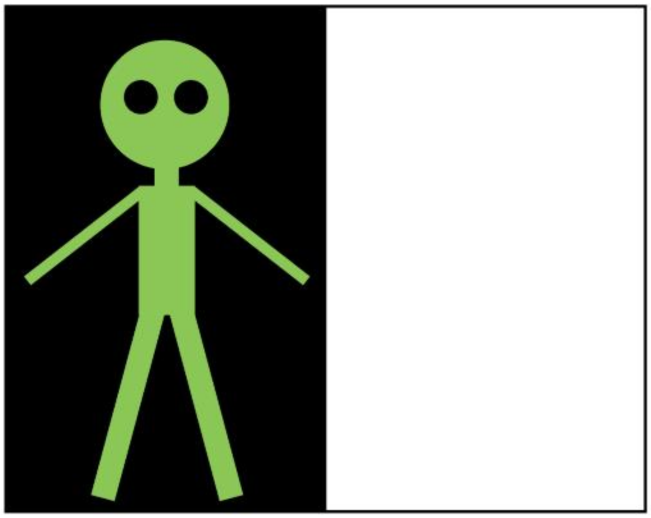
Ghostly Apparitions

Is your brain haunted by phantom perceptions?

HANDS: RVLSOFT/DREAMSTIME.COM. BACKGROUND: AMANDEE/DREAMSTIME.COM

Stare at the little green man on the opposite page for 20 seconds, then look at the white square next to him. The purple ghost that appears will hang around for half a minute or so.

Obviously, no apparition is printed on the page; it was produced by your brain. The accuracy of your brain's color perception relies on sensory mechanisms that compare opposing hues, such as green and purple, blue and yellow, and red and turquoise. When you stared at the green alien, only the green-sensitive neurons in your brain were active. But when you looked at the white space, neurons sensitive to green and those sensitive to purple were equally stimulated. Because the neurons sensitive to green had become fatigued, purple dominated, producing an afterimage. Phantom perceptions haunt other parts of the nervous system, too, as the following experiments demonstrate.



EXPERIMENT 1

Stand inside a narrow doorway, arms at your sides. Then lift them sideways until they hit the doorframe. Push hard against the frame with the backs of your hands for 30 seconds, and then quickly leave the doorway. Your arms will elevate on their own, as if commanded by an ethereal spirit. Aftermovements like this occur for two reasons. First, nerve cells in the brain and spinal cord adjust the magnitude of muscle stimulation in proportion to the force required to move an object. Strong exertion against an immovable object cranks up the nervous system in a vain attempt to budge what can't be budged. Second, there's a lag in the feedback loop between muscle sensors and the brain. When an opposing force is abruptly removed, the brain believes, for a moment, that the force is still there.

EXPERIMENT 2

The doorframe experiment produces real movement, but under the right conditions, illusory motion can also be conjured up. Lie face down, chin to the floor, with your eyes closed and arms extended above your head. Have a trusted friend lift your arms as far up as possible and hold them for 30 seconds. Then ask her to slowly lower them to their original position. Chances are your arms will feel as if they're moving right through the floor.

This illusion, like the purple ghost, is an aftereffect of opposing sensory channels. In this case, however, the opposing mechanisms are muscle receptors rather than color sensors.

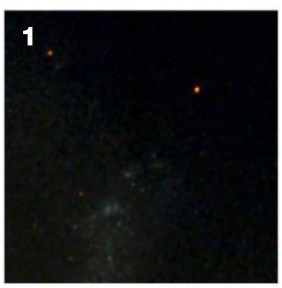
Every joint in the body moves thanks to at least two muscle groups: one that flexes the joint and one that extends it. Both sets of muscles contain receptors that tell the brain how much they have stretched or contracted. By comparing the outputs of those receptors, the brain can get a precise picture of the joint's position. This is how you descend stairs without looking at your legs, move your limbs in the dark or play an instrument without looking at the keys.

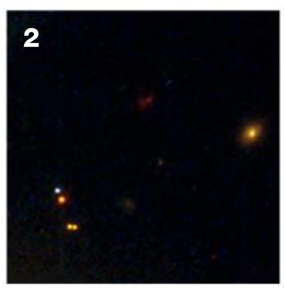
When your friend pulled your arms up over your head, your flexor muscles stretched dramatically, fatiguing their receptors; meanwhile, your shoulder extensor muscles contracted, so their receptors rested. As your arms were lowered, the sensory input from the rested extensor receptors overwhelmed those from the fatigued flexor receptors. The result: Your brain was fooled into thinking that your shoulders had flexed more than they actually had — sending your arms into the floor.

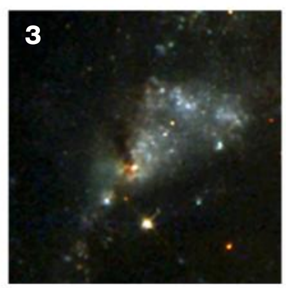
Luckily, such illusions happen only after the rare sort of abuse meted out in this experiment. Otherwise, along with car keys and pens, you'd always be misplacing your hands and feet.

STAR SEARCH

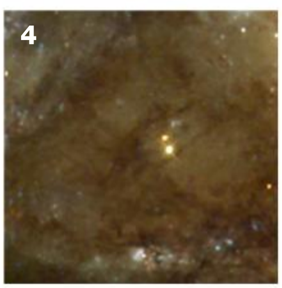
Even in an age when high-powered telescopes penetrate to the farthest edges of the universe, the naked eye remains one of astronomy's most important tools. Take a close look at the large star field, and see if you can find each of these six star formations.

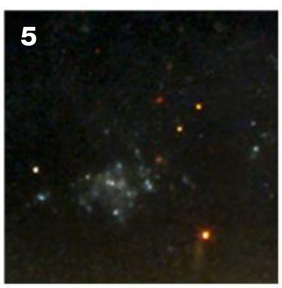


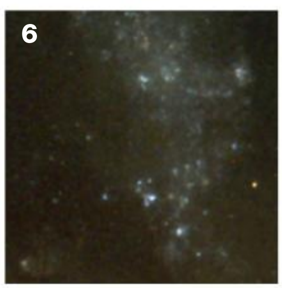




NGC 2207 AND IC 2163 BY NASA AND THE HUBBLE HERITAGE TEAM (STSCI)







DOUBLE EXPOSURE

X-rays, CT scans and other medical imaging technologies require a skilled analysis of a flat image in order to visualize the overlapping three-dimensional structures that the images represent. Each of the colorful designs shows the areas common to the letters of two overlapping words related to the human body. For instance, the first word pair is ARM and LEG. Imagine the A in ARM centered on top of the L in LEG. The area where the leg of the L and the peak of the A intersect is brown; the small divot in the leg of the L is the hole in the middle of the A, where the two letters don't overlap. Can you untangle the other word pairs?

Black and White in Color

Trick your brain into seeing a spectrum that isn't there.

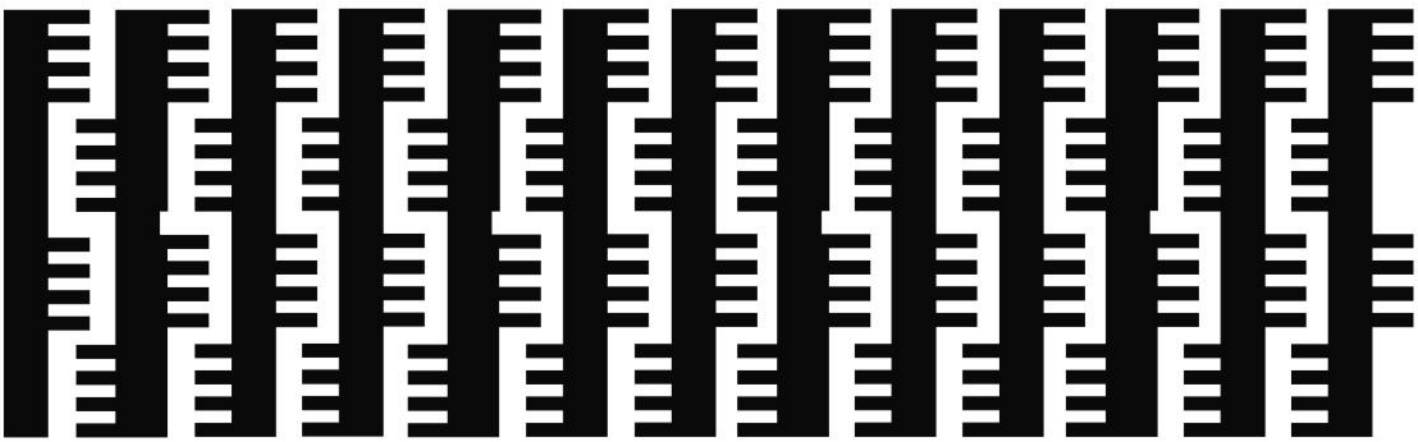
In an art class, students often learn that black and white aren't colors in the strictest sense: They consist of a complete lack of color on the one hand and an equal combination of all colors on the other. But if black and white aren't colors, then what precisely *are* they?

And what about gray? Can you really get something (gray) by mixing equal amounts of nothing (black) and everything (white)? It turns out the answer is yes, but the something you get needn't be gray. It can be a bona fide color, as you'll discover by doing the following experiments.

EXPERIMENT 1

Hold this page 10 inches from your face. Place a fingertip between the second and third rows on the left edge of the pattern below, and focus on your finger as you slide it quickly to the far right side of the figure and back to the left edge. On the left-to-right scan, the right-facing black "teeth" should take on a brownish tint while the left-facing teeth should appear bluish. When your finger makes a right-to-left traversal, the colors in the rows should reverse.

Hues derived from rapid movement of black-and-white patterns across your retinas are called subjective colors. These baffling tints were first documented by the 19th-century physicist Gustav Theodor Fechner, who formed them by spinning patterned disks like the one on the opposite page.



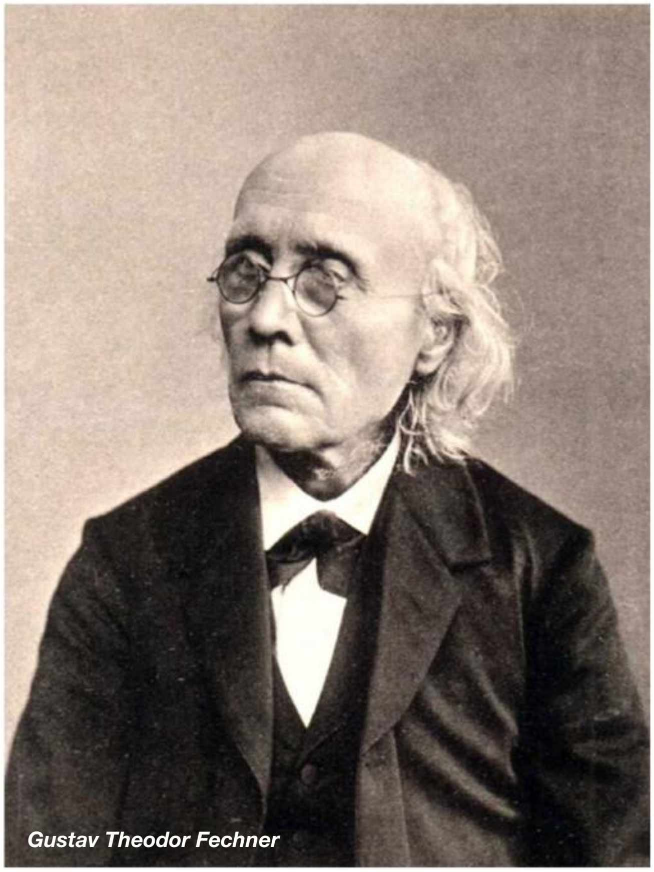
EXPERIMENT 2

Re-create Fechner's original study by cutting out the disk, pasting it on cardboard, skewering its center on a toothpick or thumbtack, and then giving it a vigorous spin. Bands of different pastels should appear as the disk moves. Reversing the spin will produce a different set of colors. (If you don't see colors immediately, try spinning the disk at different speeds.)

