What is Research?

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Outline

- What is research?
- The process of research
- Richard Hamming on research ("*You and Your Research*")
- Conclusions

Disclaimers

- General concepts presented in the CS/IT context
- No "cook book" or "how to do it yourself"

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  - Personal reflections and confessions ☺

Part 2

Why Research?

Alice's Adventures

Through the Looking Glass

Author: Lewis Carroll

Alice's Adventures

Through the Looking Glass
Author: Lewis Carroll

Situation:
Alice Running with the Red Queen

Alice's Adventures

Through the Looking Glass
Author: Lewis Carroll

Situation:
Alice Running with the Red Queen

'Well, in our country,' said Alice, still panting a little, 'you'd generally get to somewhere else – if you ran very fast for a long time, as we've been doing.'

'A slow sort of country!' said the Queen. 'Now, here, you see, it takes all the running you can do, to keep in the same place. *If you want to get somewhere else, you must run at least twice as fast as that!'*

Surviving in a World of Rapidly Developing Technologies

Need to run twice as fast to even remain in the same place . . .

- Hard (Technical) Skills
- Soft Skills

  (Leadership, Motivation, Emotional Maturity, Communication etc.)

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  Quick self-learning is enhanced significantly by doing research

Why Do People Do Research?

- Is this the main reason why people do research?

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- We'll hopefully have a better answer by the end of this talk 

Part 3

In Search of Research

What is Research?

- Carving Statues out of stones

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- Methods and tools

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- Attempt to improve the methods and tools leads to
  - Better statues
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- Methods and tools
- Attempt to improve the methods and tools leads to
  - Better statues
  - Better methods and tools
  - **Better sculptors**

In Search of Research?

- Observed Phenomena with no explanations
  - Puzzles and mysteries
- Lacunae in the known theory and/or practice
  - The need of a better understanding/method
  - Innovative ideas
- Innovative ideas waiting for new applications
  - Discovery of new puzzles, mysteries and/or lacunae

The Essence of Research

- Is building a device, research?

The Essence of Research

- Is building a new device, research?

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Research could involve any of the above, or none of the above

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- Research is a game of innovative ideas that are significant

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- The significance of ideas could lie in any of the following:
  - Beauty
  - Utility
  - Enhancement of knowledge

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Ingredients of Good Research

- Innovation

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- Aesthetics

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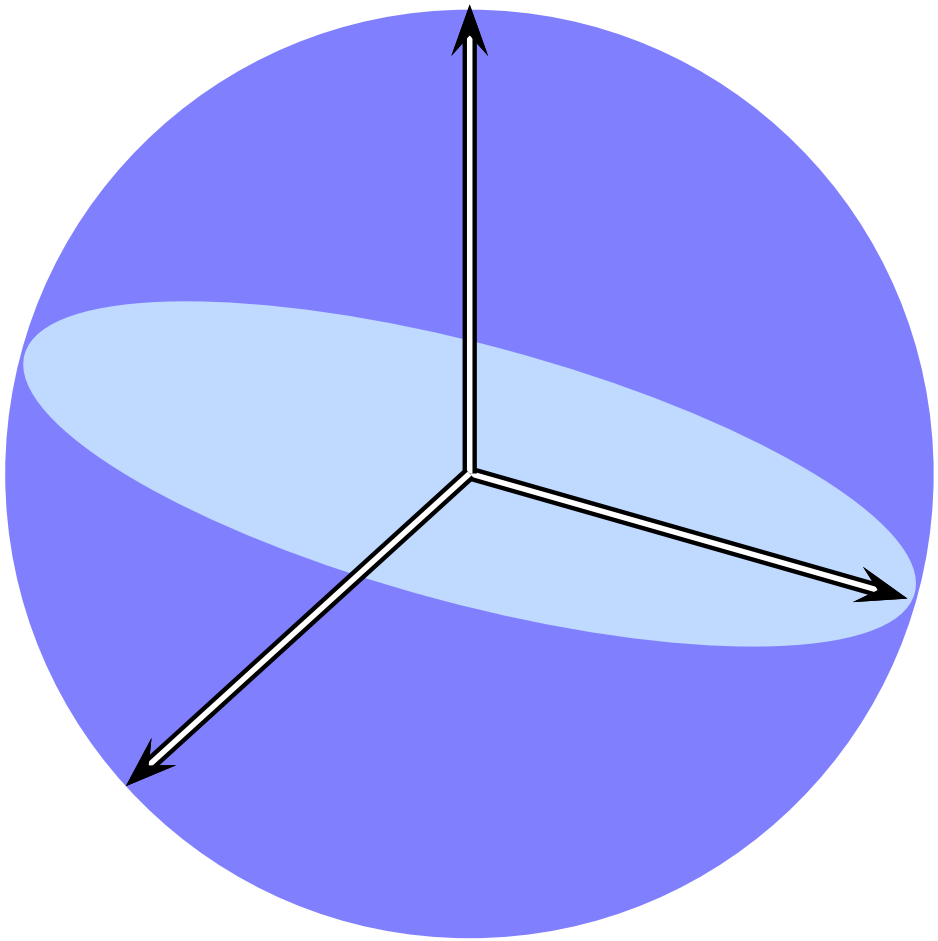
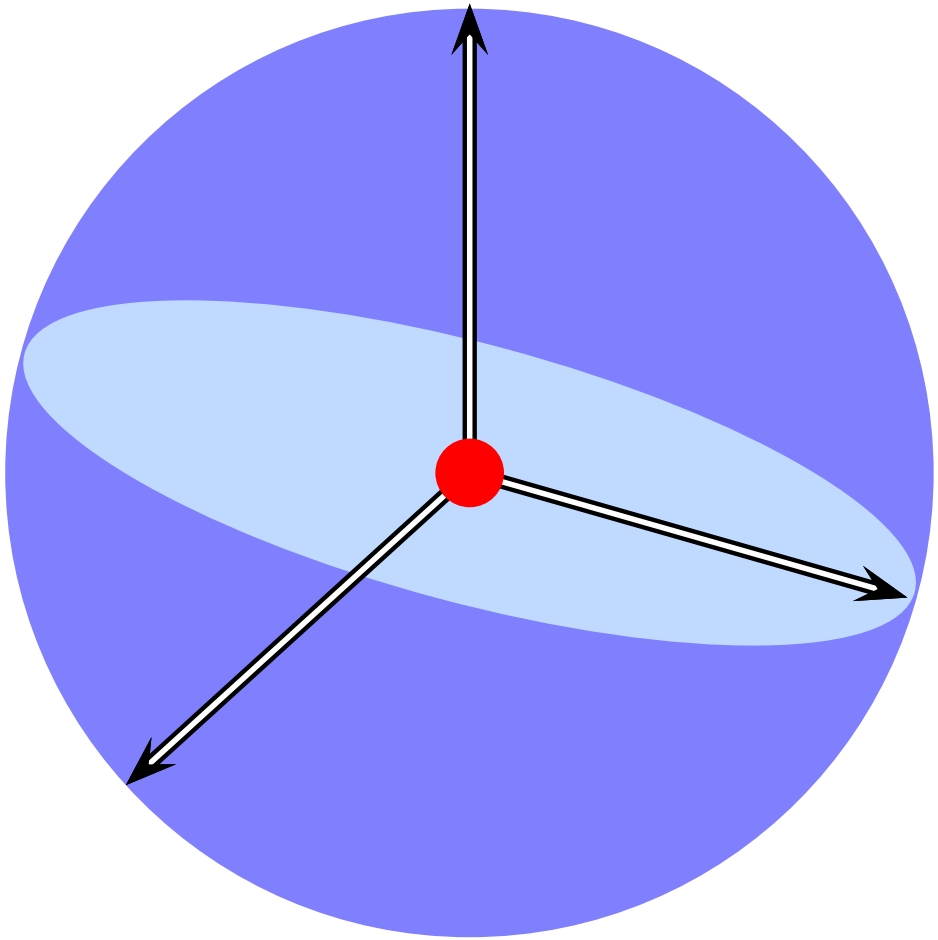
- Innovation
- Aesthetics
- Other important aspects :
  - Completeness
  - Rigour
  - Empirical demonstration
  - Effective communication

