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**Creativity in Science and Engineering:** A mental process involving the generation of new ideas or concepts, or new associations between existing ideas or concepts.

Creativity is one of the essential attributes we would like our graduates to have – all others are useless without creativity.

Innovation and Invention are impossible without creativity.

# Convergent vs. Divergent Thinking

**Divergent thinking:** the *creative* generation of multiple solutions to a given problem. In Science and Engineering, this is followed by evaluation of the answers and a choice of optimal solution.

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Scientists and Engineers typically prefer convergent thinking while artists and performers prefer divergent thinking.

Perhaps this is why many students in CS do not speak of the field as creative. Yet we must have DT to invent and innovate!

## Example of Divergent Thinking

A man who lived on the 10<sup>th</sup> floor of an apartment building took the elevator to the ground floor every summer morning in order to get to work. When coming home in the late afternoon, the man took the elevator to the 5<sup>th</sup> floor and walked up the stairs to his apartment on the 10<sup>th</sup> floor except on rainy days when the man took the elevator all the way to 10.

How do you explain this behavior?

## Example of Divergent Thinking

1. The man was a little person (p.c. form of midget) and could only reach as high as the 5<sup>th</sup> floor button. On rainy days, though, he could use his umbrella to hit the 10<sup>th</sup> floor button.

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2. The man enjoyed the exercise of walking up steps but could only manage 5 floors at a time. On rainy days he would create a muddy mess in the hallway so he took the elevator to 10 then.

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3. The stairs from the 5<sup>th</sup> to 10<sup>th</sup> floor are outside and unprotected. The man took the stairs when convenient to enjoy the late afternoon sun and view overlooking the Pearl river. On rainy days that was out of the question.

# Making Connections is Important!

1. Rain connects with umbrella  
umbrella connects with long stiff rod  
long stiff rod connects with enabling a higher reach  
this suggests solution 1.
2. Rain connects with mud  
mud connects with mess  
mess is to be avoided  
this suggests solution 2
3. Absence of rain connects with sun  
sun connects with pleasure outdoors  
this suggests solution 3

# Making Wrong Connections Can Be Fatal!

Three travelers go into a hotel and are charged \$30 for a room. They each contribute \$10.

That evening the hotel manager realizes that the men were overcharged: they should have received a group discount and paid \$25. So the manager sends a bellhop up to the room to return \$5. But, the three travelers cannot equally split the \$5, so they give the bellhop \$2 as a tip and keep \$3 which they split among themselves - \$1 each.

Observe each traveler has paid \$9, for a total of \$27 and the bellhop has \$2 so only \$29 is accounted for.

Where has the 30th dollar gone?

# Making Wrong Connections Can Be Fatal!

Three travelers paid \$30. But now the discounted rate is \$4 so they get back \$26. Since 26 is not divisible by 3, they decide to split \$24 among themselves (\$8 each) and let the bellhop have a \$2 top.

Now each traveler has paid \$2 ( $10-8$ ), for a total of \$6. The bellhop has \$2. That makes \$8 accounted for... far from the original \$30 they paid. In other words, now \$22 are missing!

What is going on?

# Making Wrong Connections Can Be Fatal!

What is going on?

The story misleads us into making a bad connection:

Let OP = Originally Paid

(e.g. 30 – then  $OP/3 = 10$ )

Let TRA = Total Returned Amount

(e.g. 5 – then  $IRA = TRA/3 = 1$  and  $tip = TRA \bmod 3 = 2$ )

Somehow we are lead to believe (integer division):

$$OP = OP - 3*(TRA/3) + TRA \bmod 3$$

$$30 = 30 - 3 + 2$$

In other words, that  $3*(TRA/3) = TRA \bmod 3!!$

# Making Wrong Connections Can Be Fatal!

TRA	$3*(TRA/3)$	TRA mod 3	“Missing”
0	0	0	0
1	0	1	-1
2	0	2	-2
3	3	0	3
4	3	1	2
5	3	2	1
6	6	0	6
7	6	1	5
...			
26	24	2	22
...			
30	30	0	30

# **The Mind Can Refuse to Make Connections**

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Q. Noah is hosting an animal conference. All animals but one attend. Which one?

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A. The lion who is freezing his butt off in the refrigerator

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How do you do it?

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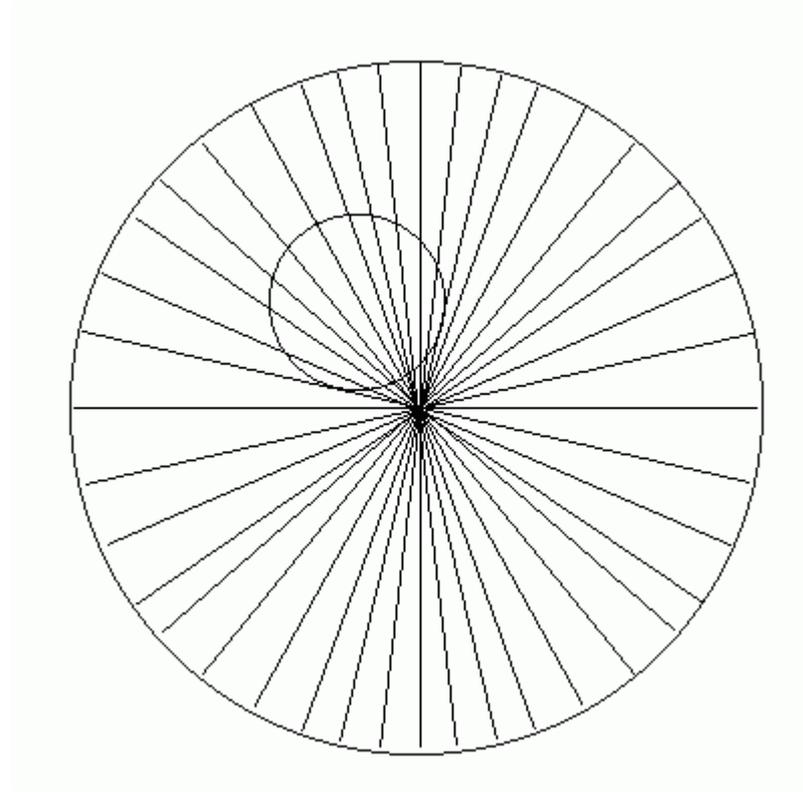
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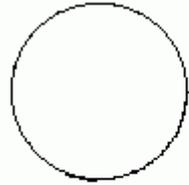
Q. You want to cross a river that is inhabited by crocodiles. How do you do it?

A. Swim across – the crocs are at the conference.

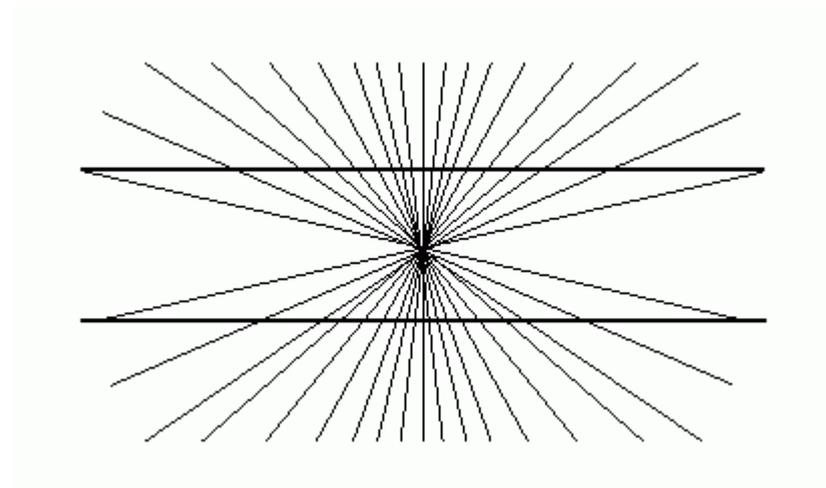
# Things Often Are Not What They Seem To Be