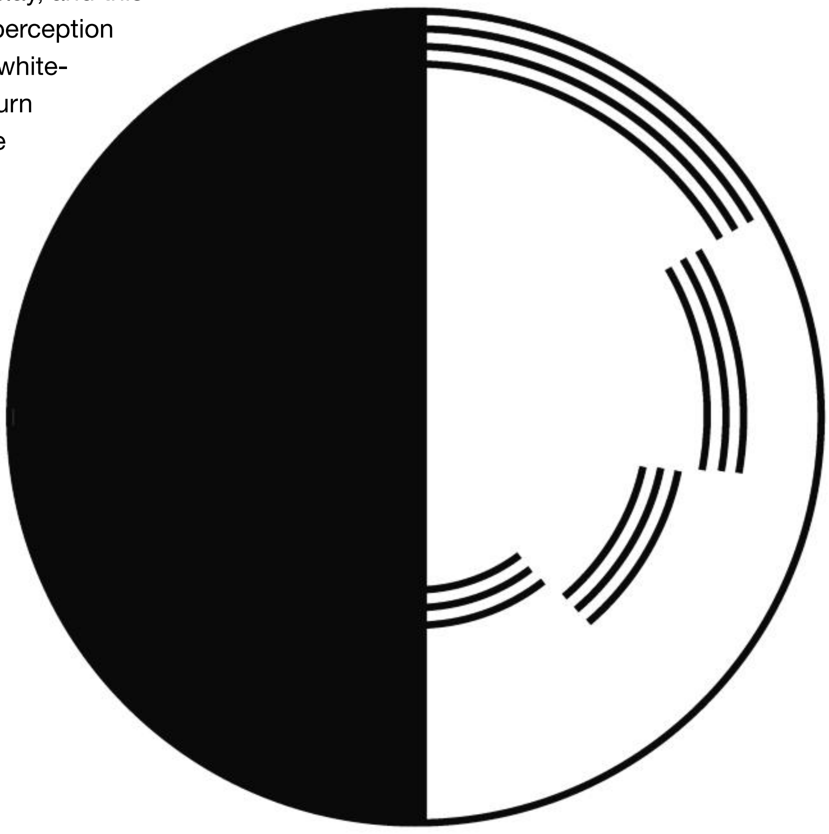
Some research suggests that subjective colors may be caused by the varying response of different receptors in your eyes. The sensation of color arises from neural excitations in visual photoreceptors called cones, which come in three flavors: those most sensitive to blue, green or red wavelengths of light. All visible wavelengths excite all three cone types to one degree or another, but when the amount of stimulation of all three cone systems is equal, we see white. (White dims to gray or black when the relative stimulation of the three cone systems stays equal but the intensity of light decreases.)

When presented with rapid on-off stimuli in black and white, each of the three types of cones turns on and off with a slightly different delay, and this momentary imbalance triggers the perception of color. For instance, a brief black-white-black sequence will take longer to turn on the blue-sensitive cones than the green and red variety, producing an initial sensation of yellow or brown (both are mixtures of red and green light), quickly followed by a transient perception of blue. Reversing the order of stimulation to white-black-white swaps the order in which yellow and blue sensations occur (hence the reversal effects in our two experiments).

These strange effects prove that there's more to color vision than meets the eye!



Gustav Theodor Fechner



TOP: SCIENCE SOURCE

Suppose you created a computer that mimicked the human mind. What task would you have it perform? In the 1960s, artificial-intelligence researchers tried to get a computer to play chess because they viewed that game as the pinnacle of human intellectual achievement.

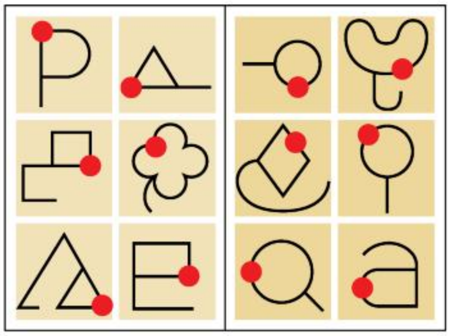
Nowadays computers routinely beat the best chess players. Chess turns out to be relatively easy for computers to master. What remains beyond the grasp of machine intelligence is the simple visual pattern recognition that we do every day. Bongard problems, invented by Russian computer scientist Mikhail Bongard in the 1960s, are classic examples of concise pattern-recognition problems that yield to human reasoning yet stump even the most sophisticated computers. The following puzzles were inspired by the original 100 Bongard problems.

FRED11/DREAMSTIME.COM

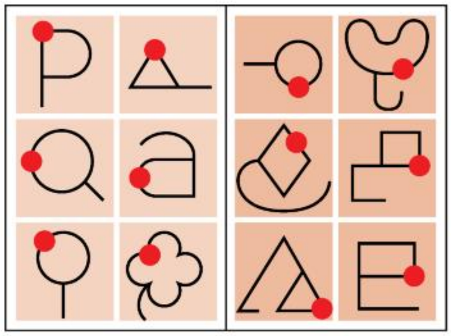
SHAPES

In each of these three puzzles, your challenge is to describe what features the six figures on the left side share that distinguish them from the six figures on the right. To make matters more confusing, the puzzles use the same figures in different combinations.

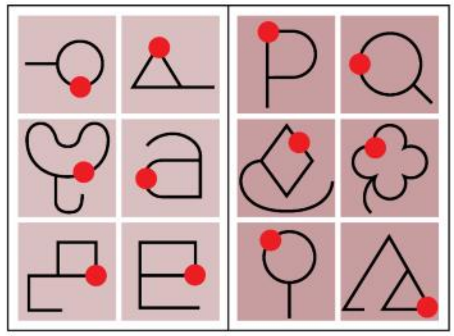
1. [EASY]



2. [TRICKY]



3. [DIFFICULT]



NUMBERS

Bongard problems also work with numbers. In each of these three grids, the task is to describe what the six numbers on the left have in common that differentiates them from the six numbers on the right. Each puzzle requires a slightly different way of thinking about the numbers.

1. [EASY]

16	38	27	49
44	92	51	83
34	82	48	97

2. [TRICKY]

21	35	15	29
56	84	50	71
49	63	43	85

3. [DIFFICULT]

24	53	14	47
79	86	58	63
13	42	96	36

ELEMENTS

Finally, here are some Bongard problems based on the names of chemical elements. Same idea as before: Figure out how the six elements on the left are different from those on the right. *Hint: Consult a periodic table, and pay attention to how the elements are spelled.*

1. [EASY]

As Arsenic	H Hydrogen	Au Gold	C Carbon
He Helium	N Nitrogen	Ca Calcium	Li Lithium
O Oxygen	Pb Lead	P Phosphorus	U Uranium

2. [TRICKY]

O Oxygen	C Carbon	U Uranium	Li Lithium
H Hydrogen	N Nitrogen	As Arsenic	He Helium
Ca Calcium	P Phosphorus	Pb Lead	Au Gold

3. [DIFFICULT]

H Hydrogen	He Helium	P Phosphorus	Ca Calcium
Li Lithium	C Carbon	As Arsenic	Au Gold
N Nitrogen	O Oxygen	Pb Lead	U Uranium

Round and Round

The brain's miserly habits can make your head spin.

Your brain is a taskmaster that often makes individual neurons perform multiple operations at the same time. Like any other overworked laborers forced to juggle too many responsibilities, overwrought nerve cells are prone to make mistakes.

EXPERIMENT 1

Focus on the star in the center of Figure A. Slowly move your head toward the page and then away from it. The rotation you perceive is called the Pinna-Brelstaff illusion. Vision researchers Filippo Pinna and Gavin Brelstaff theorize that illusory rotation arises from the brain's strategy of making certain neurons responsible for detecting both the orientation and the direction of movement of visual lines and curves.

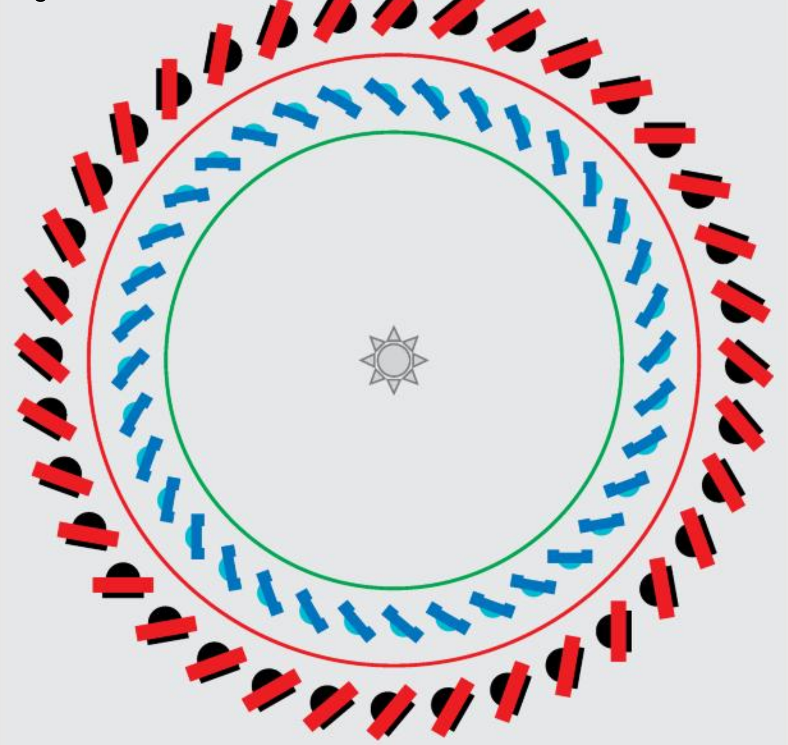
Neurons in the visual cortex of the brain are organized into subgroups, each of which responds best to lines oriented at a specific angle. Neurons that "prefer" the particular angle of an object viewed at any given moment are more active than those preferring other orientations. A subgroup of visual neurons gets most excited when a line with a preferred orientation is in motion and the direction of that motion is at a right angle to the line's orientation.

Just as the brain determines the orientation of objects by "looking" at which groups of orientation-selective neurons are active, it also assesses the direction of motion of objects by the activity of those same nerve cells. This doubling up of orientation and motion detection works great if a line is moving at right angles to its orientation, but if the line is moving in any other direction, the brain gets confused.