Innovation



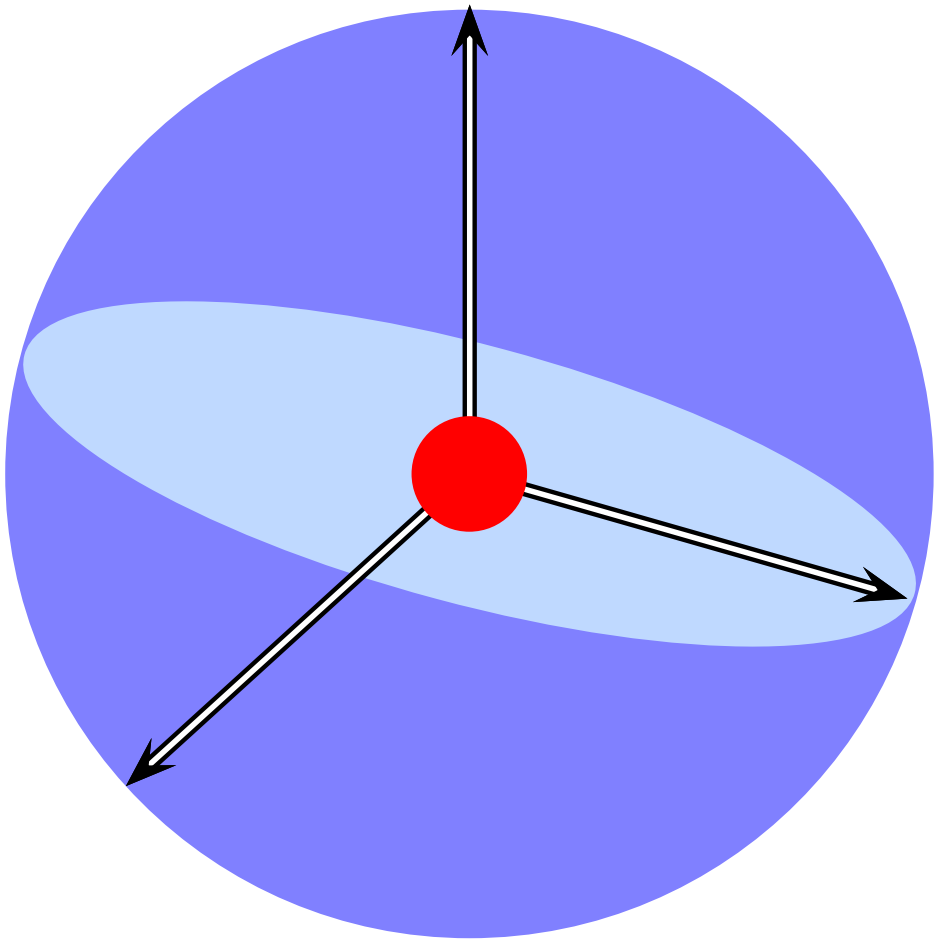
- The sphere of knowledge

Innovation



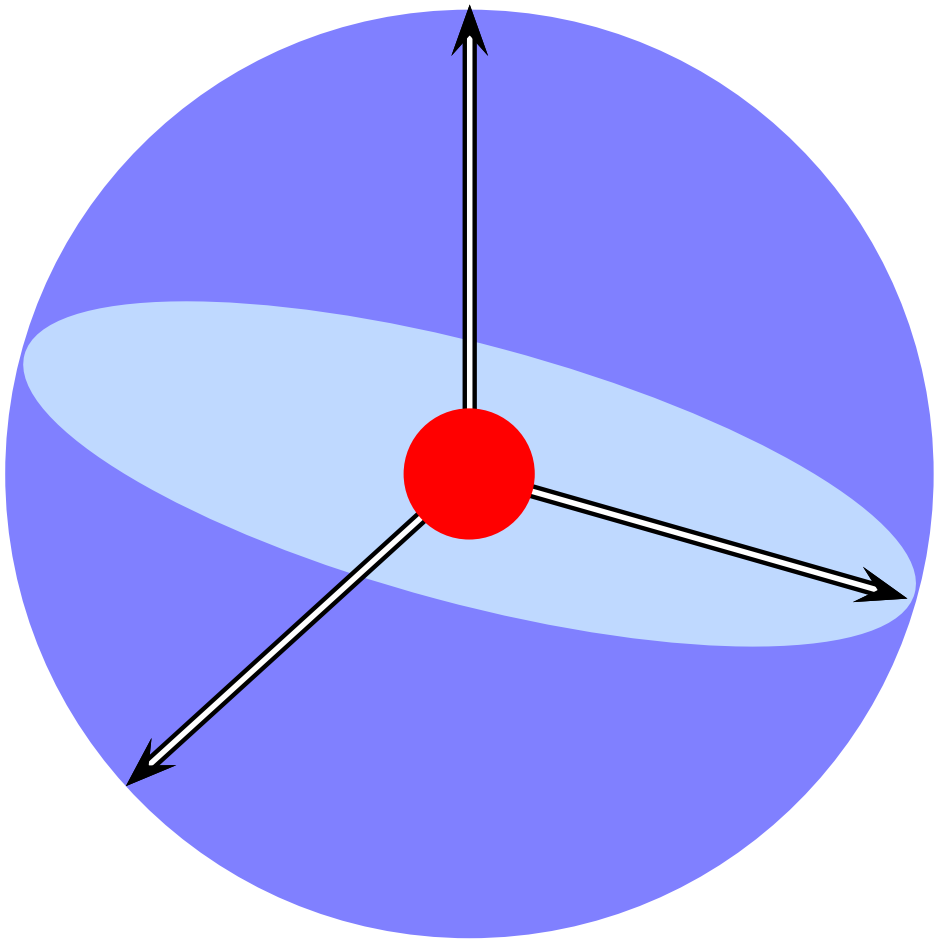
- The sphere of knowledge
- Initial general learning

Innovation



- The sphere of knowledge
- Initial general learning
- Learning increases with time

Innovation



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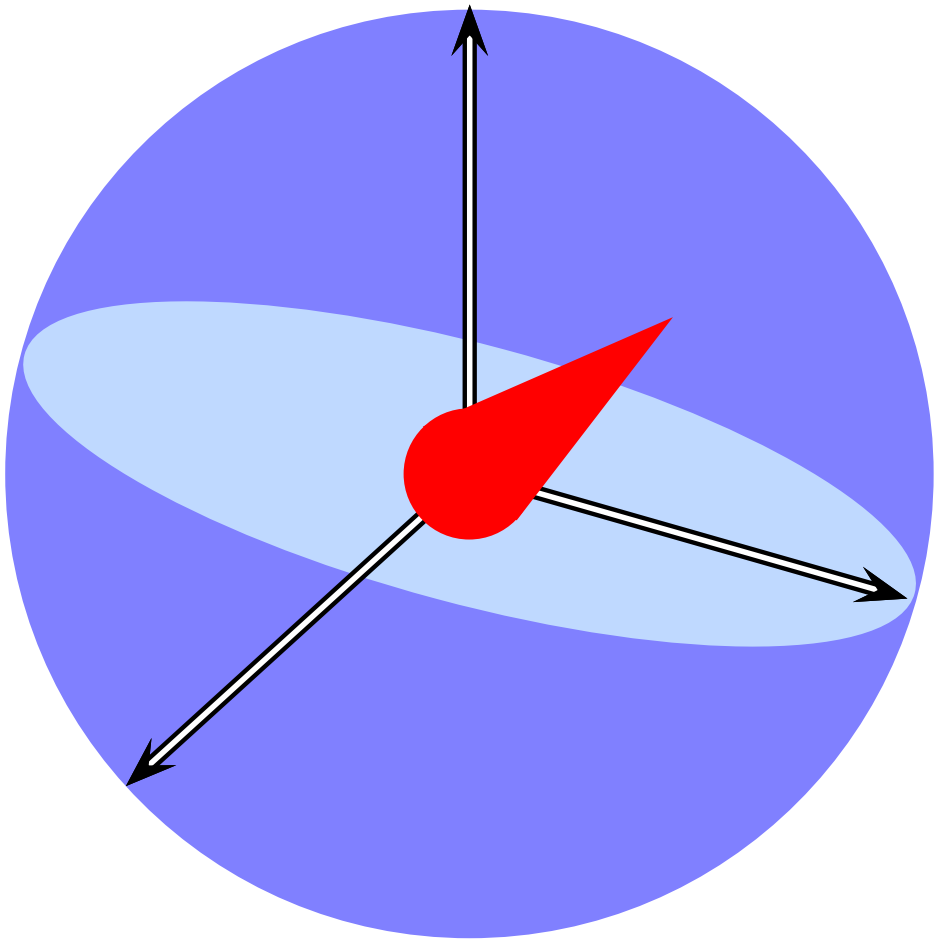
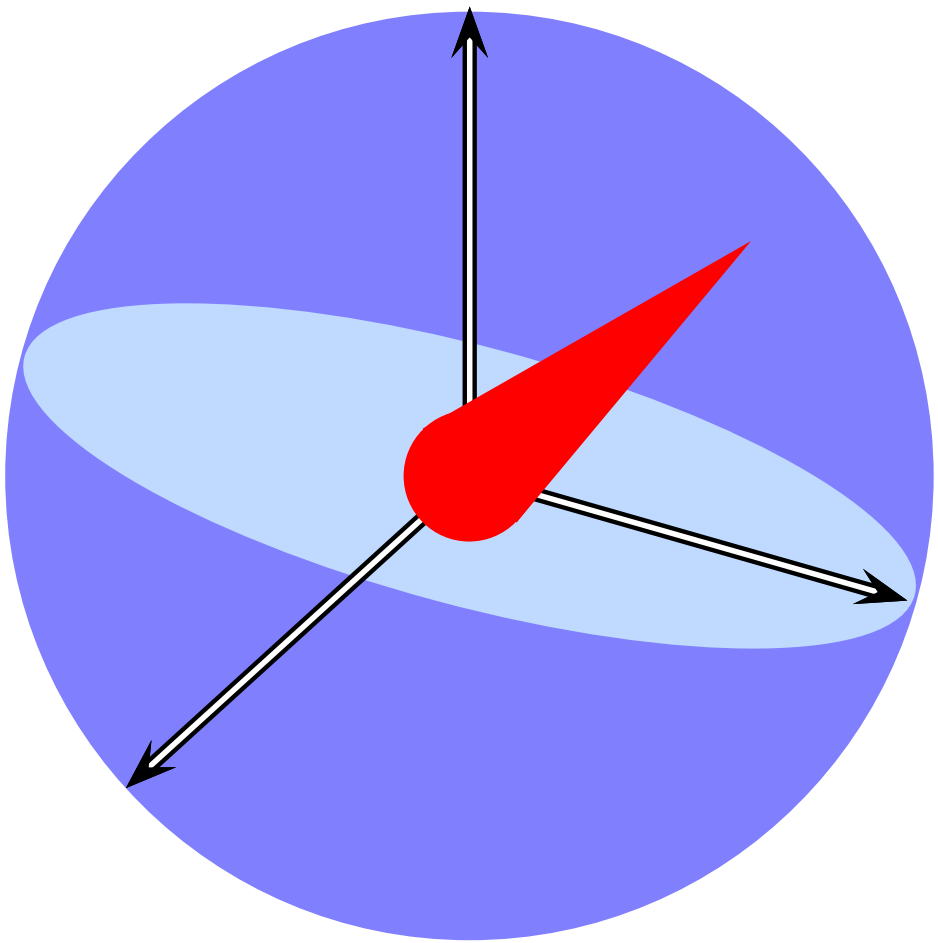