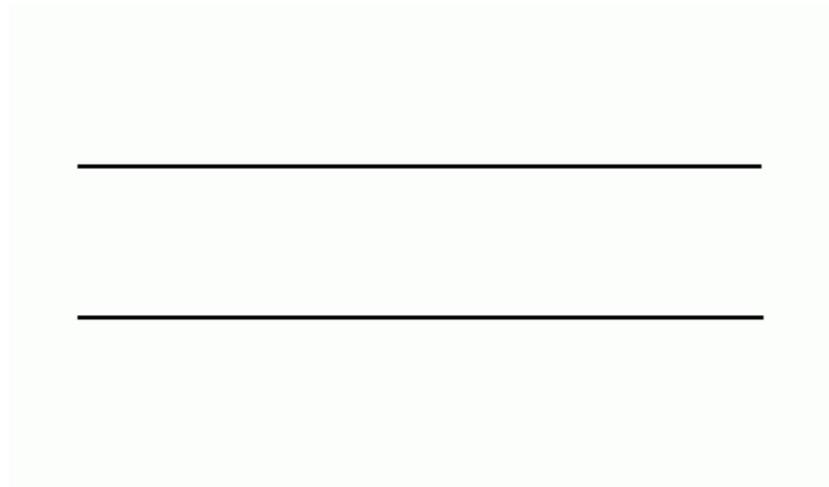
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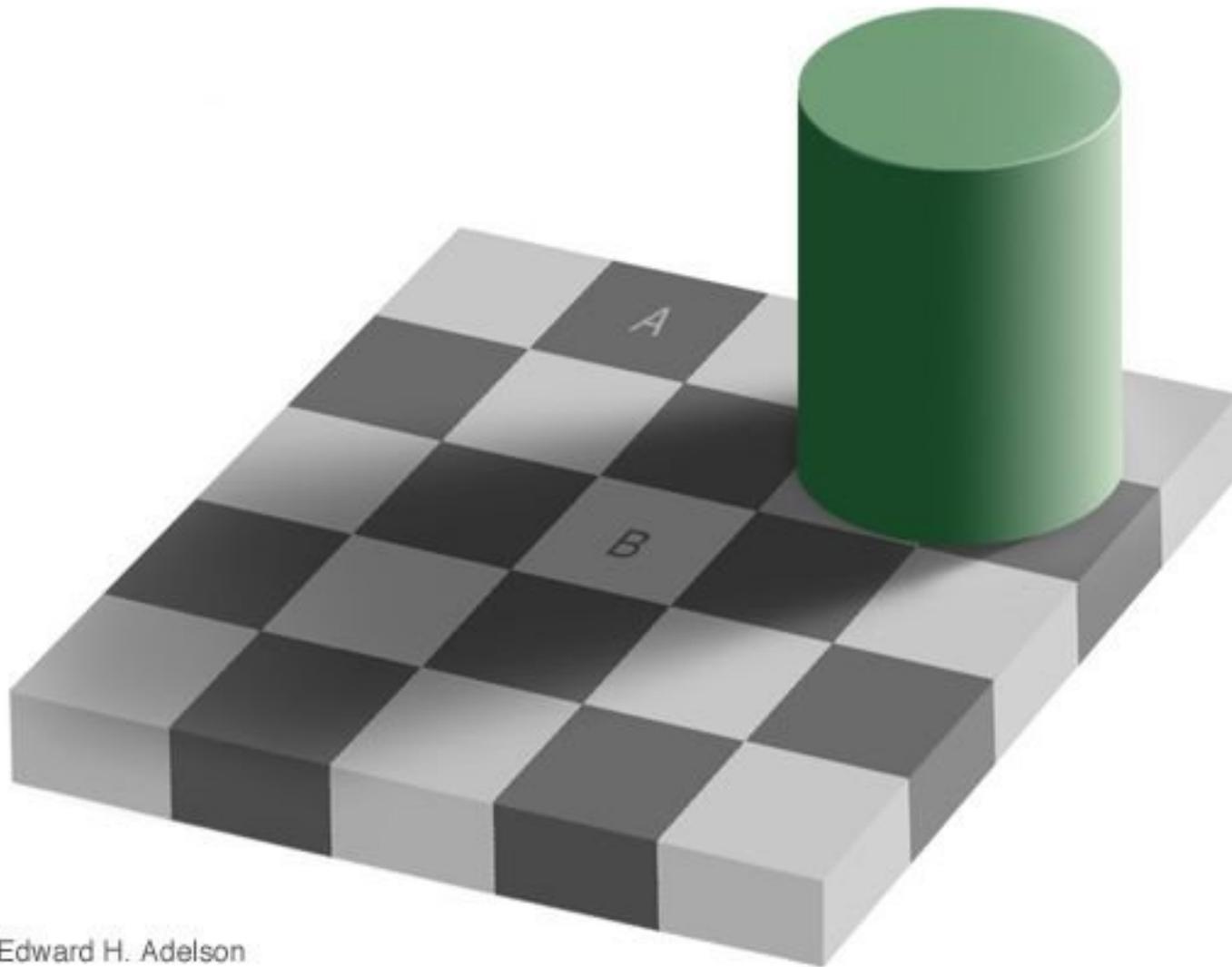
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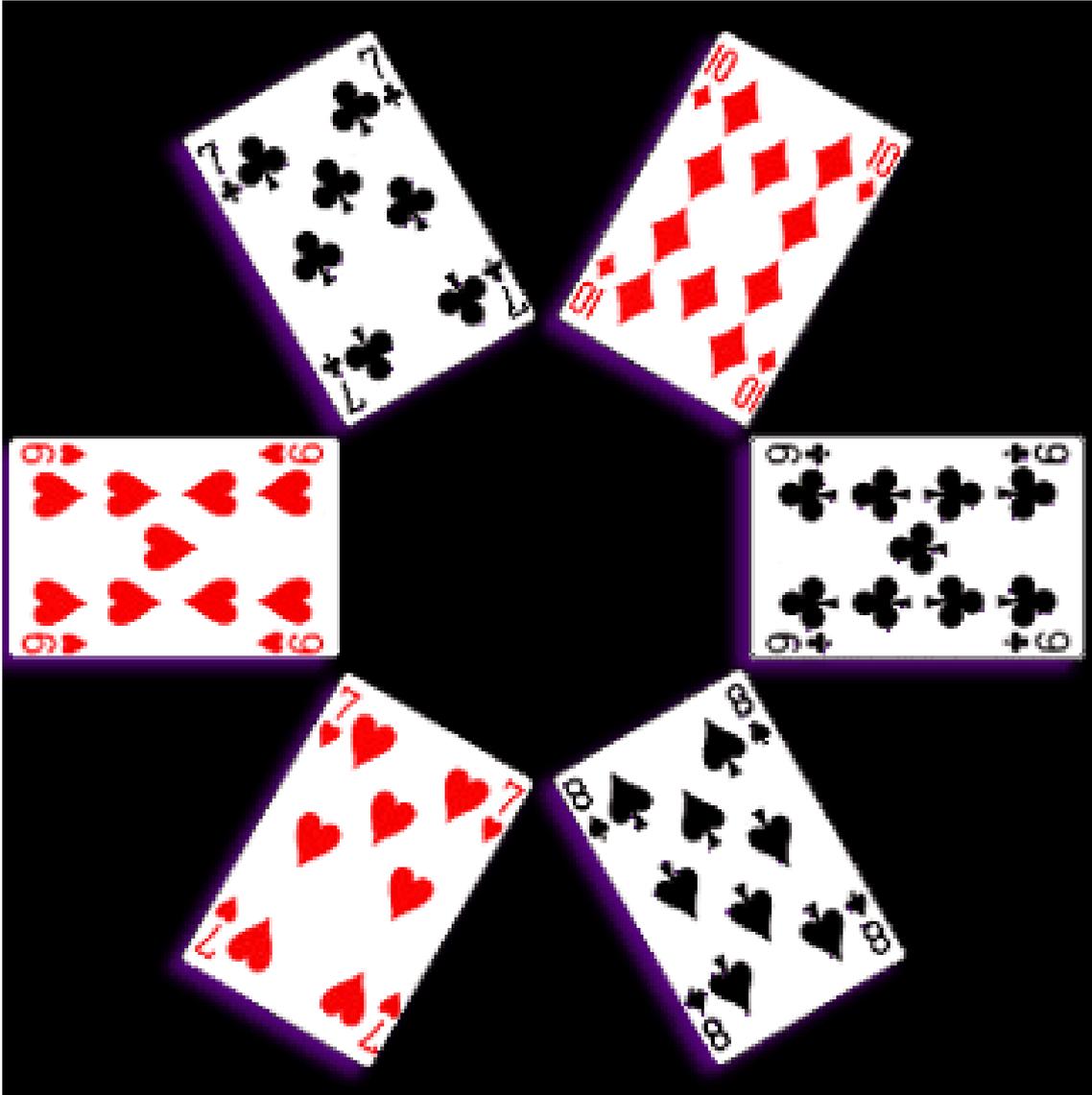