When you move your head toward Figure A, both circles appear to expand. Each bar slides outward across your retina, stimulating cells tuned to that bar's particular tilt. Because those cells are doing double duty, the stimulation convinces them that the bars are moving in a perpendicular direction as well. The two motions, added together, create an illusion of circular motion. Figure B reveals how this works for Figure A's inner circle, which appears to move clockwise. The reverse tilt of the bars in the outer circle of Figure A makes it appear to move counterclockwise.

When you move your head away from the page, both motions reverse direction, reversing the direction of the illusion.

Figure A



EXPERIMENT 2

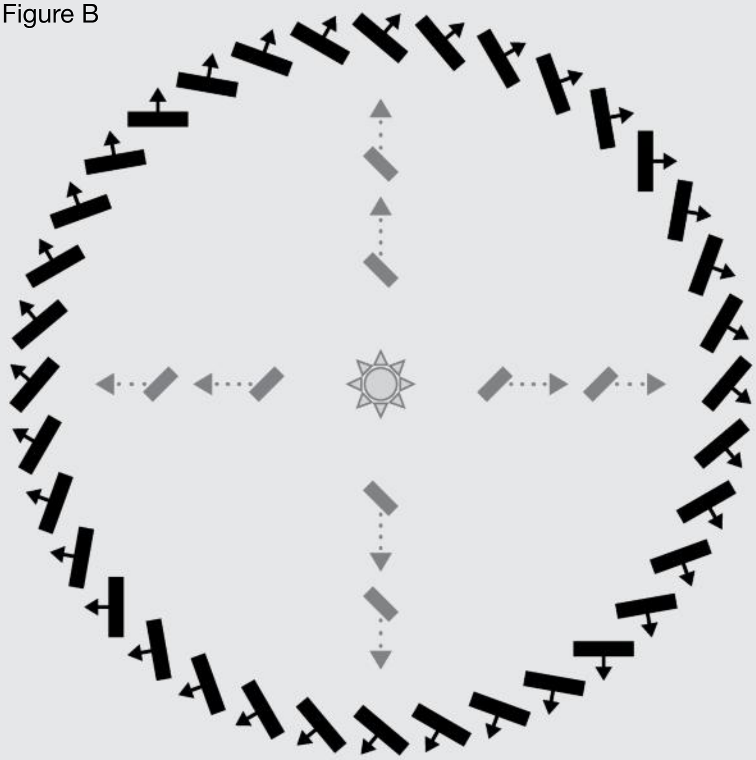
Once again, stare at the star in Figure A, but this time hold the page up between both hands and rotate it as if you were steering an imaginary car. Keep your viewing distance constant as you rotate the page. The inner circle should appear to expand, again because your brain thinks each diagonal bar is moving at right angles to itself. If you repeat Experiment 1, you'll notice some of this expansion effect here as well, but this magnification is masked by the more powerful illusory rotation effect. Actual rotation of the figure, on the other hand, masks whatever illusory rotation might be present, teasing out the radial component of the illusion.

EXPERIMENT 3

Repeat Experiment 1, but this time focus on the star in Figure B. The rotation and magnification effects will be harder to see because there is no apparent counter-rotating ring outside the circle of lines to highlight the illusion. This illustrates why the brain gets by with its frugal ways. Under normal circumstances, less than optimal performance by individual neurons in the visual cortex is good enough. And thank goodness: If the brain demanded perfection, it would need so many neurons that our heads would be the size (and weight) of medicine balls.

FAR RIGHT: POGONICI/DREAMSTIME.COM

Figure B

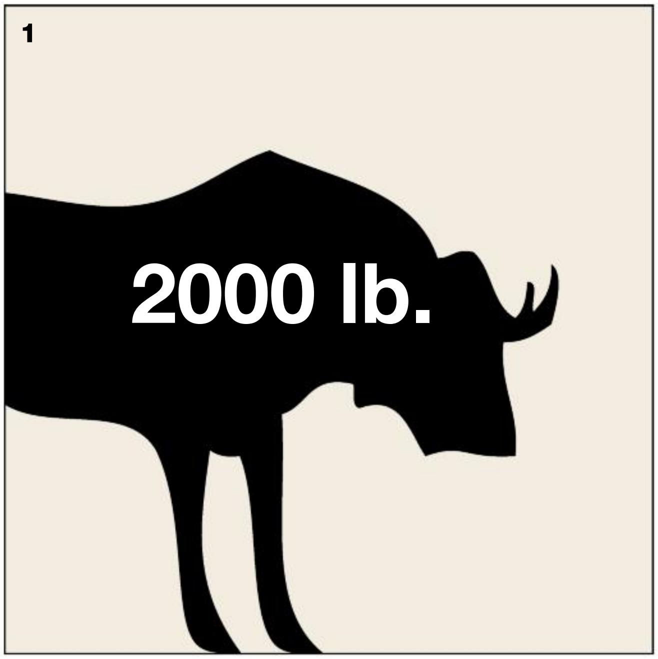


Neuroscientists know that the more links a memory makes in your brain, the more likely you are to remember it. Hence the idea behind mnemonics, clever devices that help you fix memories — whether of names, numbers or lists — in your brain by mooring them to other memories.

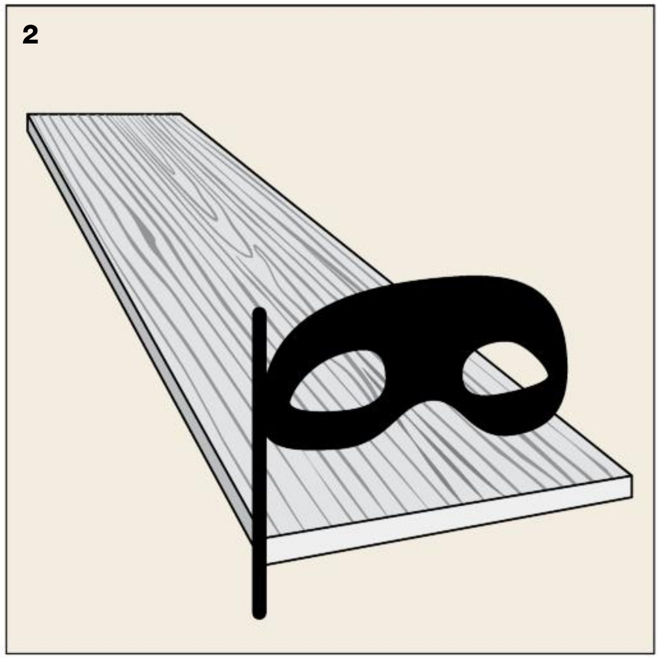
NAME GAME

A good way to remember someone's name is to imagine that person associated with the sounds of his or her name. For instance, you could think of Albert Einstein as a wild-haired L-shaped bird ("L-bird") drinking one mug ("eine stein") of beer. What other famous physicists and astronomers do the following mental pictures evoke?

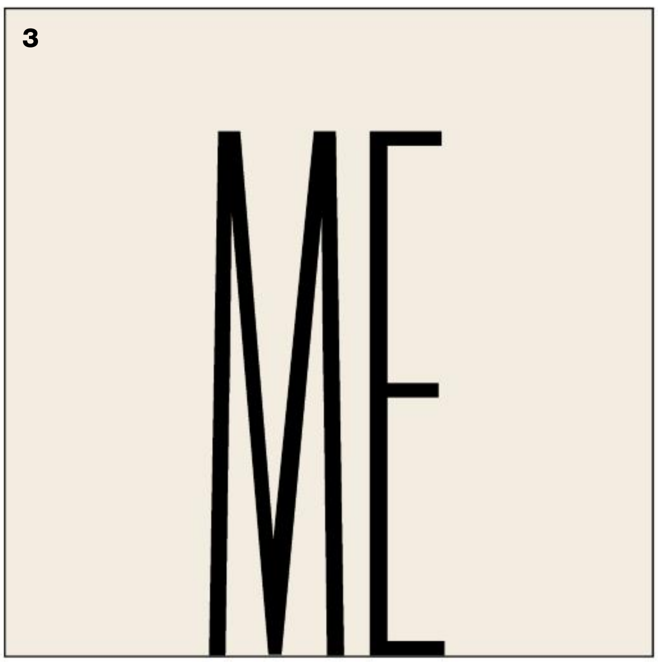
1



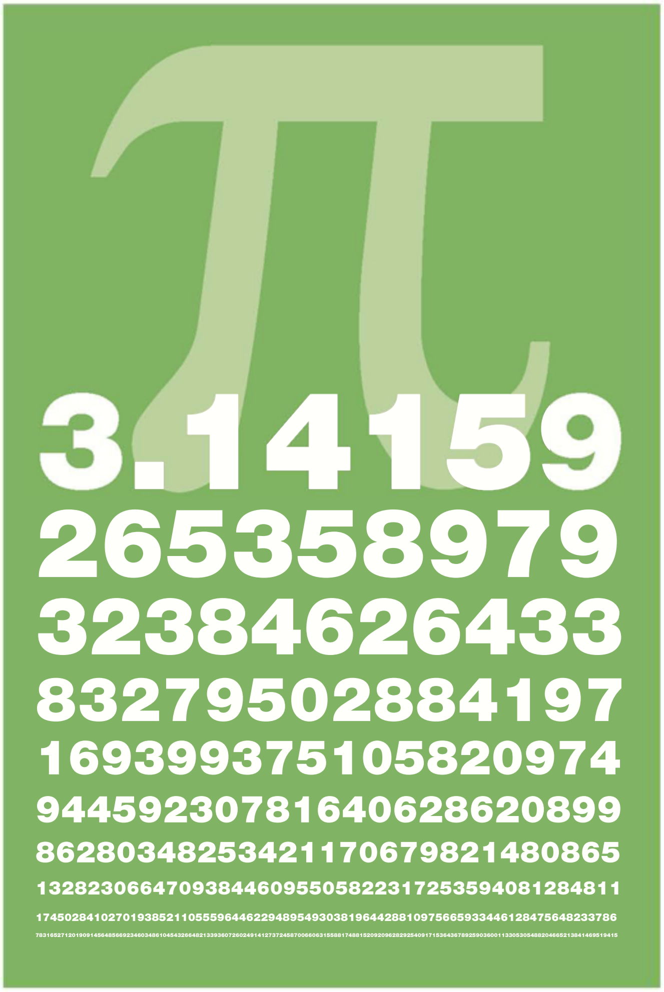
2



3



4



PI IN YOUR FACE

"May I draw a round perimeter?" is a mnemonic for remembering the first six digits of pi: Count the number of letters in each word, and you get the digits of 3.14159. Each of the following phrases is also a mnemonic for pi. Can you figure out how each mnemonic stands for pi? *Hint: Consider the spelling, sound and shapes of the words.*

1. We won your fun drive sign.
2. Circles and diameters are equally important.
3. The easy vowels echo mathematical magnitude.
4. Bring in your initial six questions.

TOP LEFT: NOAHGOLAN/DREAMSTIME.COM

ABBREVIATED SCIENCE

Mnemonics can also be used to help you remember lists or groups. For instance, "Kings Play Chess on Fine Grain Sand" is a useful mental trick for remembering the categories that biologists use to classify living things: kingdom, phylum, class, order, family, genus and species. Match each of the following mnemonics with what it stands for.