- The sphere of knowledge
- Initial general learning
- Learning increases with time
- Begin focussing and specializing

Innovation



- The sphere of knowledge
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- Learning increases with time
- Begin focussing and specializing
- Specialize more and more until you reach the unknown

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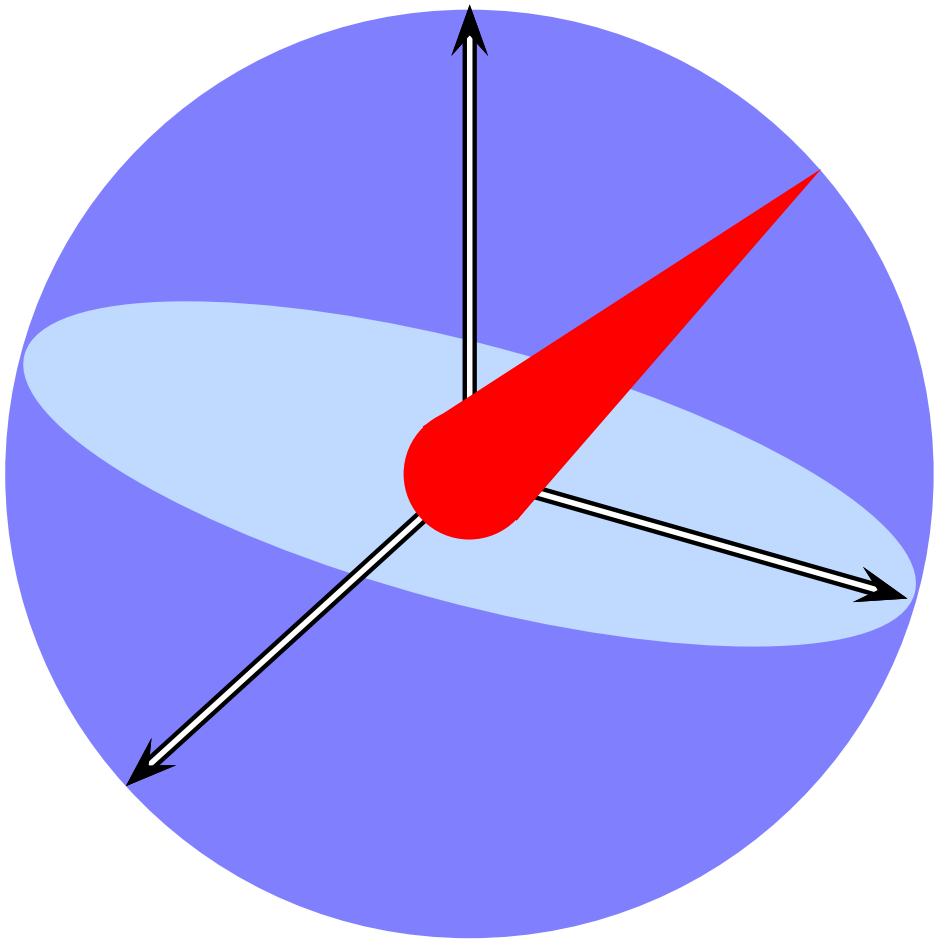

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- Try to push the boundary

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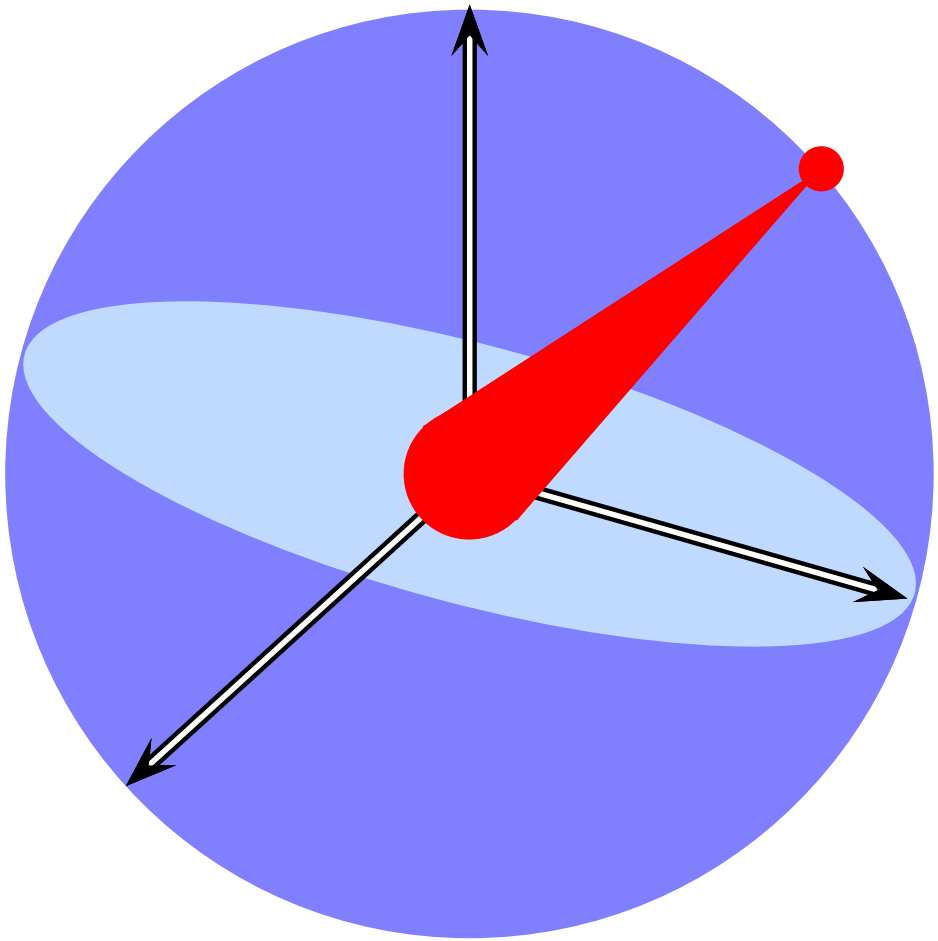
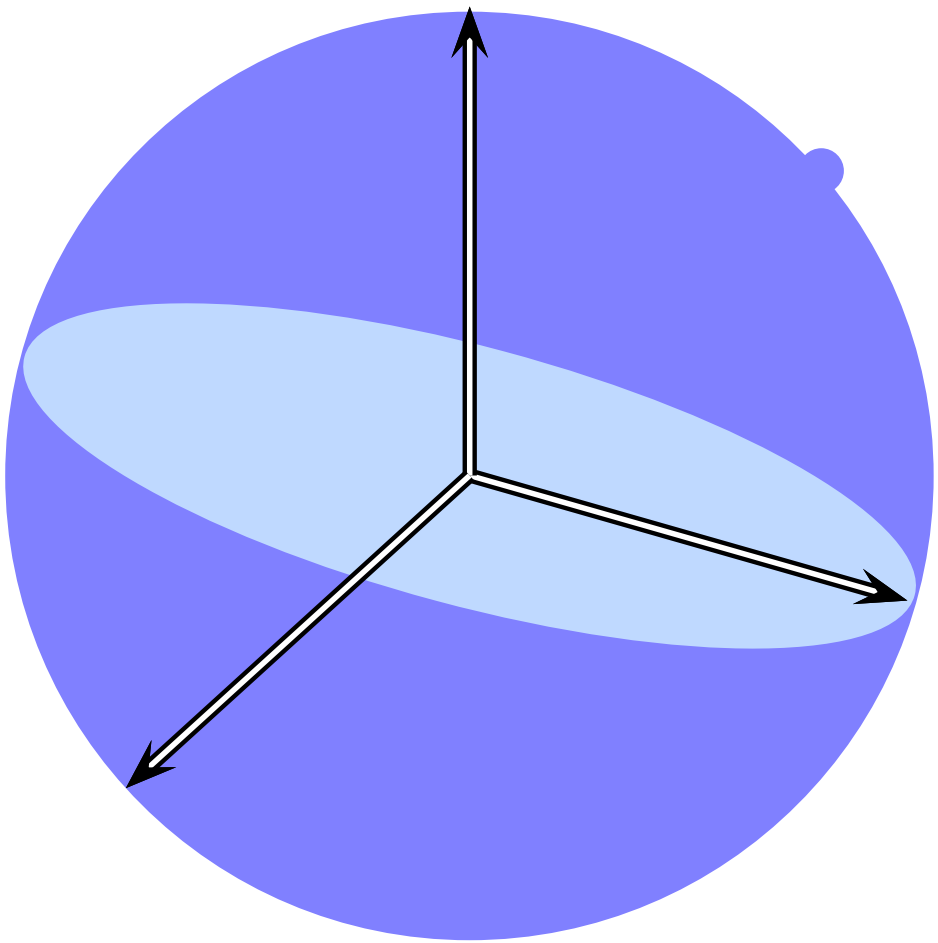


- The sphere of knowledge
- Initial general learning
- Learning increases with time
- Begin focussing and specializing
- Specialize more and more until you reach the unknown
- Try to push the boundary
- If you keep trying try hard enough, you may succeed

Innovation

- Your view of knowledge

Innovation



- The big picture

- Adapted from: *The Illustrated Guide to a Ph.D.* Matt Might. http://matt.might.net/articles/phd-school-in-pictures/

Aesthetics

- Total is greater than the sum of the parts

  "Scientists study science not because it is useful, but because it is beautiful. Here I do not talk about the beauty of appearance or beauty of qualities . . . Here I talk about that **profound beauty which comes from a harmonious order of parts** . . ."