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Edward H. Adelson

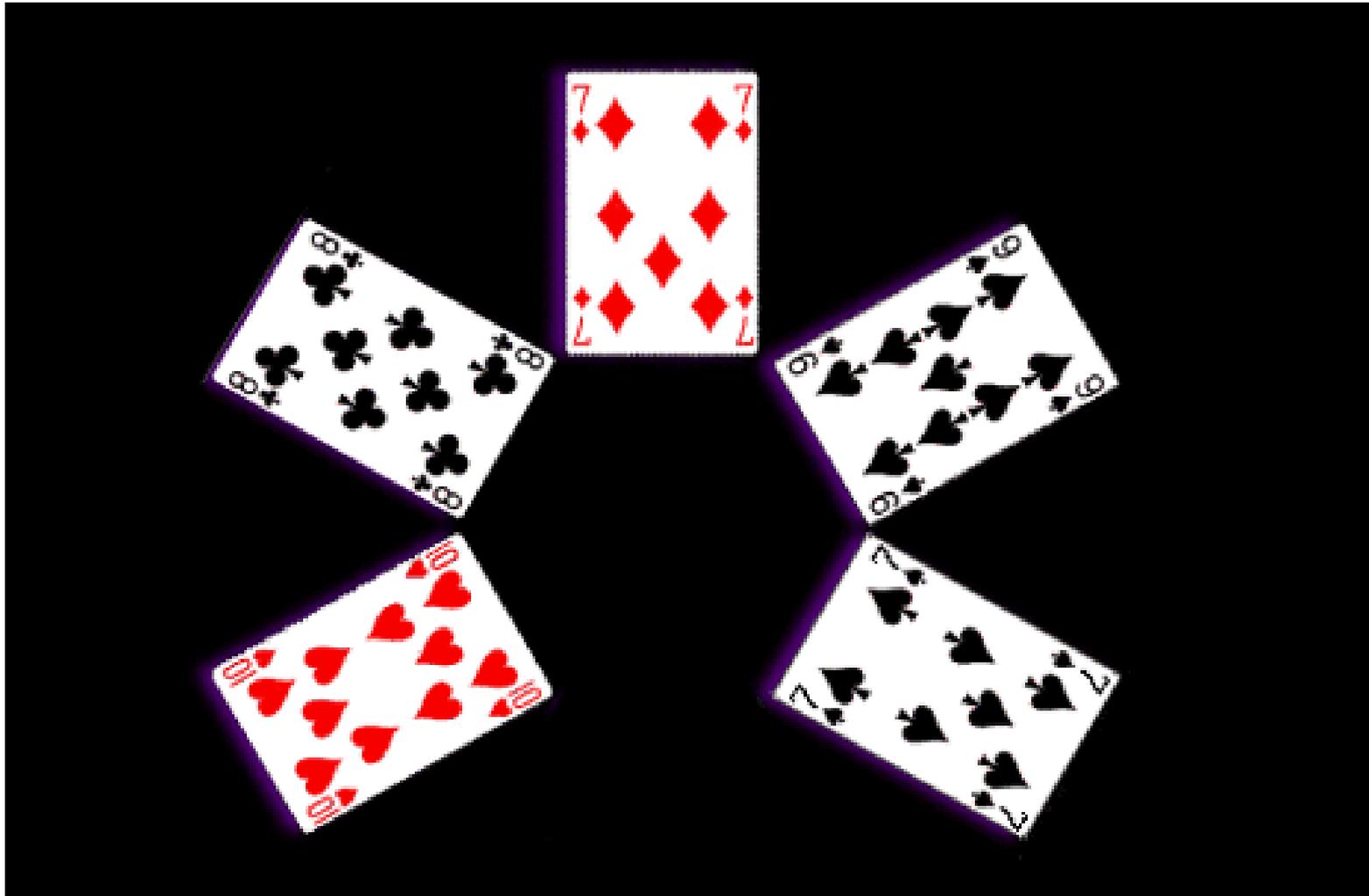
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# Making Connections That Do Not Exist



# Using The Right Language For The Problem

## Languages:

### Verbalization

- descriptions in words

### Visualization

- graphs
- charts
- pictures

### Logic

- propositional
- common sense
- non-monotonic ...

### Mathematics

- algebra
- calculus ...

### Sensory Expression

- laugh, thunder, flowers

## Using The Right Language For The Problem

One morning, exactly at sunrise, a Buddhist monk began to climb a tall mountain from a temple gift shop. The narrow path, no more than a foot or two wide, spiraled around the mountain to a glittering temple at the summit. The monk ascended the path at varying rates of speed, stopping many times along the way to rest and to eat the dried fruit he carried with him. He reached the temple shortly before sunset. After several days of fasting and meditation, he began his journey back down the same path, starting at sunrise and again walking at variable speeds with many pauses along the way. His average speed descending was greater than his average climbing speed so he arrived at the gift shop before sunset.

## Using The Right Language For The Problem

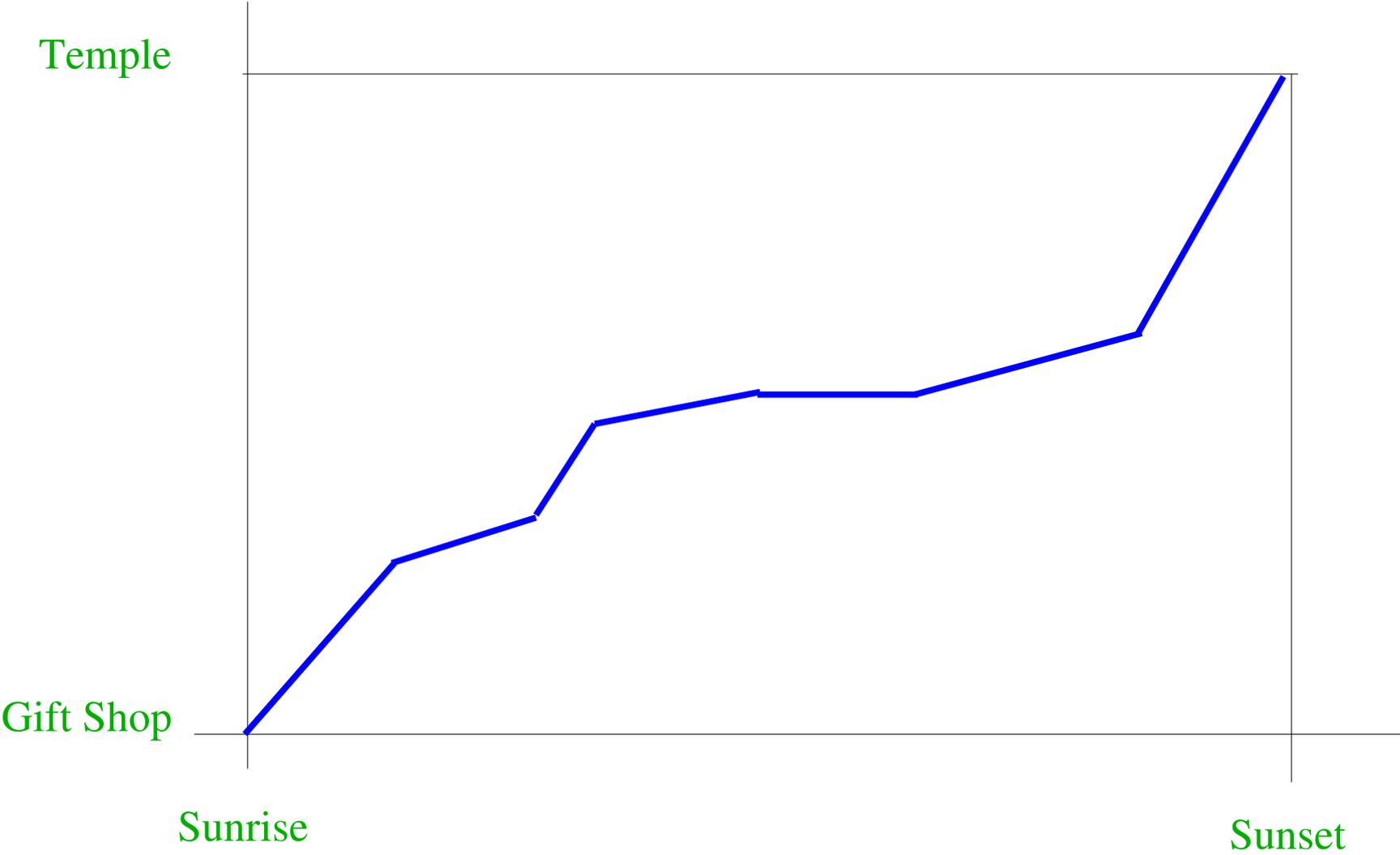
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Prove that there is a spot along the path the monk will occupy on both trips at precisely the same time of the day.