1. Big Boys Romance Our Young Girls Behind Victory Garden Walls
2. Better Go Home Every Night Completely Paid
3. Camels Often Sit Down Carefully Perhaps Their Joints Creak
4. Empty Garbage Before Daddy Flips
5. Harry He Likes Beer But Can Not Obtain Food
6. My Very Eager Mother Just Served Us Nachos

A. The order of the planets
B. The first nine elements in the periodic table
C. The color bands used to identify electronic resistors
D. The countries of Central America
E. Geologic time periods
F. The notes that correspond to the lines in the treble clef

Secrets of Illusion

Why is your brain so eager to believe in magic?

Without practice, props and a few "abracadabras," no magician is likely to amaze you with his tricks. But illusion requires another ingredient more critical than anything a conjurer brings to the stage — your brain. Four experiments reveal why you're so easily fooled.

EXPERIMENT 1

Odds are you'll see a solid square in the image at right, even though all that's there are four Pac-Man-like figures. But cover any two of the corners, and — presto! — watch

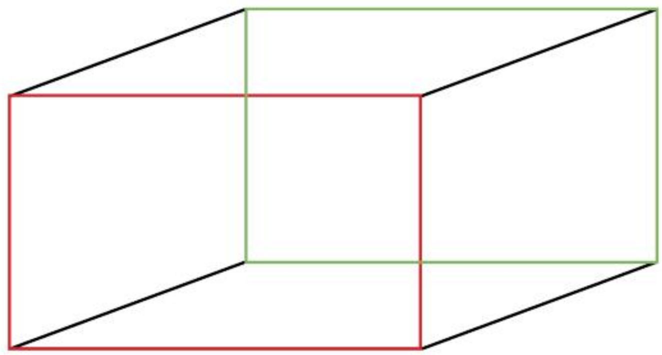
TOP: ENZOLIS184/DREAMSTIME.COM

the square vanish.

Why? The visual area of your cerebral cortex has learned to analyze the defining contours of an object (in this case, the corners) and then fill in the blanks to form a perception of the whole object. This is an excellent shortcut to compress the amount of information the brain must process and store, but under certain conditions it leads you to see what you expect to see, not what's really there. An illusionist plays on these expectations when he cuts a rope, then makes you believe he's put it back together. What he actually did was line up the severed ends of the rope, hiding the point where they meet with his hands. Your brain does the rest by filling in the gap.

EXPERIMENT 2

Staring at the box at right, you can easily convince yourself that the red face is closest to you while the green face is recessed — or that the opposite is true. But it should be impossible to perceive both the red and green boxes standing out from the page simultaneously. Your brain's inability to focus on more than one thing at a time allows a magician to conceal small movements (like palming a coin) by distracting you with larger movements (like waving a wand).



EXPERIMENT 3

Paris
in the
the Spring

At first blush, nothing seems amiss in the phrase at left, but look again and you'll discover why a magician is good at hiding things up his sleeve. At first glance, your brain will not see what it does not expect to see.

EXPERIMENT 4

The gaps in your brain's defenses are so profound that you can even fool yourself. Try this: Snugly tie a 2-foot length of string around a paperweight or small stone to make a pendulum. Holding the end of the string between thumb and forefinger, make the pendulum hang perfectly still.

Next, focus on the weight. Taking care not to move your hand at all, will the weight to sway left to right. As you concentrate, the pendulum should begin to swing in the direction your mind tells it to.

To prove this wasn't a fluke, steady the pendulum once more, then command it to move forward and back. Again, you'll witness "telekinesis."

What happened? The previous three experiments should tell you.

First, because your brain wanted to see the pendulum swing, it unconsciously moved your hand ever so slightly in the appropriate direction. Just like the square that materialized from the mere suggestion of corners, pendular motion arose from the suggestion that your mind can rule matter.

Second, the pendulum distracted your brain so much that it didn't notice your hand's subtle movements.

Finally, you didn't feel your hand move because you didn't expect it to.

Word Up

Lingo Mania *p.10*

RECOMBINANT WORDS

1. DNA, and
2. none, neon
3. reef, free
4. unable, nebula
5. brainy, binary
6. dilate, detail
7. algorithm, logarithm
8. triangle, altering
9. calibrate, bacterial
10. prenatal, paternal, parental

MISSING LINKS

1. DRY ICE AGE
2. PERPETUAL MOTION SICKNESS
3. STROBE LIGHT WAVE
4. CLEAN ROOM TEMPERATURE
5. BINARY STAR FISH
6. FUEL CELL DIVISION
7. FOOD CHAIN REACTION
8. COMMON COLD FUSION

Finding a Connection *p.11*

I'M LOOKING FOR MY MISSING LINK

1. NEEDLE-EYE-LIGHT-LIGHTBULB
2. CLOCK-HANDS-CLAWS-LOBSTER
3. STYROFOAM-CUP-CHALICE-PRAYER
4. TREE-LEAF-VEIN-PIPE
5. EGG-GOAD-DIG-TUNNEL
6. CEMENT-BUILDING-OBSERVATORY-STAR
7. LICENSE-PLATE-FOOD-CABBAGE
8. PEPPER-BLACK-KEYS-PIANO

WORD SCRAMBLE

1. CRIME **2.** FORCE **3.** RUINS **4.** LOGIC **5.** HELIUM **6.** LARYNX

Pure Deduction *p.12-13*

ASSEMBLING CLUES

1. GUISE
2. SENSE

FINDING PATTERNS

1. Straight vs. curved
2. Touch the baseline at two points vs. touch at one point
3. Hole vs. no hole
4. First half of the alphabet vs. last half
5. Vertically symmetrical vs. asymmetrical
6. Could hold water vs. couldn't hold water

FOCUS ON FRAGMENTS

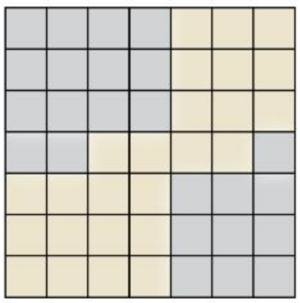
Think Inside the Box *p.16-17*

GRIDLOCK

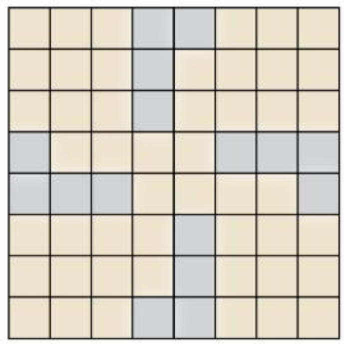
1 S	2 A	3 W	4 S
5 T	R	A	P
6 A	E	R	O
7 R	A	P	T

PLAY BY THE RULES

1. It is impossible because each row and column of a 6x6 grid can contain at most one word that's at least three letters long. In a 6x6 grid, there are only 12 rows and columns, so there is room for just 12 words.



2. There are other possible configurations.



3. There are other possible configurations.

NUMBER CRUNCHING

1

				T					
				E					
S	E	V	E	N			O	N	E
I			I					I	
X			G					N	
			H		F	I	V	E	
			T	W	O				
					U				
			T	H	R	E	E		

2

E					S	I	X	
I			O	N	E			
G					V		T	
H		F	I	V	E		E	
T	W	O			N	I	N	E
		U						
T	H	R	E	E				

3

T	S	N	F	F	E
H	E	I	S	O	I
R	V	N	I	U	G
E	E	E	X	R	H
E	N	O	W	T	T

Word Processing *p.18-19*

FRIEZE FRAMES

1. Continental drift
2. Big Bang
3. Circular reasoning
4. Compressed air
5. Fuzzy logic
6. Standing wave
7. Blue-green algae
8. Double helix
9. Peripheral vision
10. Melting point
11. Light wave
12. Zinc (Z in C)

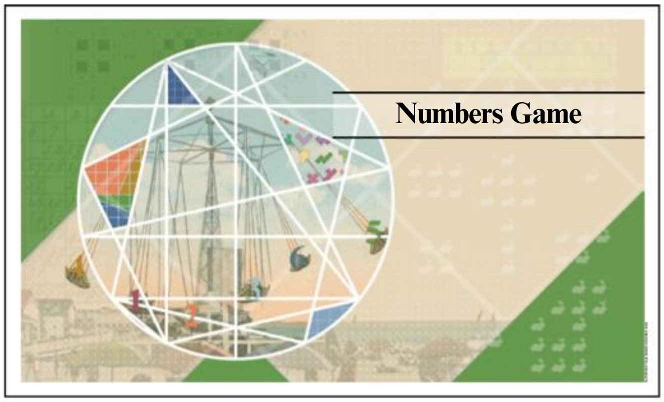
STRATIFIED LEXICON

Quotation: "There are no passengers on spaceship Earth. We are all crew." — Marshall McLuhan

O	Y	O	R	R	A	C	O	A	L	F	N	T
H	D	E	R	M	E	N	A	R	A	A	O	E
N	O	E	G	L	A	V	A	U	Y	L	B	W
P	M	A	L	C	A	C	L	T	A	L	R	E
S	M	I	L	T	A	T	N	T	L	O	A	T
S	E	O	N	L	A	U	S	N	P	Y	C	L
B	V	G	D	E	O	Y	E	V	A	C	R	A
A	E	E	R	M	R	B	I	T	U	M	E	N
S	R	S	A	C	O	A	S	N	S	P	S	D
A	A	E	C	E	S	H	L	H	I	P	Y	S
L	S	E	R	E	F	I	U	Q	A	A	E	R
T	A	E	P	T	H	W	E	A	R	L	G	E
F	J	O	R	D	A	L	L	C	R	E	E	W

HIDDEN IDENTITIES

1. CHARLES DARWIN—EVOLUTION
2. CARL SAGAN—COSMOLOGY
3. ALAN TURING—TURING TEST
4. JAMES WATSON—DOUBLE HELIX
5. LINUS PAULING—MOLECULES
6. LOUIS PASTEUR—VACCINATION
7. THOMAS EDISON—PHONOGRAPH
8. RACHEL CARSON—ECOLOGY
9. GREGOR MENDEL—HEREDITY

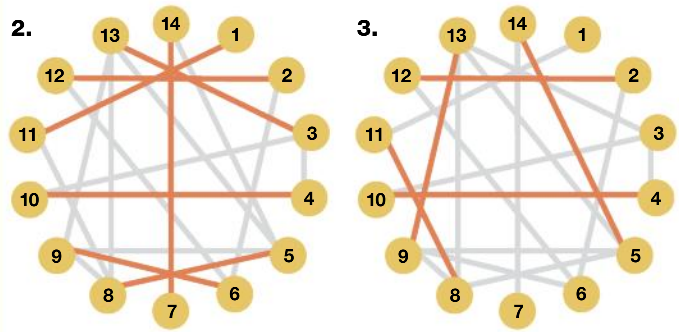


Numbers Game

Matchmaker *p.22-23*

ORGAN SWAP

1. Couples 1 and 7 have only one potential match because there is only one line ending at each of these circles.



BLOOD TYPES

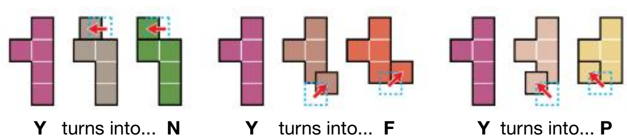
1. Type O- can donate to all the other blood types. Type AB+ can receive from all the other blood types.
2. There are six possible such chains:

O- to O+ to A+ to AB+	O- to A- to AB– to AB+
O- to O+ to B+ to AB+	O- to B- to B+ to AB+
O- to A- to A+ to AB+	O- to B- to AB- to AB+

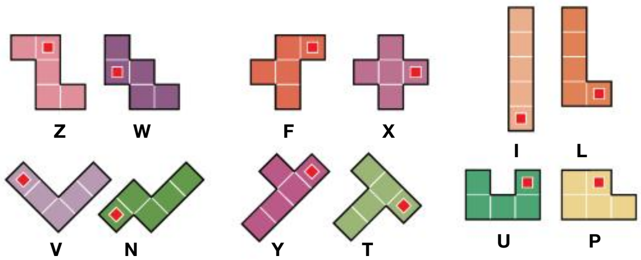
3. There are two such sets of three mutually incompatible blood types: A-, B- and O+ and A+, B+ and AB-.