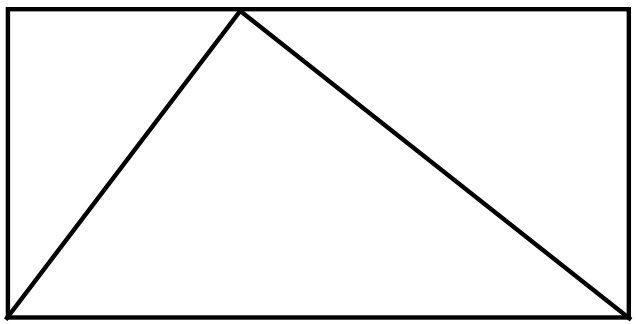
  – Henry Poincare

- Example : Painting

  Proportion of colours Vs. their arrangements

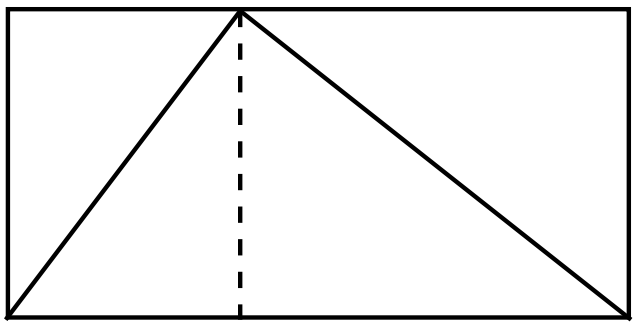
- Cassarole design

Aesthetics and Beauty of an Idea



- What proportion of the box does this traingle occupy?
- Would the result hold for *any* traingle in a box?

Aesthetics and Beauty of an Idea



- Idea: Draw a vertical line to divide the rectangle in two parts

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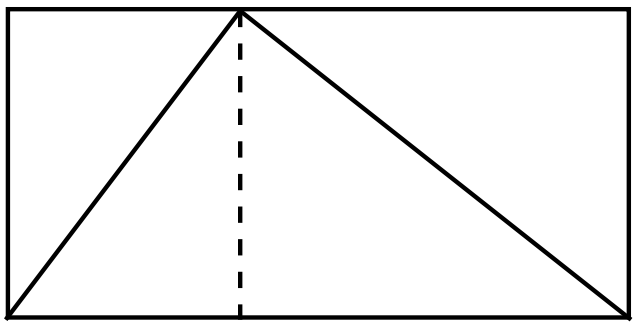

- Idea: Draw a vertical line to divide the rectangle in two parts
- The slanting lines now divide the two boxes in two equal parts

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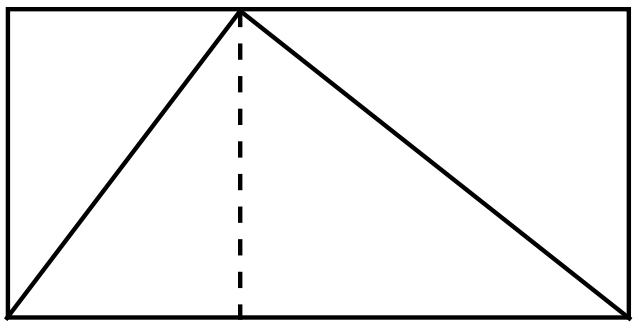

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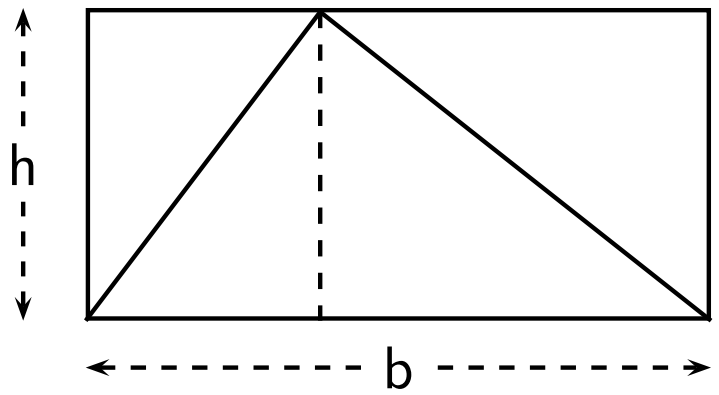
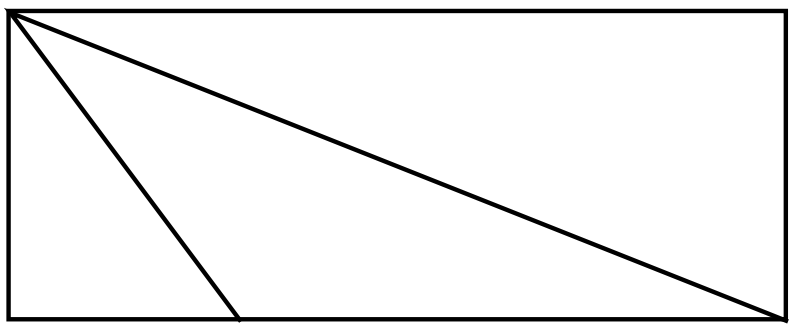


- Idea: Draw a vertical line to divide the rectangle in two parts
- The slanting lines now divide the two boxes in two equal parts
- Exactly as much area outside of the traingle as there is inside
- Area of a triangle $= \frac{1}{2} \times b \times h$

Food for Thought

What about this triangle?

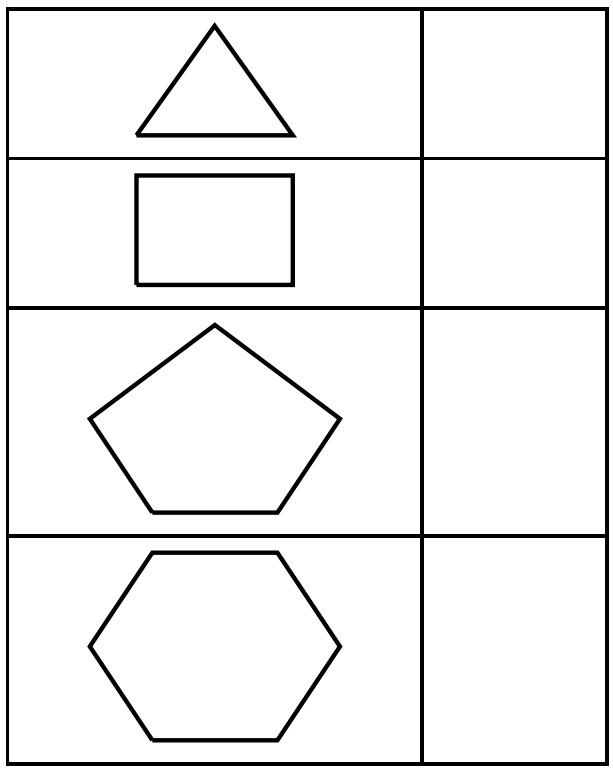


Beauty of an Idea

- Ideas talk back to us
  When we fix one idea, it fixes some other ideas
- Beauty lies in creating simple ideas that
  - bring in unexpected implications
  - relate the seemingly unrelated things
  - illuminate and reveal much more than anticipated
- Total is greater than the sum of the parts

Another Example of Beauty of an Idea

- Question: What is the sum of all internal angles of a polygon?