Logic Mathematics Words Visualization Sensory

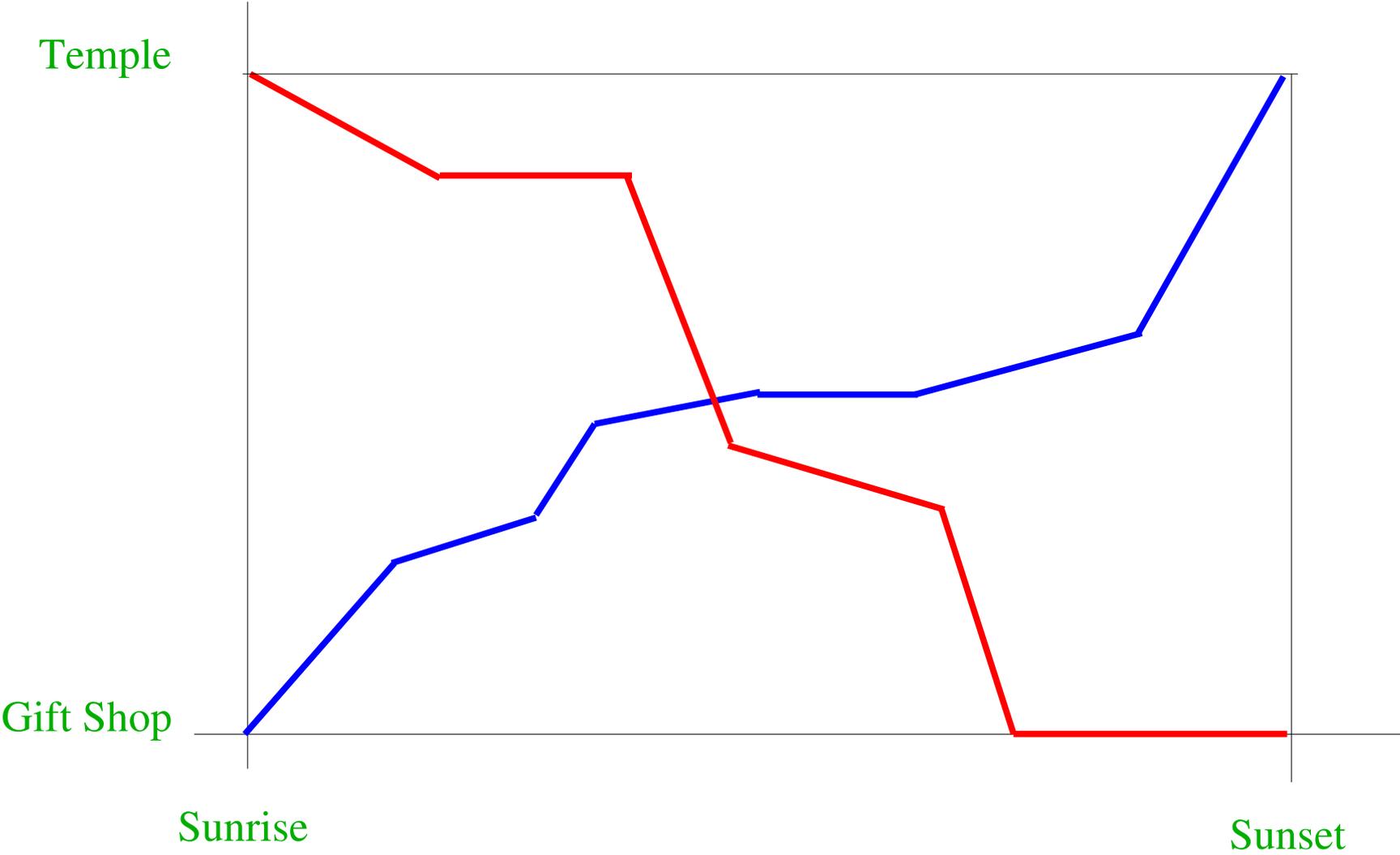
# Using The Right Language For The Problem

Best solved visually:



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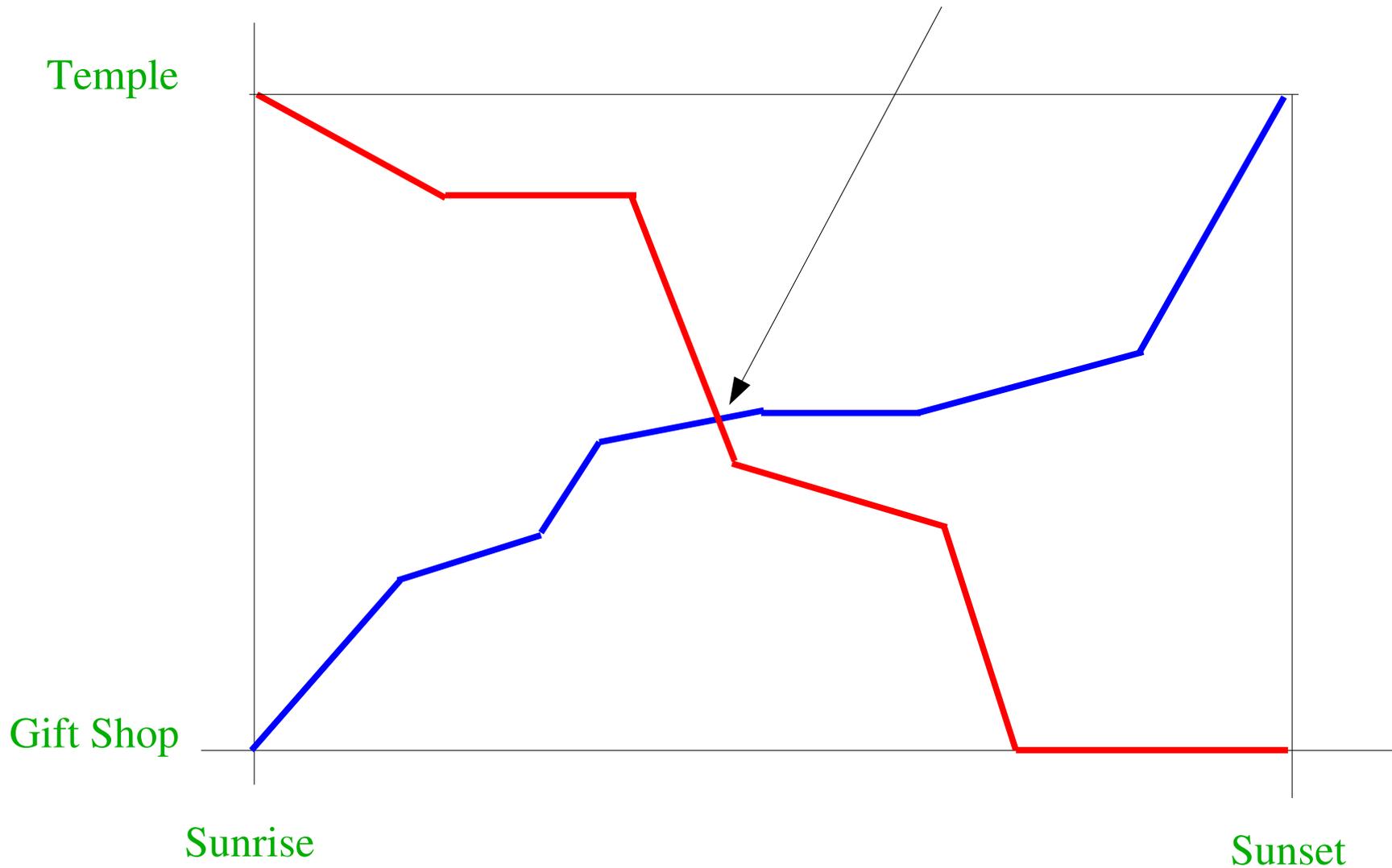
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# Using The Right Language For The Problem

**Best solved visually:**

Where the lines cross, Monk is at same place at same time



## Using The Right Language For The Problem

There are a number of fueling stations located at various points around a race circuit. Suppose the amount of fuel at each fueling station is different but that the total fuel around the circuit is exactly what is needed by a race car to make one complete circuit.