SHAPE COUSINS

1. Y is also a cousin of N, F and P.

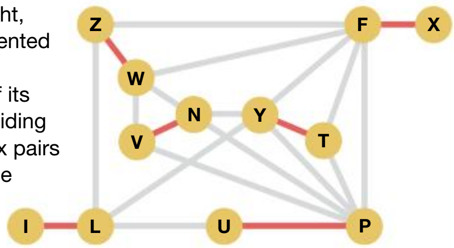


2. There are two shapes that have only one cousin each: I is a cousin only of L, and X is a cousin only of F.



3. Above is the unique solution. The square that changes one shape to its cousin is marked with a small red square. You can find the solution by exhaustively trying all combinations, but it is easier to first diagram all of the relationships (graph theorists call such a diagram a graph).

In the graph at right, each shape is represented by a node, which is connected to each of its cousins by a line. Dividing the 12 shapes into six pairs of cousins is the same as finding six lines in the graph whose endpoints include all 12 nodes. Notice that no two of these lines will end at the same node because no shape can appear in two different pairs.



Start by choosing the lines connecting I to L and F to X because these choices are forced (I connects only to L, and F connects only to X). Remove all of the remaining lines connected to L and F. Nodes U and Z now have only one cousin each, which forces you to pair them with P and W. Finally, the remaining nodes V, N, Y and T must be paired as V-N and Y-T. The result is a graph that contains only the six red lines.

Connecting the Dots *p.24*

GAUSS' SHORTCUT

1. Instead of adding 1 + 2 + 3 + 4 . . . + 100, add the numbers in pairs, like this: (1 + 100) + (2 + 99) + (3 + 98) . . . + (50 + 51). Each pair adds up to 101, and there are 50 pairs, so the total is 101 x 50, or 5,050.
2. The same method yields 500 pairs (1 + 1,000) + (2 + 999) + (3 + 998) . . . + (500 + 501) that each adds up to 1,001. So the answer is 500 x 1,001, or 500,500.
3. The sum of the even numbers from 2 to 2,000 is simply twice the sum of all the whole numbers from 1 to 1,000. So the answer is twice 500,500, or 1,001,000.
4. The sum of a series of odd numbers starting with 1 is always a square number. To be exact, 1 + 3 + 5 + 7 + (2n – 1) equals the square number n^2. So the sum of the odd numbers 1 to 1,001 is 500^2, or 250,000.

ADDING BACKWARD

1.

127	241	150	130
301	130	222	522
+546	+427	+318	+834
974	798	690	1,486

2. To compute a 15 percent restaurant tip on a $26.14 bill, first compute 10 percent, which is $2.61. Half of that is $1.30, which is 5 percent of the bill. Add the two numbers together to get the standard 15 percent tip: $2.61 + $1.30 = $3.91.

Out of the Ballpark *p.25*

1. At each successive moment the number of balls keeps increasing: 1, 2, 3, 4 and so on. So at midnight the number of baseballs will be the limit of this series, namely infinity.
2. Each time the pitcher throws balls into the room, the person inside the room throws half as many back out. The pitcher threw in an infinite number of baseballs, so the person inside threw out half of infinity, leaving half of infinity inside. (But, of course, half of infinity is still infinity.)
3. Every ball thrown in is eventually thrown out before midnight, so no balls remain.
4. The question itself is flawed because there is a limit to the speed at which balls can be thrown. (And, in theory, if you keep splitting the remaining time in half, some would argue that midnight would never strike.)

Counting Houses *p.26-27*

1. Here is the completed order form for the numbers 1 to 99:

ORDER FORM

0	1	2	3	4	5	6	7	8	9
9	20	20	20	20	20	20	20	20	20

Except for 0, each digit appears 10 times in the tens place and 10 times in the ones place. In standard street addresses from 1 to 99, 0 appears only nine times in the ones place.

2. Here is the completed order form for the numbers 1 to 999:

ORDER FORM

0	1	2	3	4	5	6	7	8	9
189	300	300	300	300	300	300	300	300	300

Except for 0, each digit appears 100 times in the ones place, 100 times in the tens place and 100 times in the hundreds place. The numeral 0 appears 99 times in the ones place and 90 times in the tens place; it never appears in the hundreds place.

3. Here is the completed order form for the other self-descriptive four-digit number:

ORDER FORM

0	1	2	3
2	0	2	0

4. The only 10-digit self-descriptive number is:

ORDER FORM

0	1	2	3	4	5	6	7	8	9
6	2	1	0	0	0	1	0	0	0

There are no self-descriptive numbers with two, three or six digits. You can, however, extrapolate from the pattern of digits that appears in the 10-digit number to make self-descriptive numbers of seven through 13 digits. They are: 3211000, 42101000, 521001000, 6210001000, 72100001000, 821000001000 and 9210000001000. The only self-descriptive five-digit number, 21200, does not follow this pattern.

Permutations *p.28-29*

MUSICAL CHAIRS

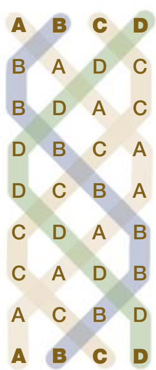
1. 24 weeks. Consider seating the four people in order, one at a time. The first person has a choice of four chairs. That leaves the second person with a choice of three chairs, for a total of 4 x 3 = 12 combinations so far. The last two people can sit in the remaining two chairs in two different ways, so the total number is 4 x 3 x 2 = 24 combinations.
2. 8 weeks. The north and south chairs can be occupied by either the Reds or the Blues, with the other couple in the east and west chairs (2 combinations), and for each of those combinations each couple can be in one of two orders (4 combinations). Altogether, 2 x 4 = 8 combinations.
3. 16 weeks. There are 24 combinations allowing anyone to sit anywhere. Remove the eight combinations in which members of each couple sit opposite each other, and you are left with the combinations in which members of each couple sit side by side. Altogether, 24 – 8 = 16.
4. For six people, the answers to the three questions are 720 (6 x 5 x 4 x 3 x 2), 48 (six couple patterns times eight ways to switch members of all couples) and 96 (12 couple patterns times eight ways to switch members of all couples).

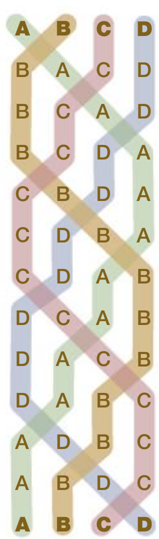
ANAGRAMS

1. NO MORE STARS
2. ALBEDO-DOABLE 354612
SILVER-LIVERS 621345
PROTON-PRONTO 123564

RINGING IN THE CHANGES

1. Bell B and bell D follow paths that are mirror images of bells A and C (right).





2. Two successive sequences in a peal can differ only by switching consecutive bells. If, for instance, bell C is in position 2 in one sequence, it can stay in position 2 in the next sequence or switch to position 1 or 3. That means that in a four-bell peal, the distance from one occurrence of a bell to the next occurrence of the same bell must always be four, three or five bells, never one bell.
3. The peal is 12 sequences long. Notice that the order of the bells rotates by one bell every three sequences. First the A migrates to the end, then B migrates to the end and so on until the sequence has rotated through all four possible positions.

Fibonacci's World *p.30-31*

FIBONACCI'S RABBITS

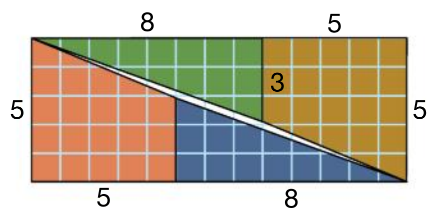
1. 144. The complete sequence is 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144. By the way, the reason that each Fibonacci number is the sum of the two previous numbers is that the number of rabbit pairs in a generation is equal to the number of rabbit pairs in the previous generation that are still alive (rabbits never die in Fibonacci's problem!) plus all the newborn pairs, which is equal to the number of pairs that are at least two months old.
2. 4,096. The number of pairs doubles each month: 1, 2, 4, 8, 16…
3. 41. The first few numbers in the sequence are 1, 1, 1, 2, 3, 4, 6, 9 … Each number in the sequence is equal to the sum of the previous number and the number three places back in the sequence (1 + 3 = 4, 2 + 4 = 6, 3 + 6 = 9 and so on).
4. 376. The first few numbers in the sequence are 1, 2, 4, 7, 12, 20 … Each number in the sequence is one more than the sum of the previous two numbers (1 + 2 + 1 = 4, 2 + 4 + 1 = 7, 7 + 12 + 1 = 20 and so on).

THE GOLDEN RATIO

1. 2x3 inches, 6x10 inches, 7x11 inches and 8x13 inches.
2. More squat. 11/8.5 = 1.294 … which is much closer to the proportions of a square than the golden ratio.
3. European paper (297/210 = 1.414 …) and traditional television sets (4/3 = 1.333 …) are more squat than the golden ratio, whereas American business cards (3.5/2 = 1.75) and high-definition televisions (16/9 = 1.777…) are more skinny.

AREA PARADOX

1. Of course, it is impossible to cut up a shape and reassemble the pieces to make a shape with a different area. The trick here is that the edges that seem to meet along the diagonal of the rectangle do not, in fact, meet; they leave a long skinny hole with an area of 1 square. The hole is so skinny that it is hard to notice. Here is an exaggerated version of the figure that makes the hole more obvious.



2. The apparent area of this figure is 63 squares, one less than the area of the original square. Again, the culprit is diagonal edges that do not align exactly; instead of a skinny hole, there is a skinny area of overlap in this figure that accounts for the missing square.
3. If you use the next pair of Fibonacci numbers, you get three figures with the areas 13 x 13 = 169, 8 x 21 = 168, and 170. Notice that the rectangular figure now has one square less of apparent area than the square figure instead of more; instead of a long skinny hole, there is now a long skinny area where adjacent pieces overlap. And the other figure now has one square more of apparent area than the square figure.

Ultimate Math *p.32-33*

DRAW THE LINE

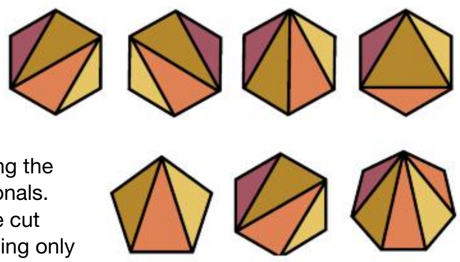
1. A pentagon has five diagonals. A heptagon has 14 diagonals.