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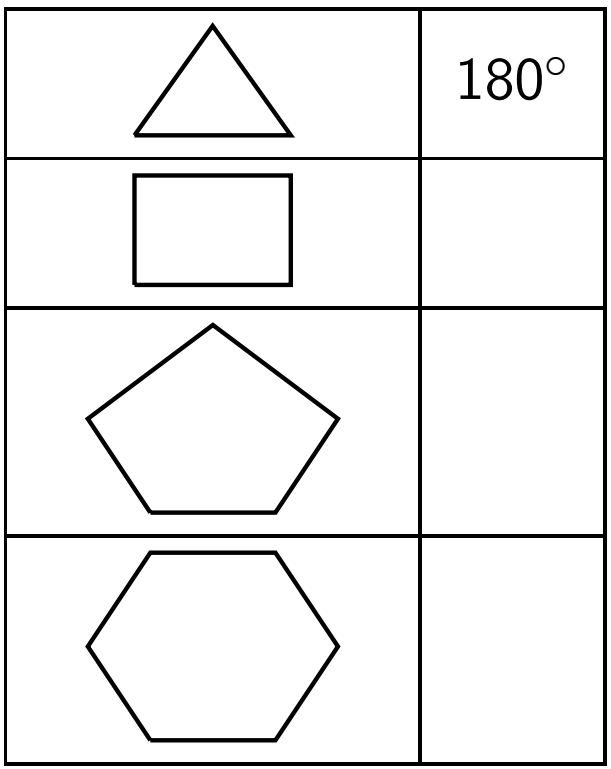

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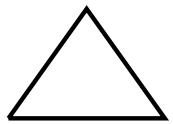	180°
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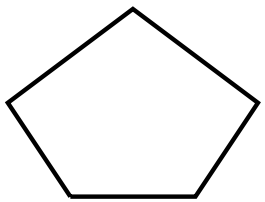	
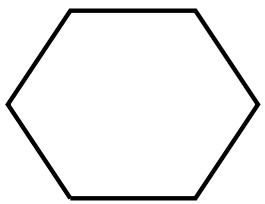	

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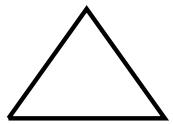	180°
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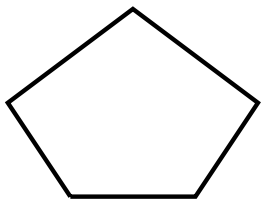
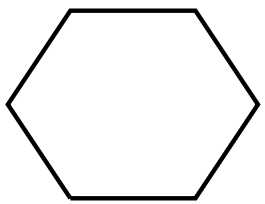
	540°
	

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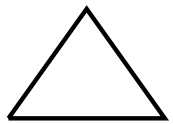	180°
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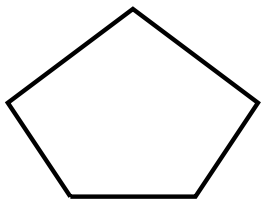
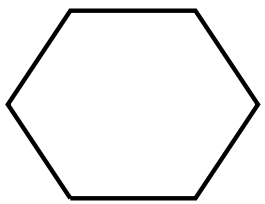
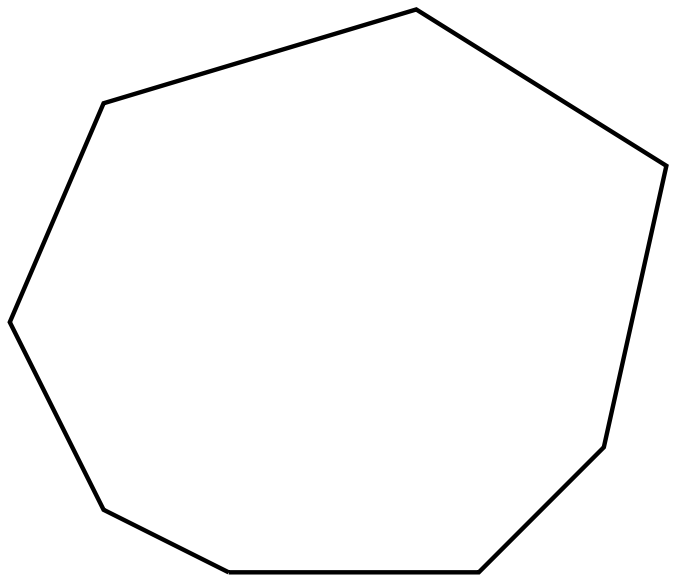
	540°
	720°

Another Example of Beauty of an Idea

- Question: What is the sum of all internal angles of a polygon?
  - Consider an n sided polygon



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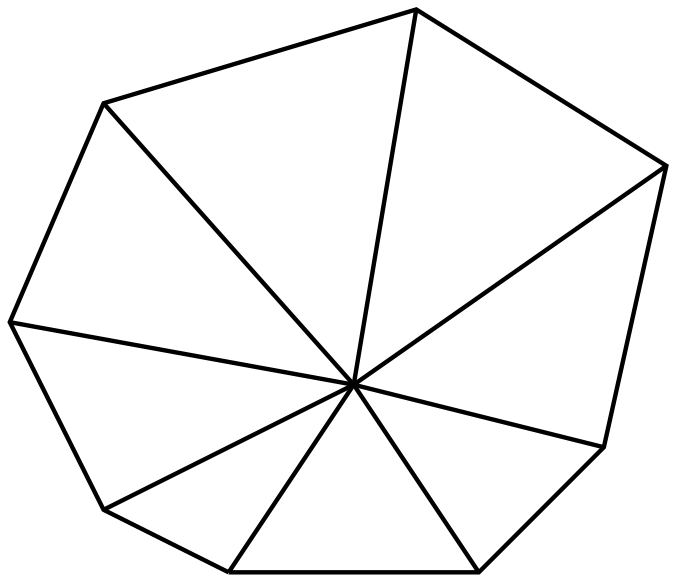

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- Question: What is the sum of all internal angles of a polygon?
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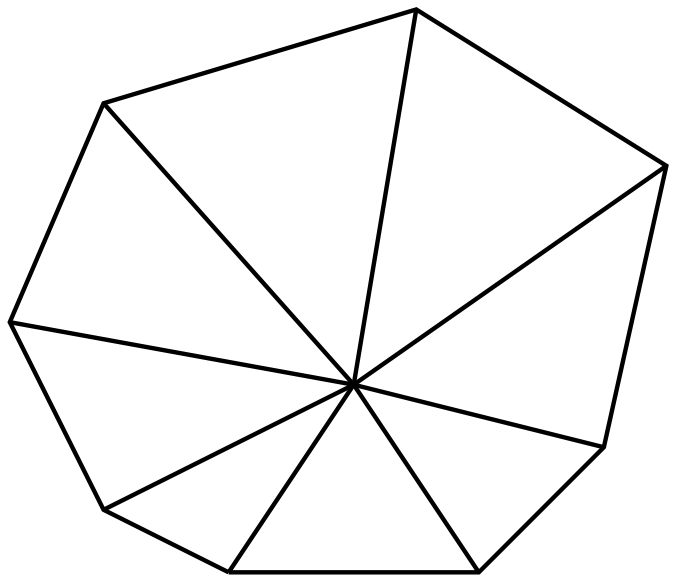
  - We have n triangles



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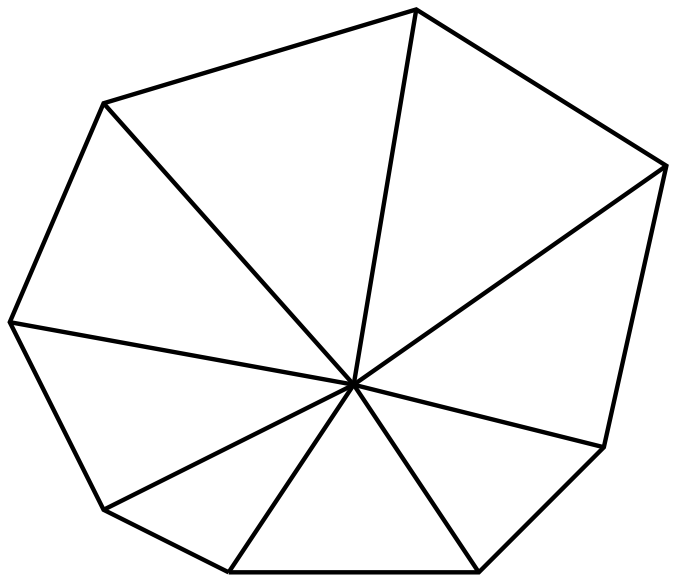
  - Sum of all angles $= n \cdot 180^\circ$



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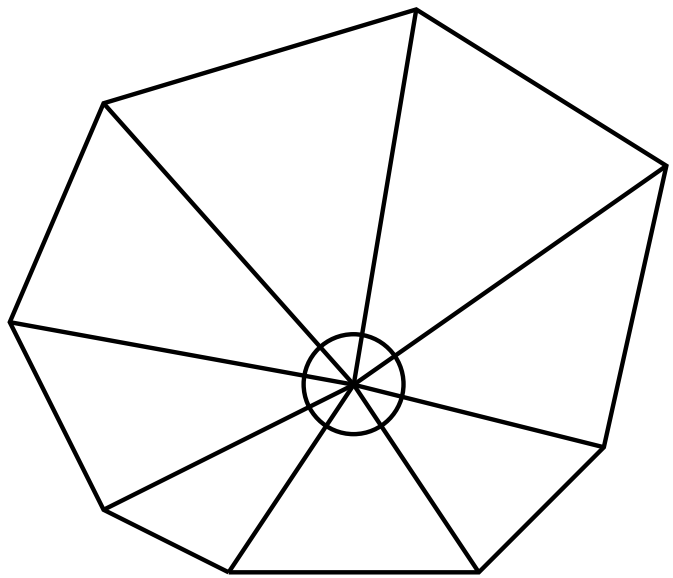
  - Exclude the sum of the angles incident on the chosen point