## Using The Right Language For The Problem

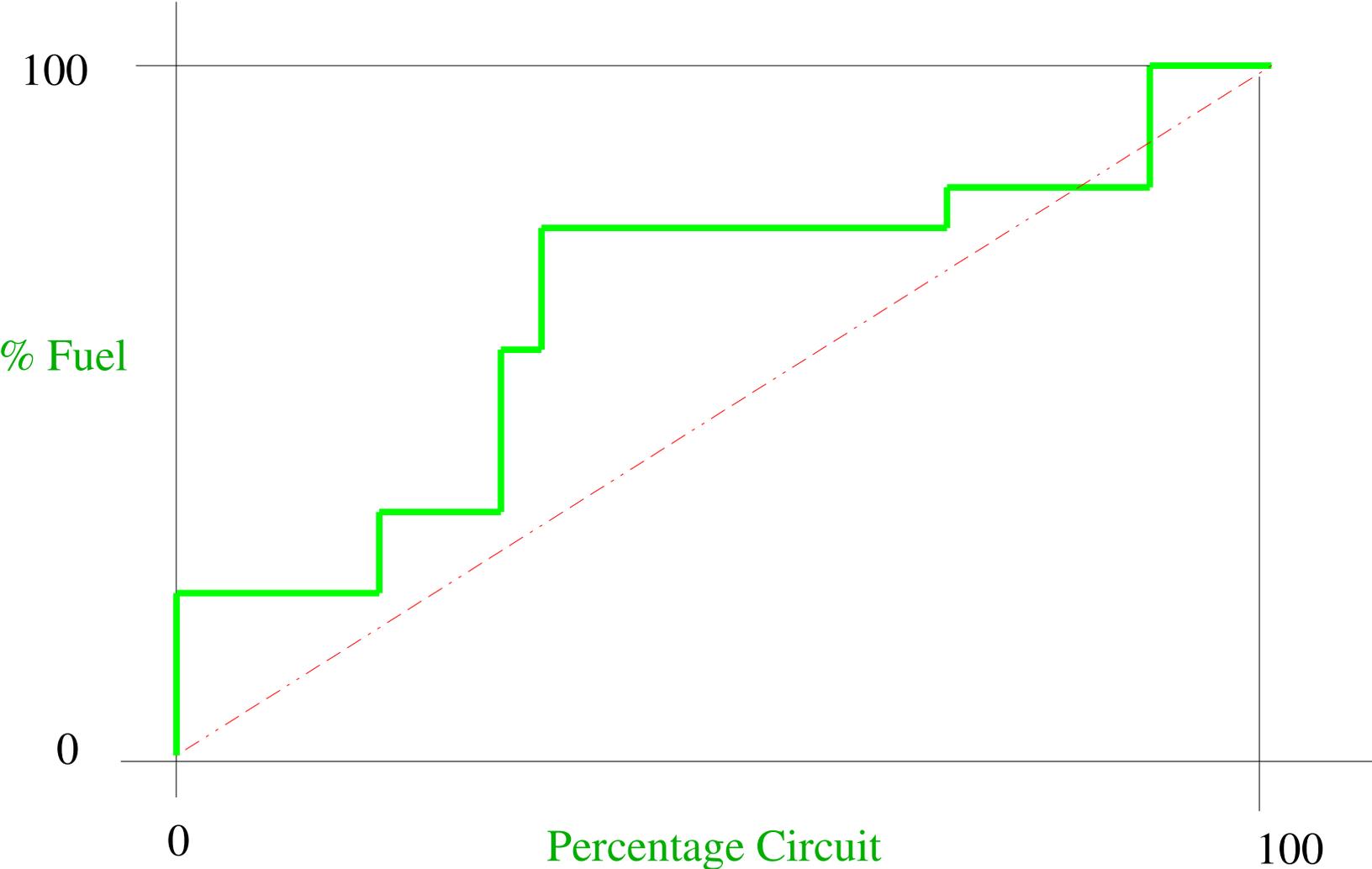
There are a number of fueling stations located at various points around a race circuit. Suppose the amount of fuel at each fueling station is different but that the total fuel around the circuit is exactly what is needed by a race car to make one complete circuit.

Prove that there is a point on the circuit from which a race car with an empty tank may make one complete circuit without running out of fuel by tanking up at every fueling station in the circuit. Assume the tank is large enough to hold enough fuel to complete the circuit.