2. The table below shows the number of diagonals for polygons with four through 10 sides. The pattern is that the number of diagonals for *n* sides is (*n* – 2) plus the number of diagonals for (*n* – 1) sides. You could also come up with an equation that relates the number of sides (*n*) to the number of diagonals (*d*): $d = [n(n - 3)]/2$.

Number of sides	4	5	6	7	8	9	10
Number of diagonals	2	5	9	14	20	27	35

HOW YOU SLICE IT

1. There are 14 ways to cut a hexagon into triangles using only nonintersecting diagonals. Here are the four basic patterns and the number of different dissections that can be obtained by rotating the configuration of diagonals.



2. A pentagon can be cut into three triangles using only nonintersecting diagonals. A heptagon can be cut into five triangles.

3. The number of triangles that a polygon can be cut into, using only nonintersecting diagonals, is always two less than the number of sides.

PEAK PERFORMANCE

1. The pentagon, hexagon and octagon at right have been dissected into isosceles triangles using only nonintersecting diagonals.

2. At right is a dissection of a dodecagon into isosceles triangles using only nonintersecting diagonals. Notice that you can create this dissection by starting with the dissected hexagon above and adding a skinny isosceles triangle "peak" to each side of the hexagon dissection (doubling the number of sides). To produce a similar dissection for a 24-gon, add an isosceles triangle peak to each side of this dodecagon dissection. For a 48-gon, add peaks to the 24-gon. For an 80-gon, add peaks to the dissected pentagon four times.

MISSING NUMBERS

1.

10	–	9	x	1	=	1
/		+		+		
5	–	4	x	2	=	2
x		–		–		
3	x	8	–	7	=	3
=		=		=		
6		5		-4		

2.

4	x	9	/	6	=	6
+		–		–		
3	+	7	–	8	=	2
+		x		+		
1	x	5	/	10	=	½
=		=		=		
8		10		8		

3.

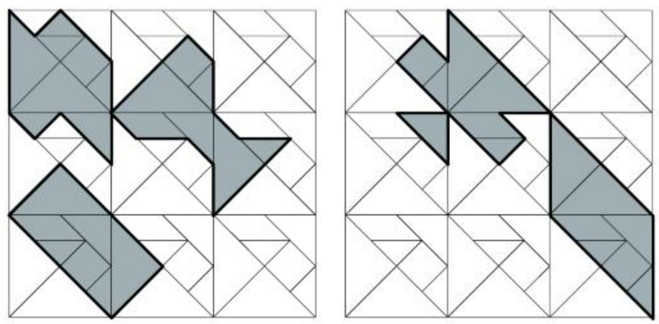
8	/	4	x	2	=	1
–		–		x		
7	+	9	+	6	=	22
+		/		/		
5	+	1	–	3	=	3
=		=		=		
6		-5		4		

The Shape of Things

Going to Pieces *p.38-39*

TANGLED TANGRAMS

We've shown the same grid twice for clarity's sake (several of the pieces overlap). Please note that some of the shapes appear more than once in the grid.

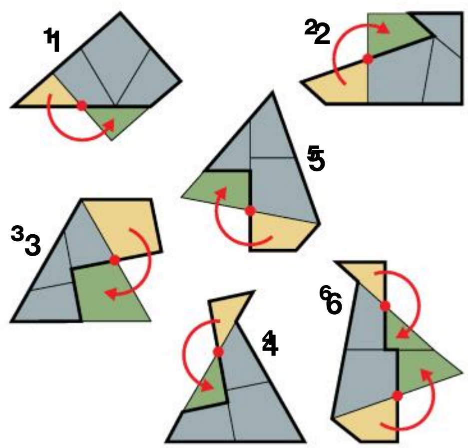


HINGED DISSECTIONS

1. In each figure below, the yellow piece swings around the red pivot point to reach the green position and form a square or triangle.

2. Figure 6 requires two swings and forms a triangle. All others require just one swing of one piece to form a square or triangle.

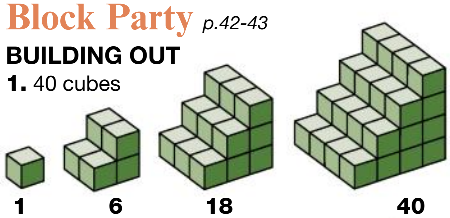
3. In figure 2, the swinging piece would collide with the top blue triangle, unless the triangle were first moved out of the way.



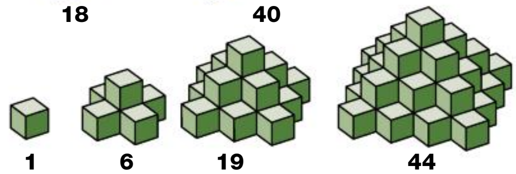
Block Party *p.42-43*

BUILDING OUT

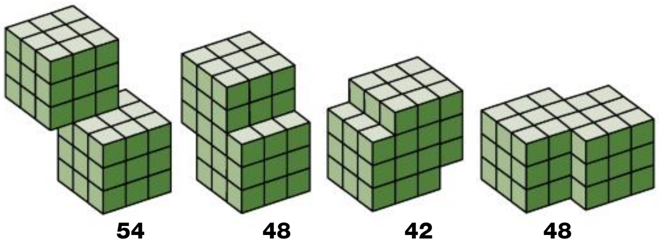
1. 40 cubes



2. 44 cubes

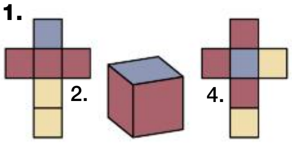


3. 48 cubes. The blocks are traveling through each other, diagonally and to the right, one cube at a time.

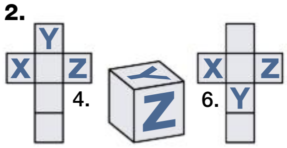


FOLDING IN

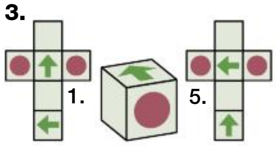
1.



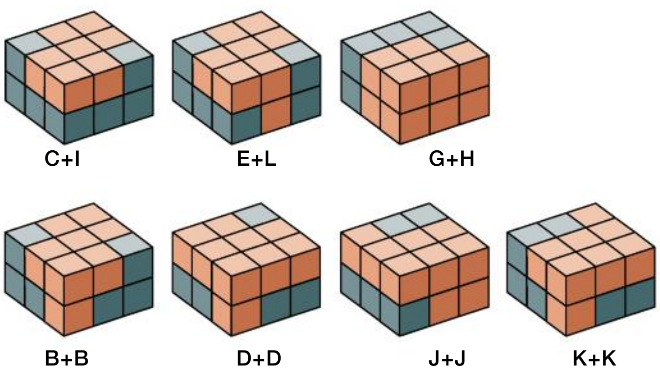
2.



3.



STACKING UP



Rubik's Cubism *p.44-45*

THE CUBIES

1. There are six cubies colored on one side, one in the middle of each face of the cube. There are 12 cubies colored on two sides, one in the middle of each edge of the cube. And there are eight cubies colored on three sides, one at each corner of the cube. There is one uncolored cubie in the center of our imaginary cube. There are no cubies colored on four, five or six sides.

2. The three pairs of colors on opposite sides of the cube that never appear together on a single cubie are blue and green, yellow and white, and red and orange.

3. The cube has six faces, and each face can be twisted 90 degrees clockwise or counterclockwise for a total of 12 possible face twists.

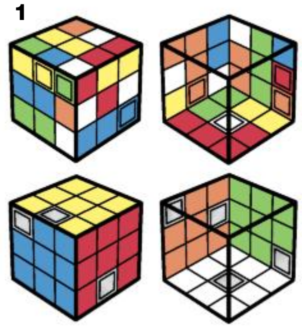
4. When you twist a face, 19 cubies stay in position: the center cubie of the twisted face and the 18 cubies in the rest of the cube. (This answer applies only to our imaginary cube. An actual Rubik's Cube has no center cubie.)

5. Since the center cubie of each face never changes position, it always signals which color that face should be in the solved cube.

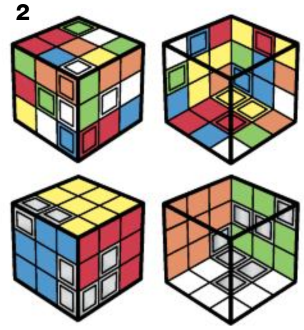
THE COLORS

For each cube, the pair of diagrams on top shows the answer, and the pair of diagrams on the bottom shows where the grayed-out cubies would be in the cube's starting position.

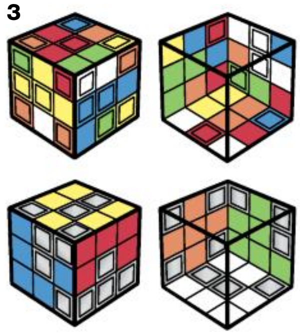
1



2



3

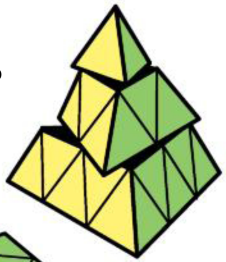


ANSWERS

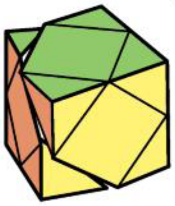
THE VARIATIONS

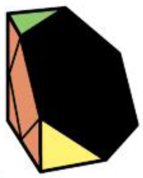
1. A Pyraminx needs 36 stickers: nine triangles in four different colors. The Skewb Cube needs 30 stickers: four triangles and a square in each of the six different colors.

2. A Pyraminx has eight twists: two each along four different axes perpendicular to the four faces. The two basic twists are at right.

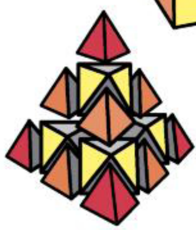


The Skewb Cube has four twists: one along each of the four different axes that connect opposite corners of the cube. The basic twist is shown at right. If we remove the rotating half, we see that the plane of the cut is a hexagon.





3. The Pyraminx is made of 14 smaller units of three different colorations: four corner tetrahedrons colored on three sides (red), six edge tetrahedrons colored on two sides (orange) and four center octahedrons colored on three nonadjacent sides (yellow).

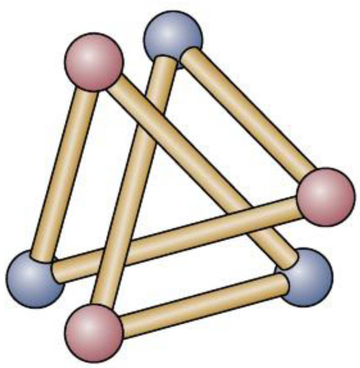


The Skewb Cube is made of 14 smaller units of two different types: eight corner tetrahedrons colored on three sides and six center squares colored on just one side.