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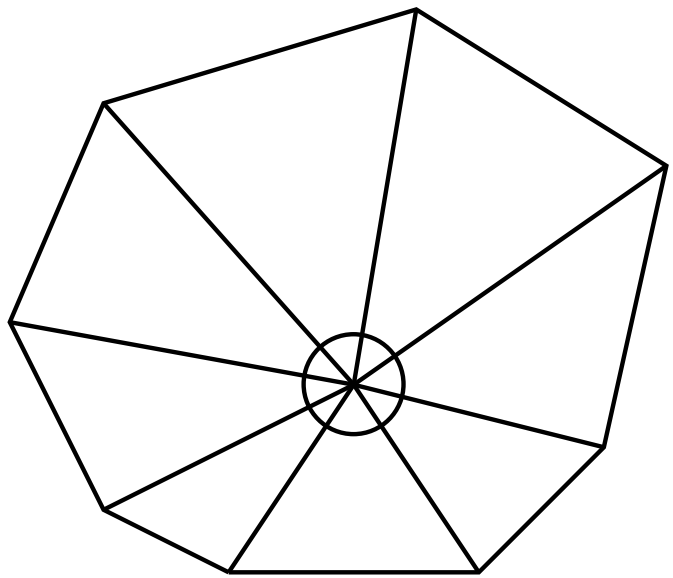

- Answer: $(n \cdot 180 - 360)^\circ$

On the Role of Rigour in an Idea

- Rigour removes imprecision and adds concreteness
- Makes an idea immune to personal interpretation

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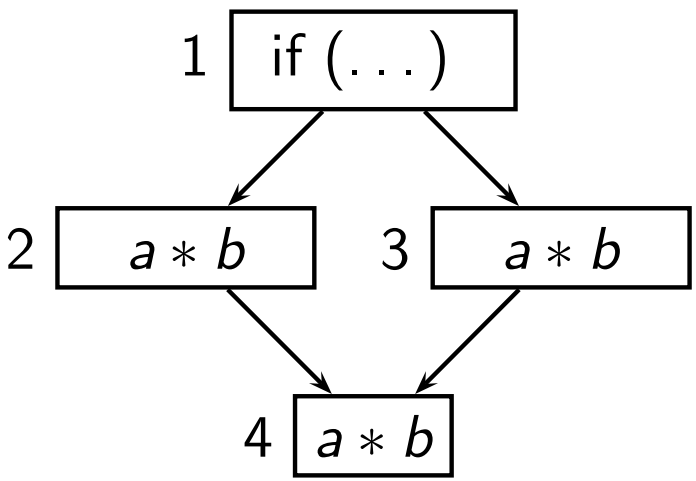
- More rigorous explanations:
  - *"Divide 6 into parts of size 2 and tell me the number of parts"*
  - *"Divide 6 into parts of size $\frac{1}{2}$ and tell me the number of parts"*

An Example of Research

- Area : Code optimization performed by compilers

  Known Optimization : Common Subexpression Elimination (CSE)



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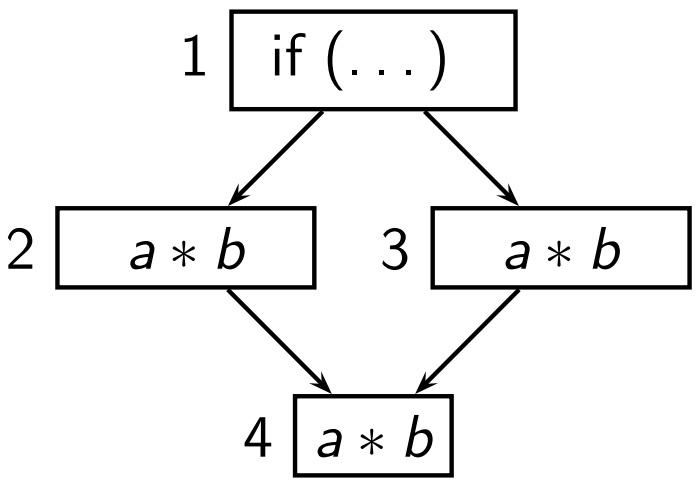

- a and b are not modified along paths $1 \rightarrow 2 \rightarrow 4$ and $1 \rightarrow 3 \rightarrow 4$

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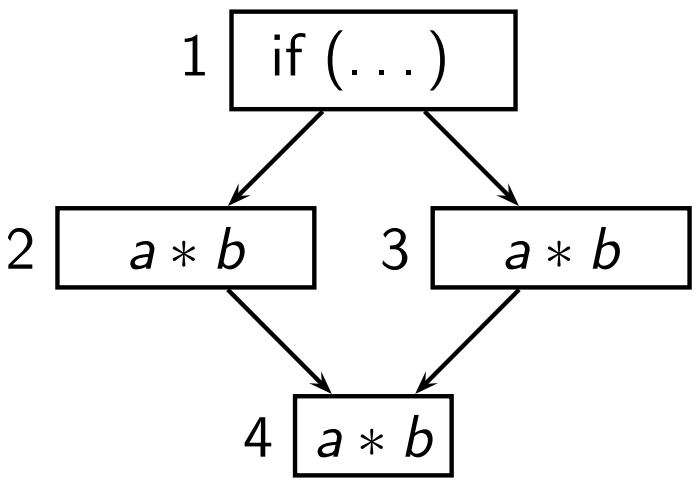

- a and b are not modified along paths $1 \rightarrow 2 \rightarrow 4$ and $1 \rightarrow 3 \rightarrow 4$
- Computation of $a * b$ in 4 is redundant

An Example of Research

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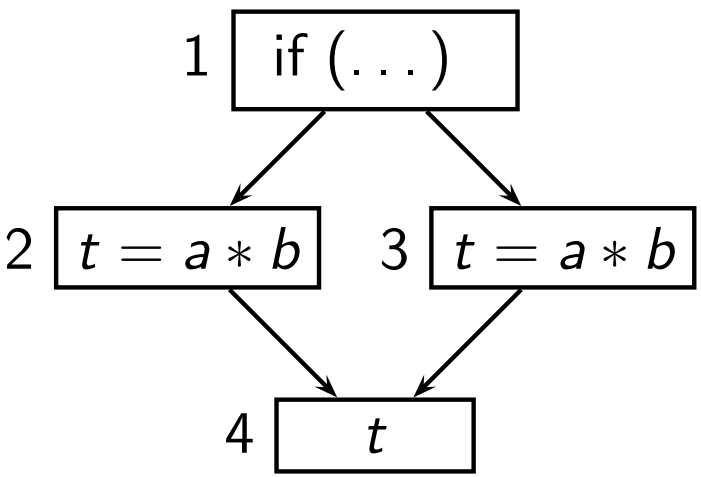
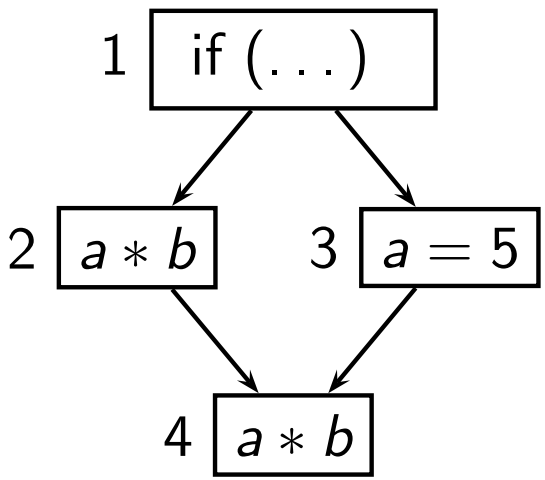


- a and b are not modified along paths $1 \rightarrow 2 \rightarrow 4$ and $1 \rightarrow 3 \rightarrow 4$
- Computation of $a * b$ in 4 is redundant
- Previous value can be used

An Example of Research

- Lacuna with CSE: Cannot optimize partial redundancy



An Example of Research

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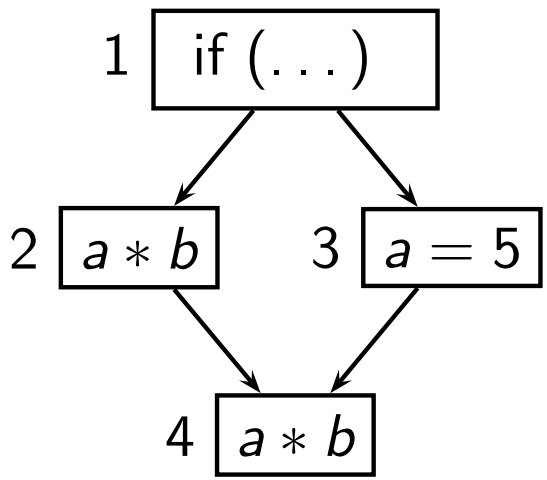

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An Example of Research

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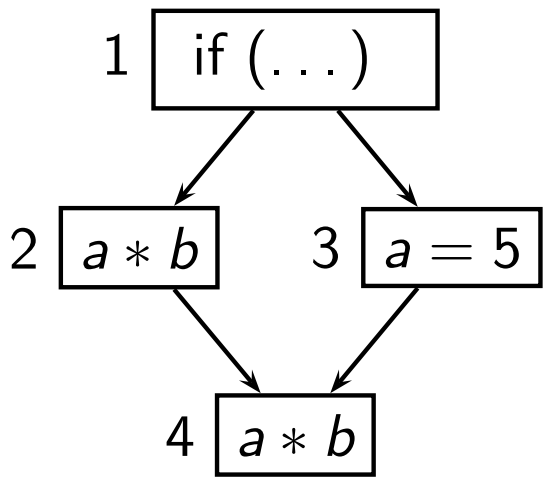