Logic Mathematics Words Visualization Sensory

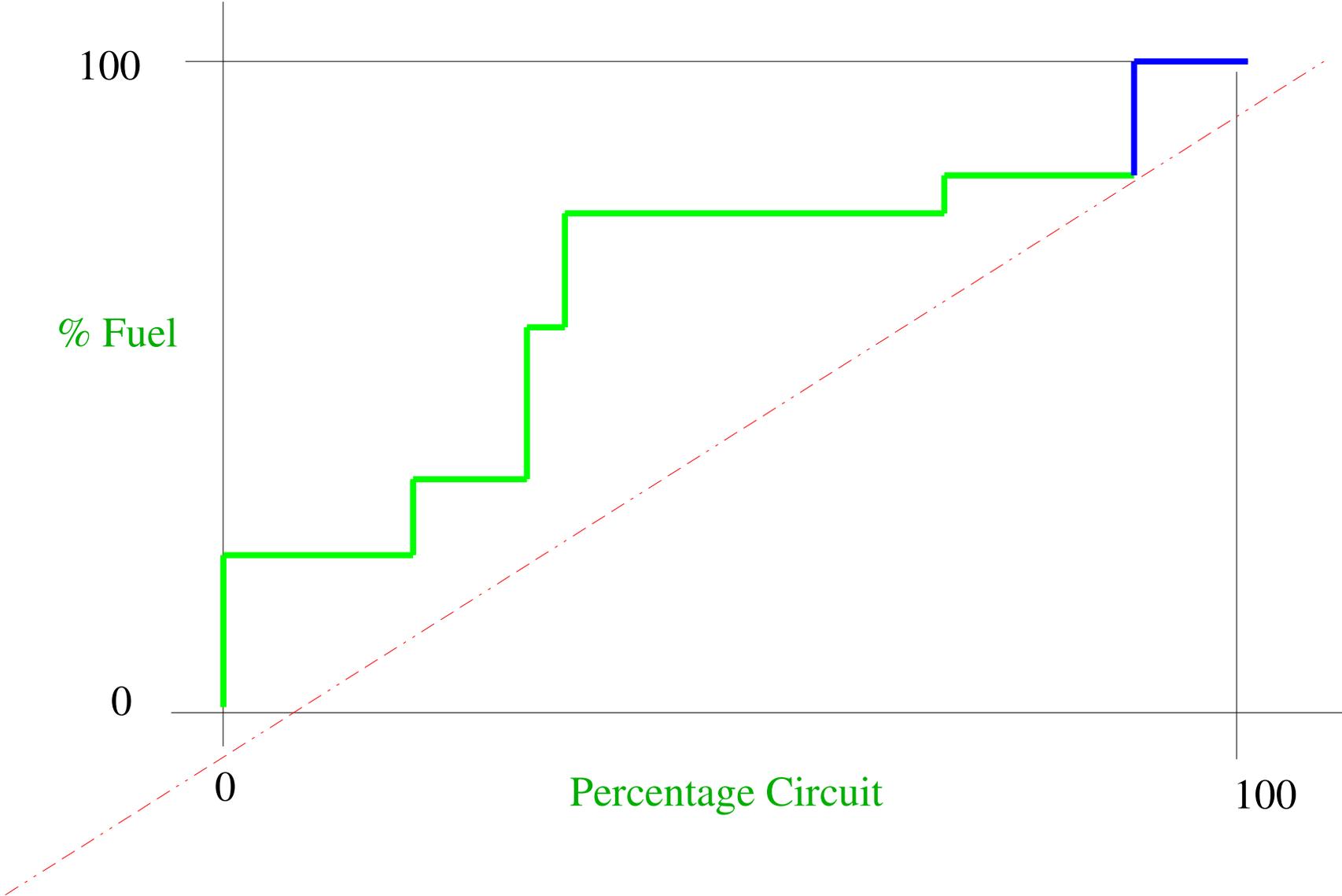
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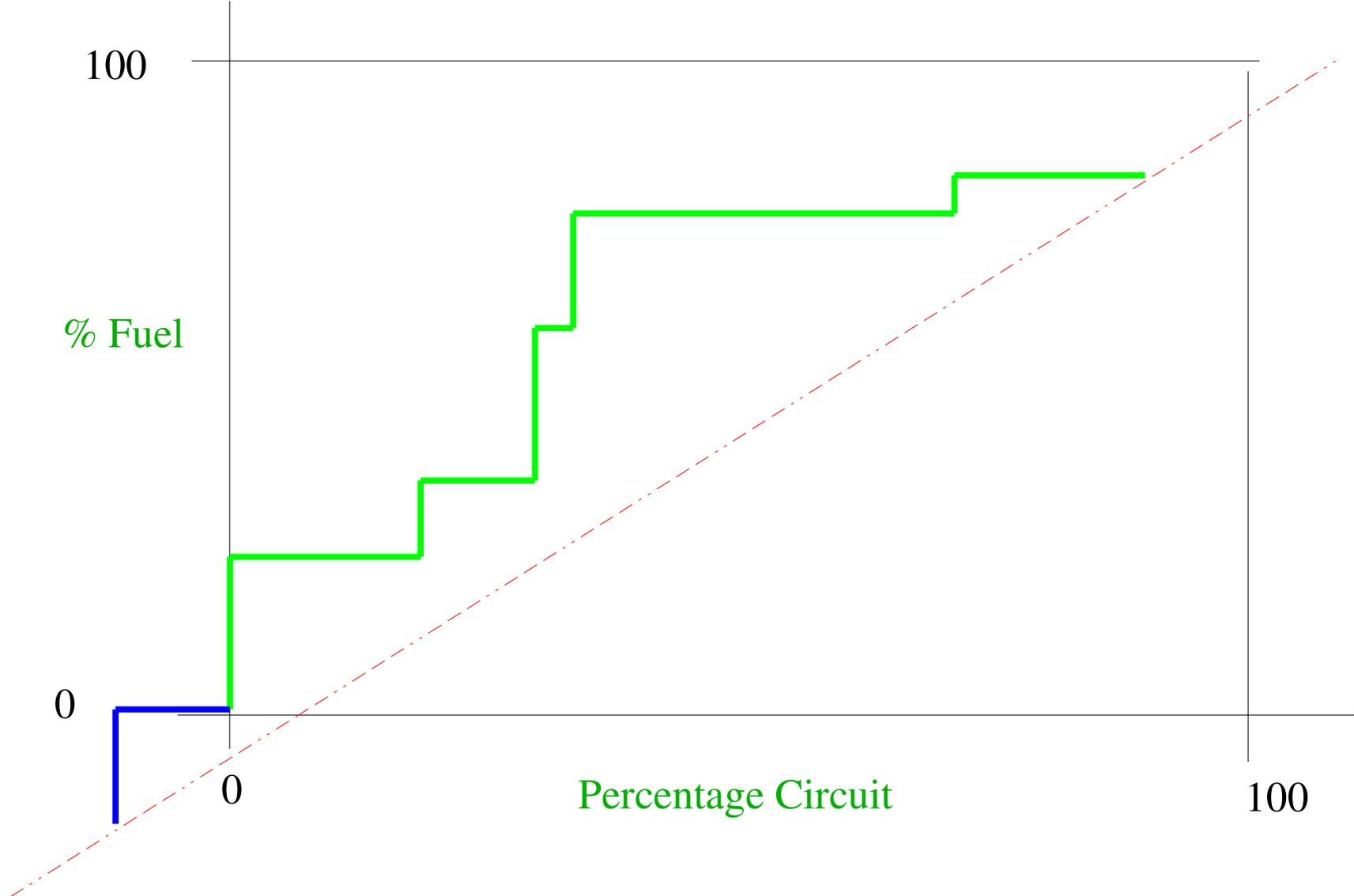
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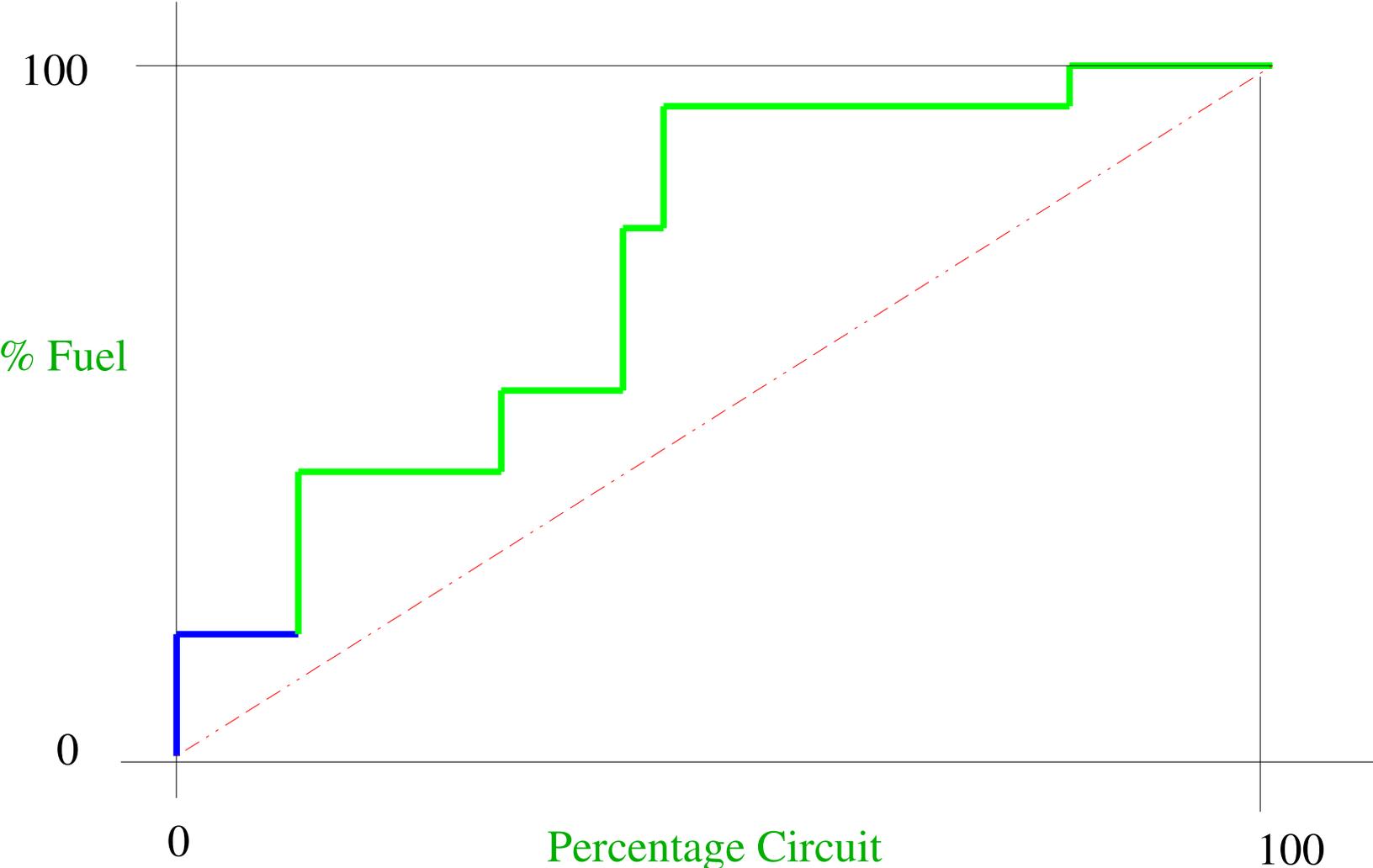
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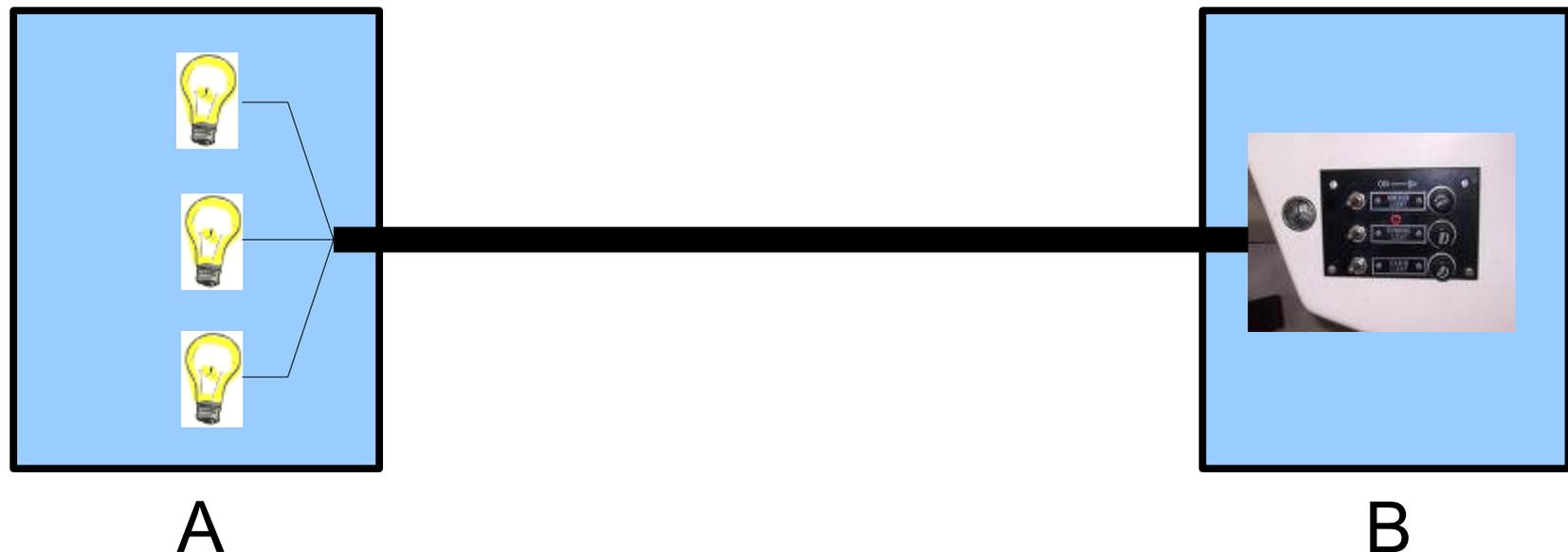
# Using The Right Language For The Problem

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# Using The Right Language For The Problem

Three light bulbs in room A are connected independently to three switches in room B. The lights are not visible from room B. The problem is to determine which switch is which being allowed just one visit to room A from B.