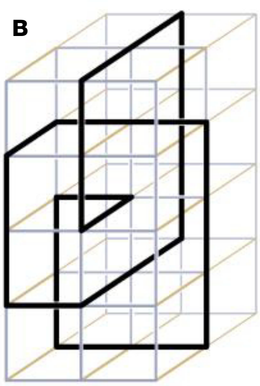
Going Loopy *p.48-49*

STICK KNOTS

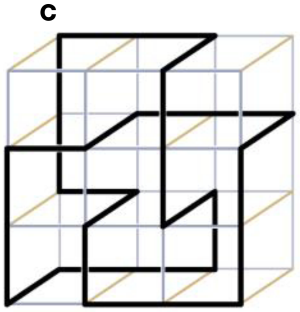
A. The purple corners rest on a higher parallel plane; the blue corners lie on a lower plane.



B

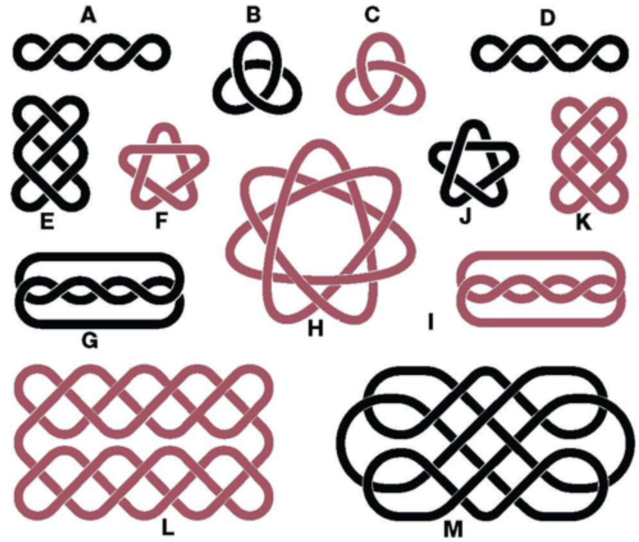


C



TRICK KNOTS

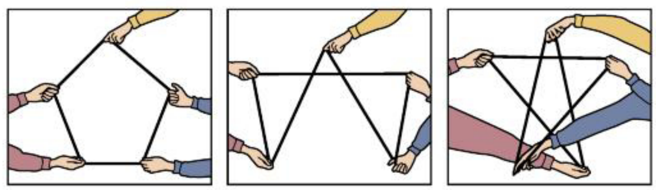
The plum-colored loops are knotted; the black loops are not.



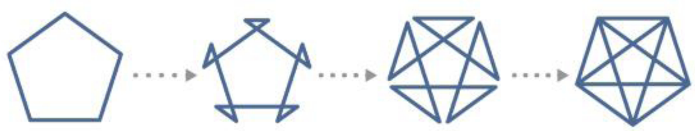
STAR FORMATION

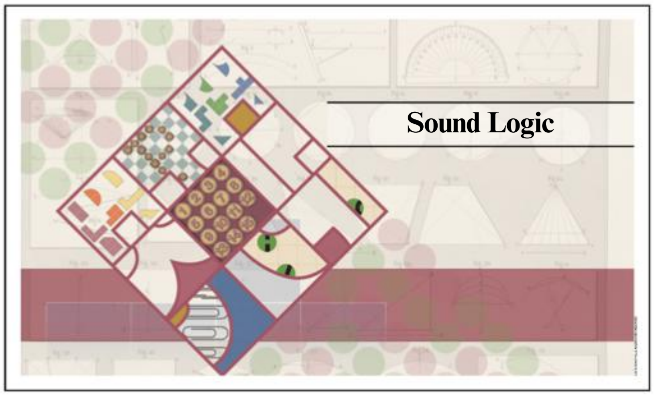
1. The easiest way to make a string star is for one person to hand a point of the loop to someone else. Then, holding a point of the loop, that first person "draws" the star by threading the string through three more hands, using the same motions used in drawing a large star.

2. The solution below uses three people, but this approach also works with four or five. First, fold the bottom of the pentagon up to make the letter A. Then cross the two legs of the A.



3. Each of the five people starts by holding a point of the pentagon with one hand. To turn the pentagon into a star inscribed in a pentagon, each person twists his or her hand to make a small loop and then uses both hands to widen the loop into a triangle. Everyone widens his or her triangle until each person is touching his or her neighbors' hands so the loop once again becomes a pentagon — but now with a star inscribed in it.





Sound Logic

The 15 Puzzle *p.52-53*

BENDING THE RULES

1. The solver put the blocks in the order at right, then turned the entire tray 90 degrees clockwise.

4	8	12	
3	7	11	15
2	6	10	14
1	5	9	13

2. The solver removed the 6 and 9, turned them upside down to make 9 and 6, and then placed the blocks back in their original positions. That change in the order of the blocks allowed them to be slid around into the appropriate sequence.

3. The solver put the cylindrical blocks in the order shown in the answer to question 1, turned the entire tray 90 degrees clockwise, and then rotated each piece 90 degrees counterclockwise.

THE IMPOSSIBLE PUZZLE

1. No matter how they're moved, the blocks in the first tray remain in ascending order (1, 2, 3) reading clockwise. The blocks in the second tray are in counterclockwise ascending order.

2. No matter how you move the blocks, the red 1 block can never get past the barrier formed by the 2 and 3 blocks.

3. However you move the pieces, the small blocks always stay in ascending order (1, 2, 3) reading clockwise around the big 4 block. The small blocks in the second tray are not in numerical order.

4. The six moves required to transform the first tray into the second tray essentially form a clockwise loop that begins with moving the 12 block down to the bottom row and shifting the 11 block to the right. To solve the puzzle in eight moves, use the same six moves, then make two extra moves that slide the 12 piece right, then left. So the puzzle can be solved in any even number of moves of six or greater.

The puzzle cannot be solved in an odd number of moves. Since the empty space starts and ends in the same position, it must travel the same number of horizontal moves left as it does right and the same number of vertical moves up as down. The number of horizontal moves and the number of vertical moves must therefore both be even numbers. The sum of two even numbers is always an even number, so the total number of moves must be even. Thus it is impossible to solve this puzzle in 99 moves or any other odd number of moves.

ALPHABET SOUP

1. The nine letters can be rearranged to make the word LABYRINTH.

2. The empty space and the unscrambled letters are shown at right. There are two possible positions for the empty space in the letter N. The empty space in the I cannot be at the left side of the middle row because reversing the positions of the other two blocks in the middle row is impossible — just as reversing the last two numbers in the 15 Puzzle is impossible.

Paleo Puzzles *p.54*

TYRANNOSAURUS REX REDUX

CRYPTO CLADISTICS

Characteristic set 1 = Diagram D
Characteristic set 2 = Diagram C
Characteristic set 3 = Diagram A
Characteristic set 4 = Diagram B

ANSWERS

It's Chemistry, Baby p.55

EXPOSED TO THE ELEMENTS

1. IRON + SP = PRISON
2. ZINC + TIE = CITIZEN
3. ARGON + AL = GRANOLA
4. COPPER + ISE = PERISCOPE
5. COBALT + KU = BLACKOUT
6. ARSENIC + E = INCREASE
7. BROMINE + ST = BRIMSTONE
8. HYDROGEN + U = GREYHOUND
9. CHLORINE + C = CHRONICLE
10. POTASSIUM + N = ASSUMPTION

MATERIAL DIFFERENCE

1. Here are equations that yield the numbers 1 to 10. (There are other solutions.)

$1 = 4 - 4 + (4/4)$
$2 = (4/4) + (4/4)$
$3 = (4 + 4 + 4)/4$
$4 = 4(4 - 4) + 4$
$5 = [(4 \times 4) + 4]/4$
$6 = (4 + 4)/4 + 4$
$7 = 4 + 4 - (4/4)$
$8 = 4 + 4 + 4 - 4$
$9 = 4 + 4 + (4/4)$
$10 = 4 + 4 + 4 - \sqrt{4}$

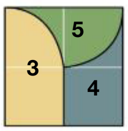
2. Here are equations that yield the numbers 11 to 15.

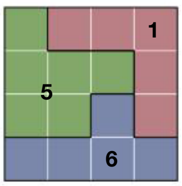
$11 = 44/(\sqrt{4} + \sqrt{4})$
$12 = (44 + 4)/4$
$13 = 44/4 + \sqrt{4}$
$14 = 4 + 4 + 4 + \sqrt{4}$
$15 = 4 \times 4 - (4/4)$

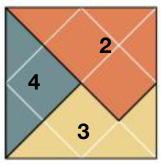
3. The number 19 cannot be made with four 4s. Here's how to make the other numbers from 16 to 20.

$16 = 4 + 4 + 4 + 4$
$17 = [4 \times 4] + (4/4)$
$18 = [4 \times 4] + (4/\sqrt{4})$
$20 = 4[4/4 + 4]$

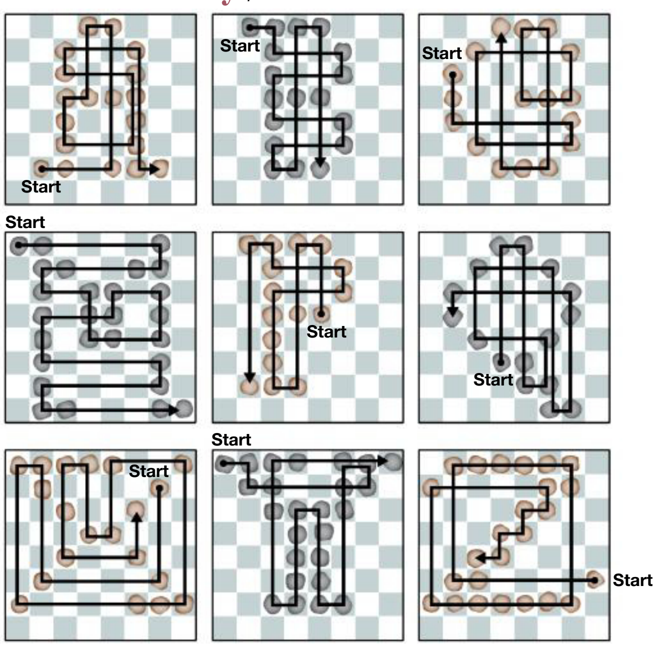
COMBINED FORMS

A


B


C


Hero's Journey p.56-57



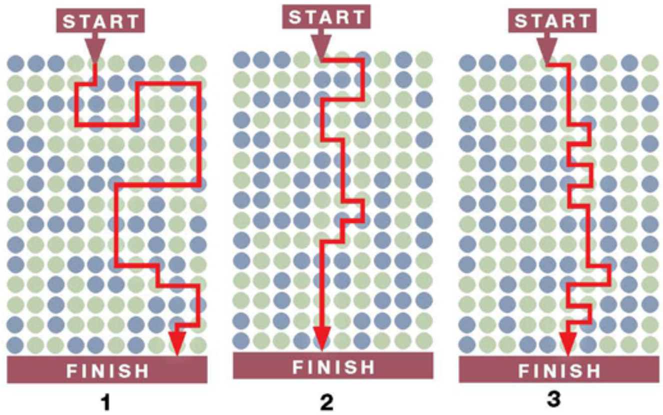
Parlor Genomics p.58-59

INHERITED TRAITS

1. Muggsvillers 3 and 7 have only one cousin each: Muggsviller 3 and Muggsviller 1 are cousins, and Muggsviller 7 and Muggsviller 8 are cousins.
2. Muggsvillers 2 and 5 have four cousins each: Muggsviller 2 is a cousin of 5, 6, 8 and 9; Muggsviller 5 is a cousin of 1, 2, 4 and 9.
3. The seating order is 3-1-4-5-9-2-6-8-7 (or backward, 7-8-6-2-9-5-4-1-3) as shown below.