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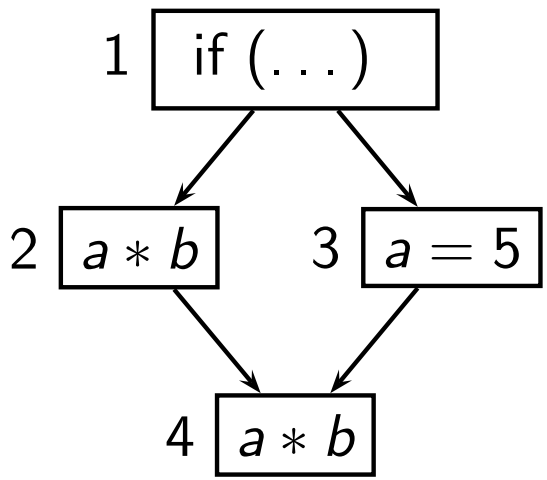
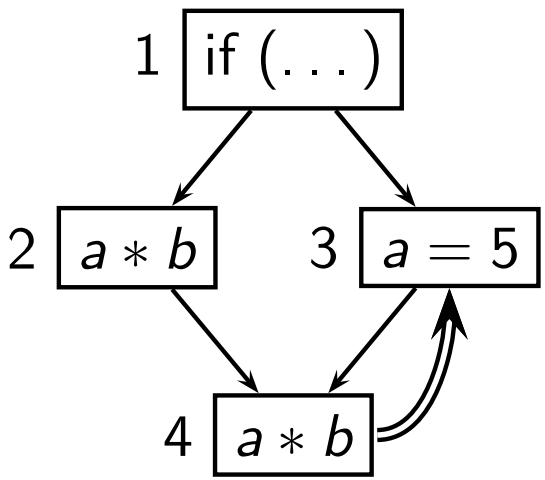


- Computation of $a * b$ in 4 is
  - redundant along path $1 \rightarrow 2 \rightarrow 4$, but . . .
  - not redundant along path $1 \rightarrow 3 \rightarrow 4$

An Example of Research

- Lacuna with CSE: Partial Redundancy Elimination



An Example of Research

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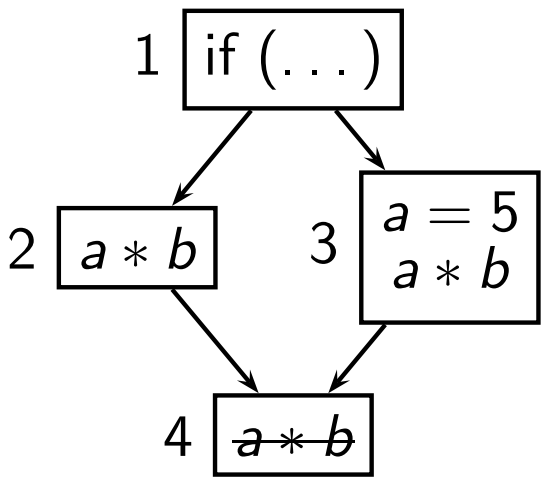


- Computation of $a * b$ in 4 becomes totally redundant
- Can be deleted

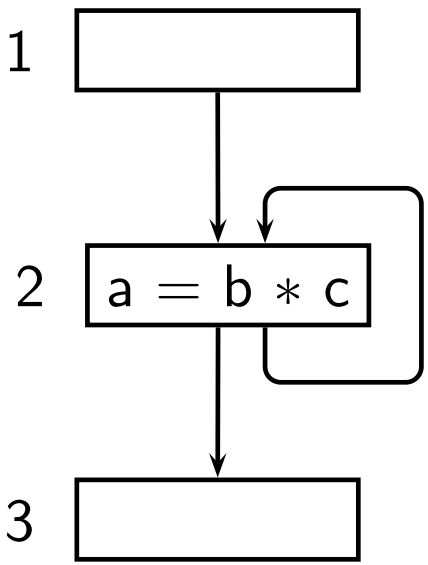
The Beauty of PRE

Subsumes Loop Invariant Movement

The Beauty of PRE

Subsumes Loop Invariant Movement

What's that?



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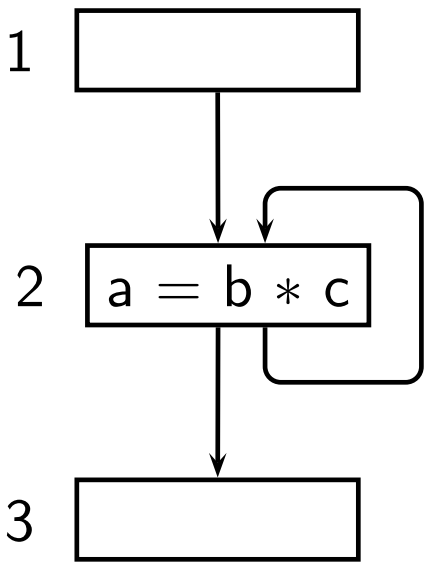

Translate to

The Beauty of PRE

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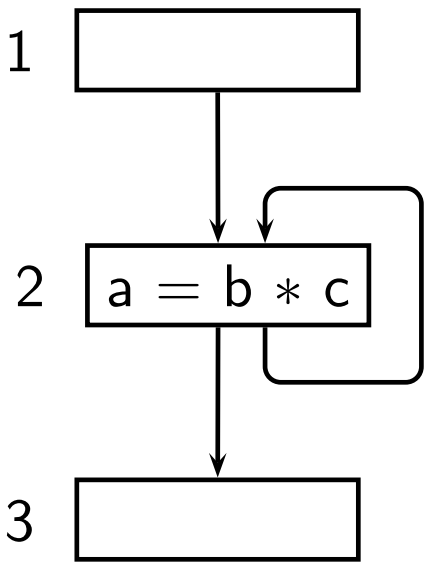

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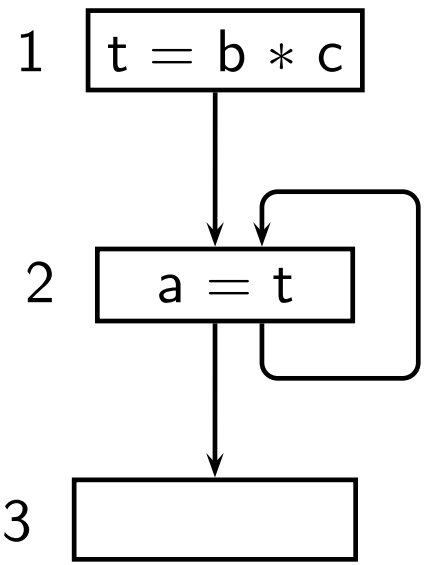

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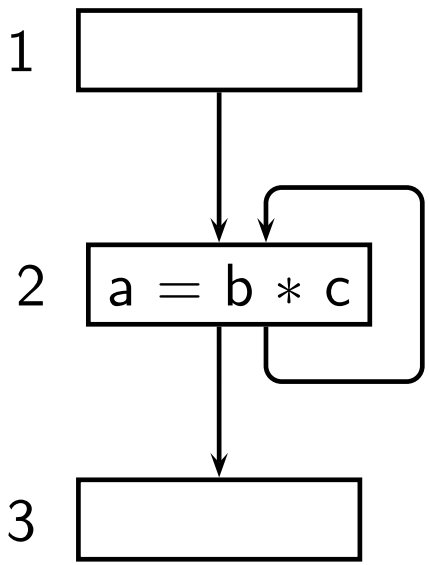

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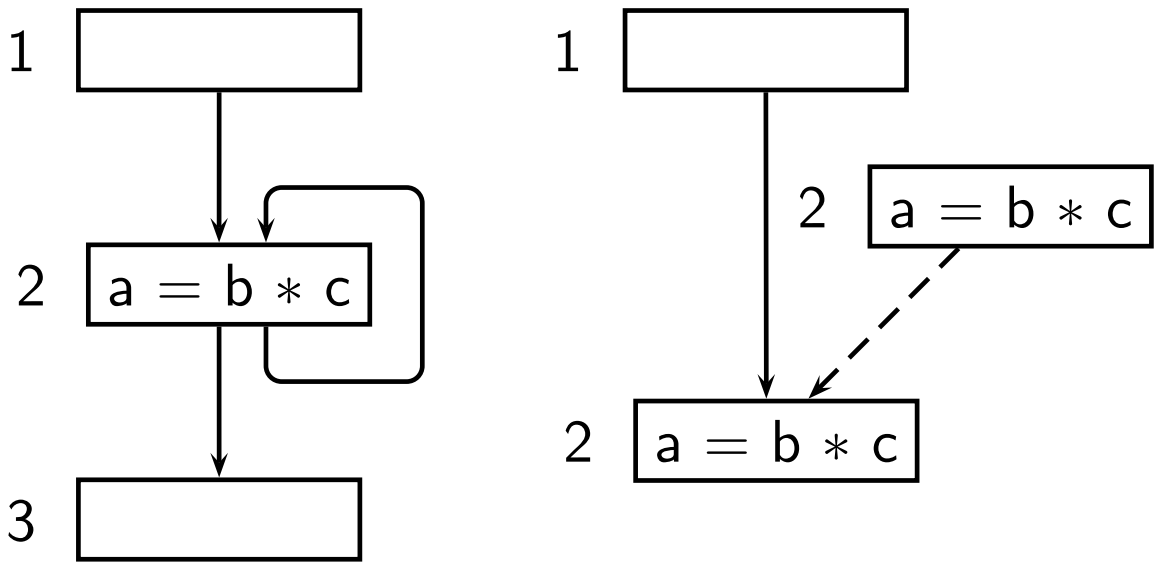