Logic Mathematics Words Visualization Sensory

# Using The Right Language For The Problem

## Best solved with sensory thinking:

Number switches 1,2,3. Turn 1 on for five minutes. Turn it off and turn on and leave on number 2.

Visit room A.

The bulb that is off and warm is connected to 1.

The bulb that is on is connected to 2.

The remaining bulb is connected to 3.

## Using The Right Language For The Problem

Burlington is part French and part English. If 70% of the population speaks English and 60% of the population speaks French. What percentage of the population speaks both languages?

Logic Mathematics Words Visualization Sensory

## Using The Right Language For The Problem

**Best solved with mathematics:**

$$\Pr(A \cap B) = \Pr(A) + \Pr(B) - P(A \cup B)$$

Let  $A$  = event that a random person speaks English

Let  $B$  = event that a random person speaks French

$$\Pr(A) = .7$$

$$\Pr(B) = .6$$

$$\Pr(A \cup B) = 1$$

$$\text{Hence } \Pr(A \cap B) = 1.3 - 1 = .3$$

# Using The Right Language For The Problem

Can a stack of pennies as high as the Empire State Building fit into a 10' by 15' room?

# Using The Right Language For The Problem

**Best solved with common sense logic:**

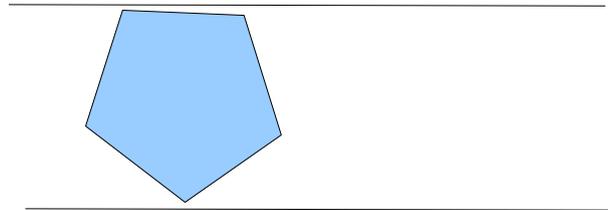
Empire state building is less than 150 floors.

The 10' by 15' room is 1 floor tall.

Hence the stack of pennies can be divided into 150 single floor stacks and all these easily fit into the room – e.g. 10 rows of 15 one floor stacks which would easily fit on a desk!

# Using The Right Language For The Problem

From a really long distance, what is the probability that a viewer sees 2 sides of the Pentagon if a viewing direction is chosen randomly?

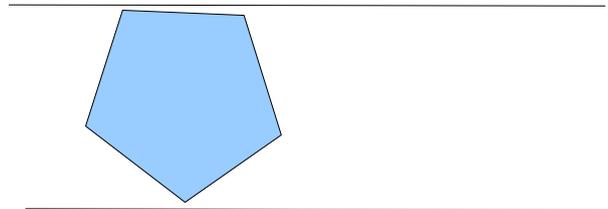
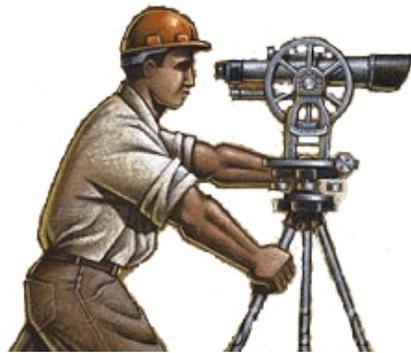


Logic Mathematics Words Visualization Sensory

# Using The Right Language For The Problem

**Best solved with common sense logic:**

Put a man at exactly the opposite side of the building on a line through the center. How many sides does he see?

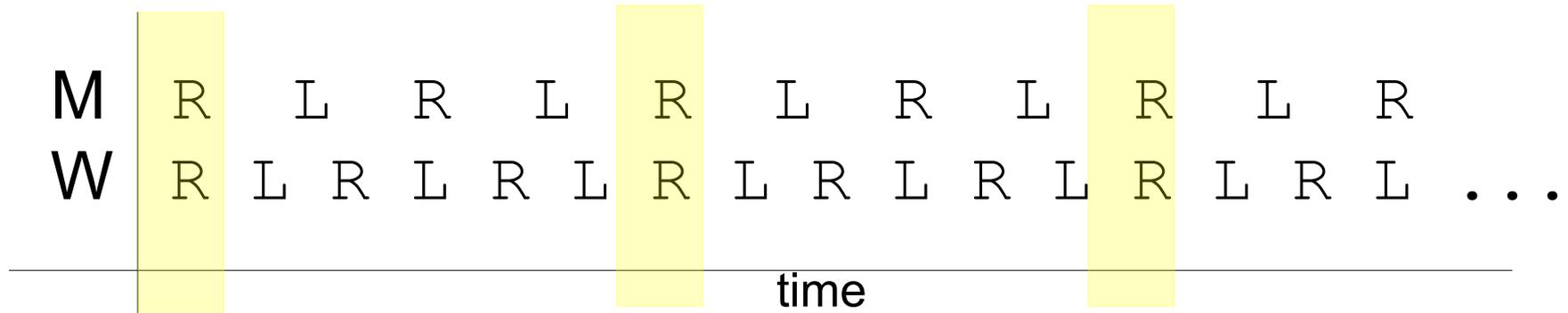


## Using The Right Language For The Problem

A man and a woman standing side by side begin walking so that their right feet hit the ground at the same time. The woman takes three steps for every two steps the man takes. How many steps does the man take before their left feet hit the ground at the same time?

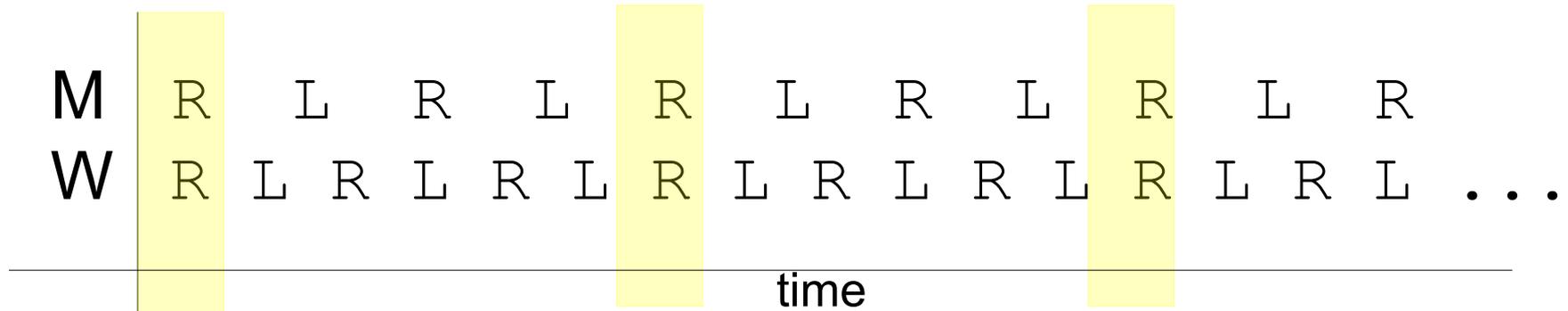
# Using The Right Language For The Problem

**Best solved visually:**



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**Solved mathematically:**

Let  $t = 0, 1, 2, 3, \dots$  be clock ticks – 2 per woman's step, 3 per man's

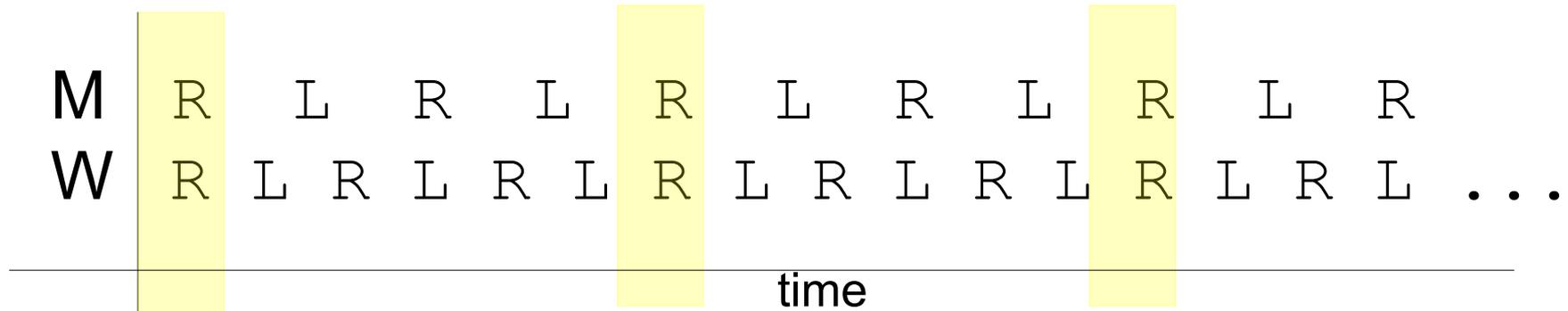
Woman's left foot hits the ground when  $(t-2) \bmod 4 = 0$

Man's left foot hit the ground when  $(t-3) \bmod 6 = 0$

Find  $t$  such that  $(t-2) \bmod 4 = (t-3) \bmod 6$ . No such  $t$ .