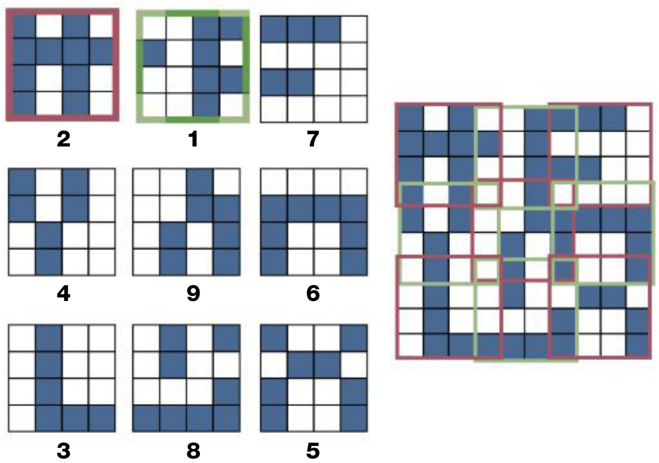
3 1 4 5 9 2 6 8 7

GENETIC TRANSCRIPTION

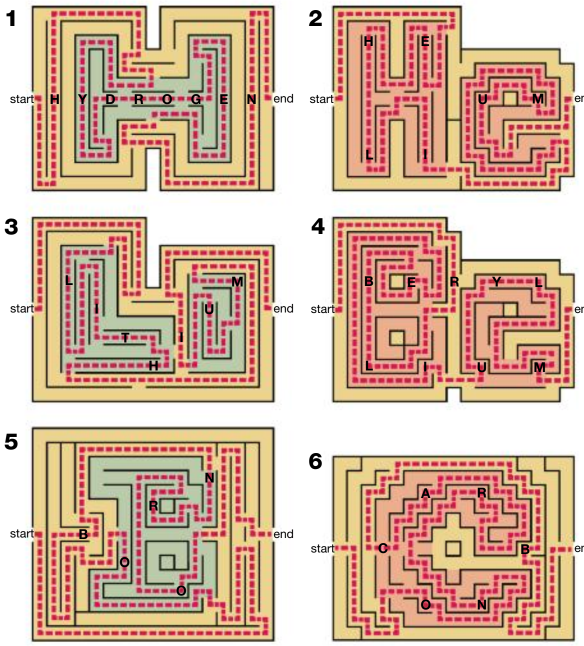


JIGSAW SEQUENCING

Here are the sequence of pieces and the final picture. The answer word is HELIX, which is the shape of the DNA molecule.



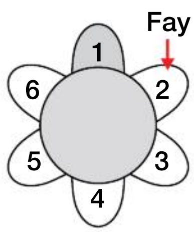
Element of Surprise p.60



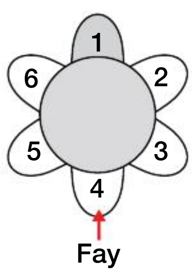
Mix, Map and Match p.61

MUSICAL CHAIRS

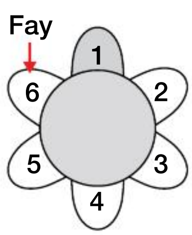
1. Monday: Fay sat in chair 2. Abe sat in chair 6, to Carl's right (chair 1). (Abe could have sat in chair 2, on the other side of the red chair, but then there would be no place for Ed to sit that would satisfy the clues.) With Abe in chair 6, Barb had to be in chair 3 and Deb in chair 4. Because Ed did not sit next to Barb, he must have sat in chair 5, leaving chair 2 for Fay.



2. Tuesday: Fay sat in chair 4. It's known that Barb sat in the red chair (chair 1), so Abe and Carl had to have sat in chairs 3 and 5. The only way for Deb to have sat opposite Abe and for Ed to have sat just to the right of Barb (in chair 1) is for Abe to sit in chair 5, Deb to sit opposite (in chair 2), Carl in chair 3 and Ed in chair 6, leaving chair 4 for Fay.

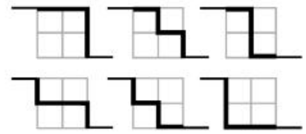


3. Wednesday: Fay sat in chair 6. With Carl in chair 1, Deb had to be in chair 2 or chair 6. If Deb had sat in chair 6, Abe would have been in chair 5, putting Barb on his right. But it's a given that Barb sat on Ed's right. So Deb had to have sat in chair 2, putting Abe in chair 3, Barb in chair 4, Ed in chair 5 and Fay in chair 6.

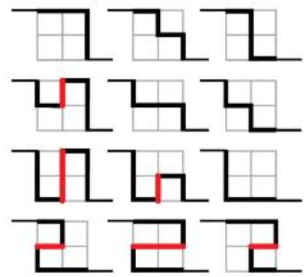


HOMEWARD BOUND

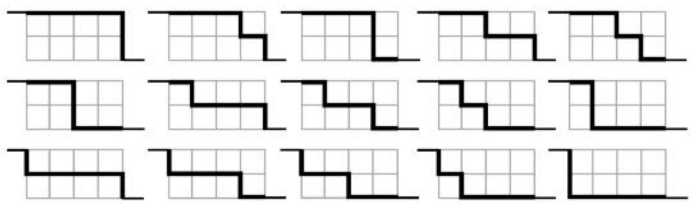
A. There are six paths home.



B. There are 12 paths home. The red lines show where the car takes advantage of the two-way roads to travel backward, away from home.



C. There are 15 paths.



A Better Mousetrap p.62-63

ACCIDENTAL TECHNOLOGY

1-F. When Jolly tried to rub out the stain, the tablecloth got cleaner. Modern dry cleaners use other liquids.

2-D. By mixing nitroglycerin with a special soil, Nobel created an explosive that was easier to handle than nitroglycerin. He later used his fortune to found the Nobel Prize.

3-C. Oil field workers often spread the substance, which they called rod wax, on wounds to help them heal. It took 10 years for Chesebrough to develop a colorless, odorless petroleum jelly.

4-G. Paper made from cotton rags was the 18th-century standard; modern paper, like wasp nests, is made from wood.

5-B. The powder turned out to be surprisingly inert and slippery. Teflon remained a military secret during World War II.

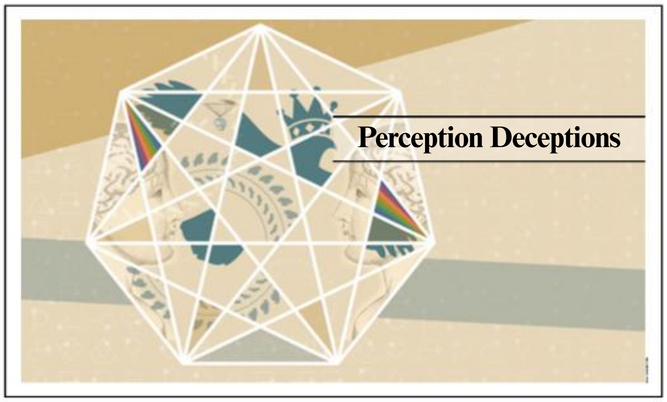
6-H. The second thing Spencer held in front of the radar equipment was a bag of unpopped popcorn.

7-A. De Mestral put the cockleburs under a microscope and saw that their spikes ended in little hooks.

8-E. When Schlatter licked his fingers, they tasted sweet. Other artificial sweeteners have been discovered through similar accidents.

EVOLUTION OF THE PAPER CLIP

1-B, 2-I, 3-H, 4-A, 5-F, 6-E, 7-G, 8-C, 9-D



Perception Deceptions

Eye Examination *p.68-69*

STAR SEARCH

DOUBLE EXPOSURE

Arm + Leg
Heart + Lungs
Head + Toes
Skull + Brain
Lymph + Spleen

Pattern Recognition *p.72-73*

SHAPES

1. LEFT: The red dot covers a corner of the figure.
RIGHT: The red dot covers a smooth part of the figure.
2. LEFT: The red dot is in the left half of the figure.
RIGHT: The red dot is in the right half of the figure.
3. Each figure consists of a loop, a handle sticking out of the loop and a red dot. LEFT: The red dot is located counterclockwise past the point where the handle meets the loop. RIGHT: The red dot is located clockwise past the point where the handle meets the loop.

NUMBERS

1. LEFT: Even numbers. RIGHT: Odd numbers.
2. LEFT: Multiple of 7. RIGHT: Multiple of 7 plus 1.
3. LEFT: The two digits that make up each number differ by 2 and add up to an even number. RIGHT: The two digits that make up each number differ by 3 and add up to an odd number.

ELEMENTS

1. LEFT: Elements whose names contain the letter E.
RIGHT: Elements whose names do not contain the letter E.
2. LEFT: Elements that occur naturally in the human body.
RIGHT: Elements that do not occur naturally in the human body.
3. LEFT: Elements with an atomic number of 8 or less. These elements appear earlier in the periodic table and have a lower atomic mass. RIGHT: Elements with an atomic number of 15 or more. Note: All elements are shown in order of atomic mass.

Memory Upgrades *p.76-77*

NAME GAME

1. Physicist Isaac Newton (gnu ton)
2. Physicist Max Planck (mask plank)
3. Ancient Greek astronomer Ptolemy (tall ME)
4. Astrophysicist Stephen Hawking (hawk king)

PI IN YOUR FACE

1. Each word rhymes with a digit of pi: *We* rhymes with 3, *won* rhymes with 1, *your* rhymes with 4 and so on.
2. Each word starts with a letter whose position in the alphabet is a digit of pi: *Circles* starts with the third letter of the alphabet, *and* starts with the first letter of the alphabet, *diameters* starts with the fourth letter of the alphabet and so on.
3. The position of the letter E in each word corresponds to a digit of pi: E is the third letter of *The*, the first letter of *easy*, the fourth letter of *vowels* and so on.
4. The first letter of each word has a shape similar to the corresponding digit: The first letter of *Bring* looks like a 3, the first letter of *in* looks like a 1, the first letter of *your* looks like a 4 and so on.

ABBREVIATED SCIENCE

1-C. Black, brown, red, orange, yellow, green, blue, violet, gray, white
2-D. Belize, Guatemala, Honduras, El Salvador, Nicaragua, Costa Rica, Panama
3-E. Cambrian, Ordovician, Silurian, Devonian, Carboniferous, Permian, Triassic, Jurassic, Cretaceous
4-F. The notes E, G, B, D, F
5-B. Hydrogen, helium, lithium, beryllium, boron, carbon, nitrogen, oxygen, fluorine
6-A. Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune

GET IN THE AIR WITH *DRONE360*™

If you're a multirotor hobbyist, have questions about drone regulations, want to capture jaw-dropping aerial videos, or wonder how drones help in research, humanitarian aid, and our everyday lives, you'll find it in ***Drone360***.

In six stunning issues a year, you'll find:

- Photo, video, and flying tips from the pros.
- Drone and equipment reviews.
- The latest on rules, regulations, and licensing.
- How-to tips for getting and keeping your drones working.
- Insightful interviews with innovators and thought leaders.

P30443

Subscribe now at Drone360Mag.com/offer