# Using The Right Language For The Problem

**Best solved visually:**



**Solved mathematically:**

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Man's left foot hit the ground when  $(t-3) \bmod 6 = 0$

Find  $t$  such that  $(t-2) \bmod 4 = (t-3) \bmod 6$ . No such  $t$ .

Man's right foot hits the ground when  $t \bmod 6 = 0$

Find  $t$  such that  $t \bmod 6 = (t-2) \bmod 4 \dots t=6$

# Blocks to Creativity

## Perceptual :

Detecting what you expect

Difficulty in isolating the problem

Inability to see the problem from different perspectives

## Emotional:

Fear of taking a risk

Need for order – but data may be missing or imprecise

Judging, not generating ideas

## Cultural:

Taboos

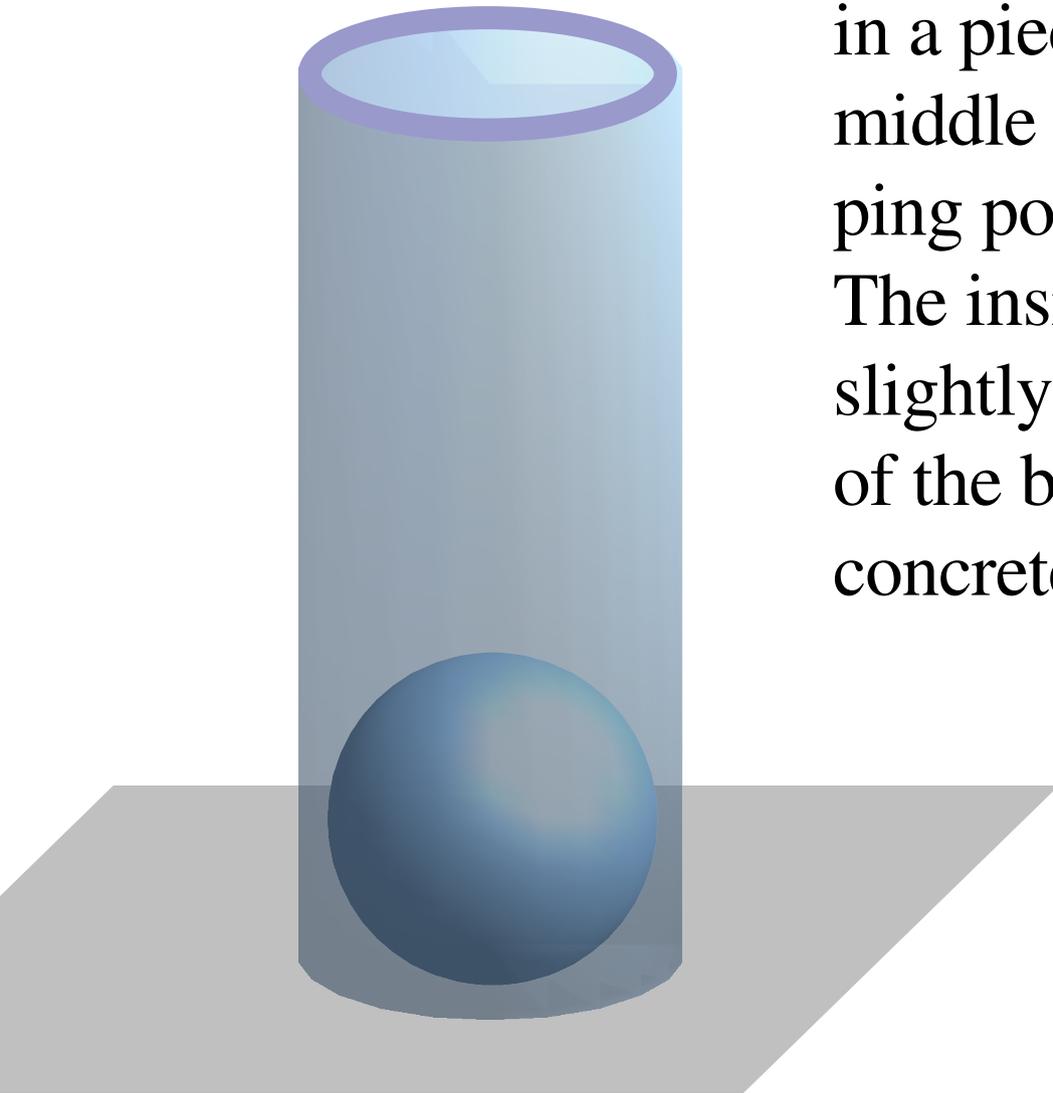
Math/analysis is better than intuition

## Expressive:

Choosing the wrong language to express/solve problem

## Example: Cultural Block

A translucent pipe is buried vertically in a piece of immovable concrete in the middle of nowhere. Inside the pipe is a ping pong ball resting on the concrete. The inside diameter of the pipe is just slightly larger than the outside diameter of the ball. The height of the pipe above concrete is about 5".



How can you get the ball out of the pipe?

# Creativity Techniques

## **Problem Definition:**

Cannot do anything without completely understanding the problem.

## **Devise a Plan:**

Look for patterns in previously solved problems that match the current problem. Evaluate alternatives.

## **Carry Out the Plan:**

Check each step. Look for proof of correctness.

## **Evaluate, Reassess:**

Does the proposed solution solve the problem most effectively? What is lacking?

# Creativity Techniques

## **Problem Definition:**

Know what is fact and what is conjecture:

# Creativity Techniques

## Problem Definition:

Know what is fact and what is conjecture:

A man stands in the center of a large square field with horses at each corner, namely a bay, a chestnut, a white horse and a black horse. The man must kill his horses. If he must remain at the center of the field, the horses stay at the four corners and he is a perfect shot, how can he make sure that none of his horses remain alive using only three bullets? Assume no more than one bullet is enough to kill a horse.

# Creativity Techniques

## Problem Definition:

What is unknown (conjecture vs. fact)?

Who owns the horses, which horses are alive – (need to kill)

# Creativity Techniques

## Problem Definition:

What is unknown (conjecture vs. fact)?

Who owns the horses, which horses are alive – (need to kill)

What are the data?

None in this case.

Conditions under which the problem is to be solved?

Only killing instrument available is a gun. Targets at corners of square, shooter at center. Shooter shoots owned targets only.

Is it possible to satisfy the conditions?

Easily

Are the conditions sufficient to determine the unknowns?

Possibly.

Draw a figure.

# Creativity Techniques

## Devise a Plan:

What potential uses can be made of the facts?

What assumptions can be used?

Bullets travel in straight lines.

Is this doable? How many solutions are there?

Shooter owns only three of the four horses.

One horse is already dead and only three need be shot.

Check feasibility, evaluate:

Perhaps shooter shares the field with another horse owner.

Perhaps there is a disease, hence the shooter is killing horses

# Creativity Techniques

## Devise a Plan:

Restate the problem:

Try to restate the problem adding in more precise information to see if one of the proposed solutions best satisfies the conditions of the problem.

Restatement of the problem from a number of different perspectives or directions is important because it will jog your mind into potential solutions that may otherwise elude you.

# Creativity Techniques

## **Devise a Plan:**

Aim to solve possible extensions to the current problem:

As you solve problems and answer questions, record the solution to the present problem perhaps in an ongoing collection of FAQs. Ponder and make note of strategies that were especially effective and are likely to be useful in solving problems that may be similar or analogous.

# Creativity Techniques

## Reassess:

If stuck, go back to square 1, study all information again:

Was everything used?

Was everything taken into account?

Are all concepts involved understood?

Are all concepts visualized?