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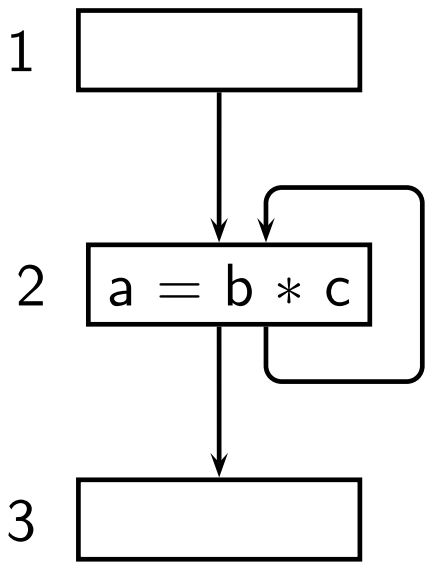
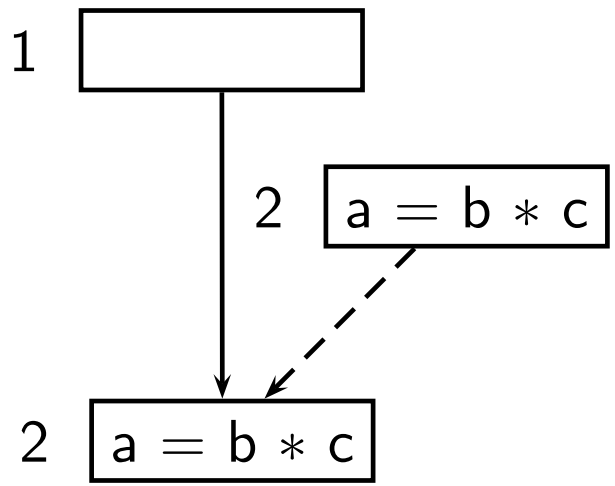
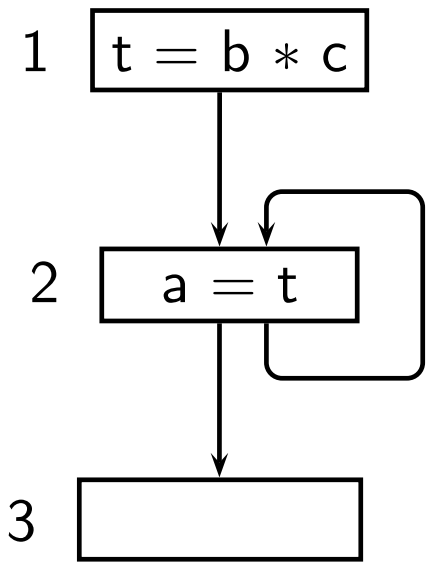


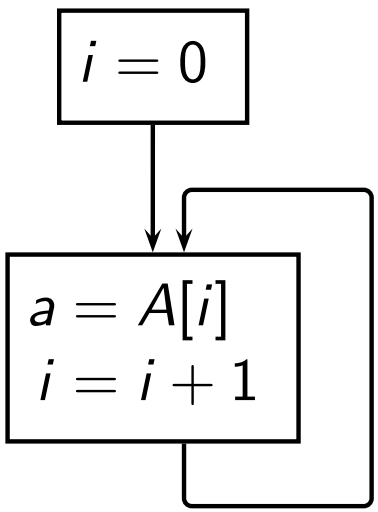




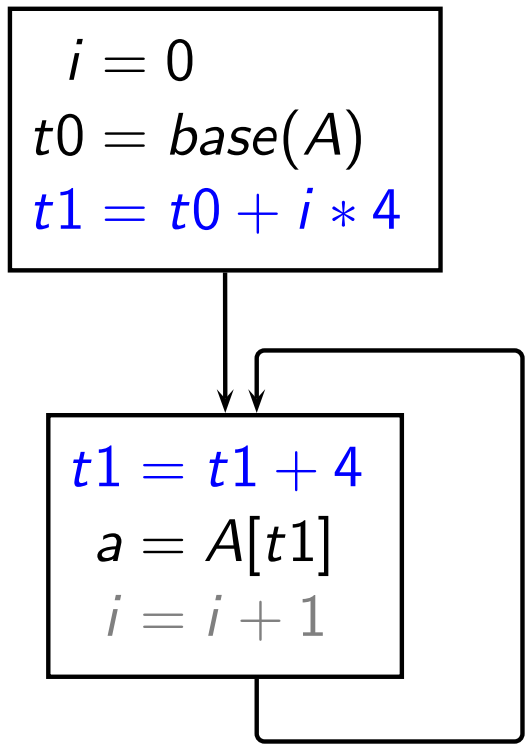
The Beauty of PRE

Can be used for Strength Reduction and Induction Variable Elimination

Original Computation



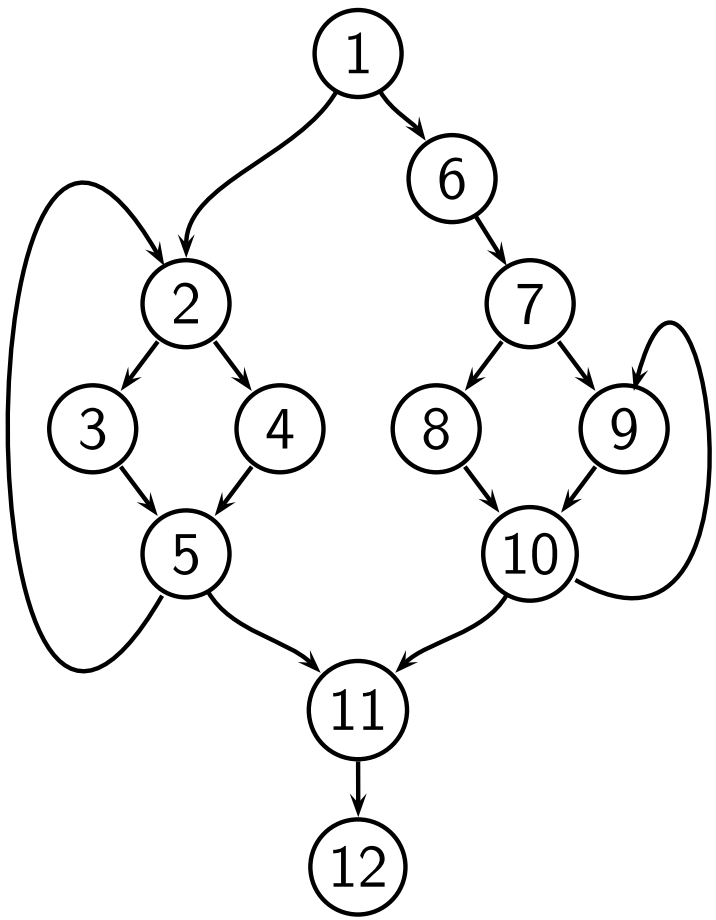
Compiled Program



- $*$ and $+$ in the loop have been replaced by $+$
- $i = i + 1$ in the loop has been eliminated

Lacuna with PRE

Theoretical Complexity
Number of (fixed order) traversals in the worst case?



- Information could flow along arbitrary paths

Lacuna with PRE

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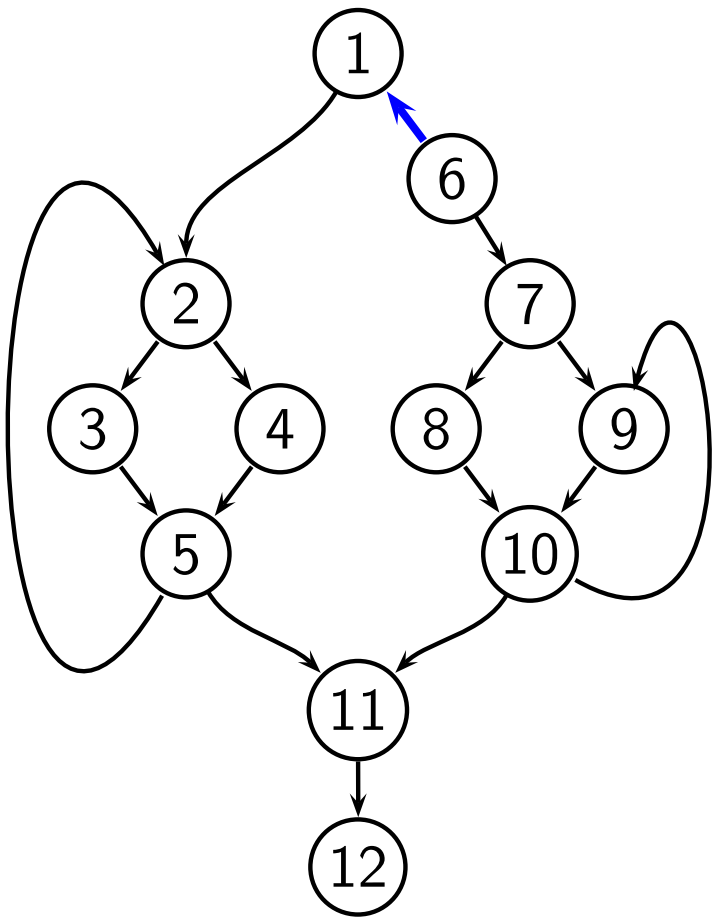

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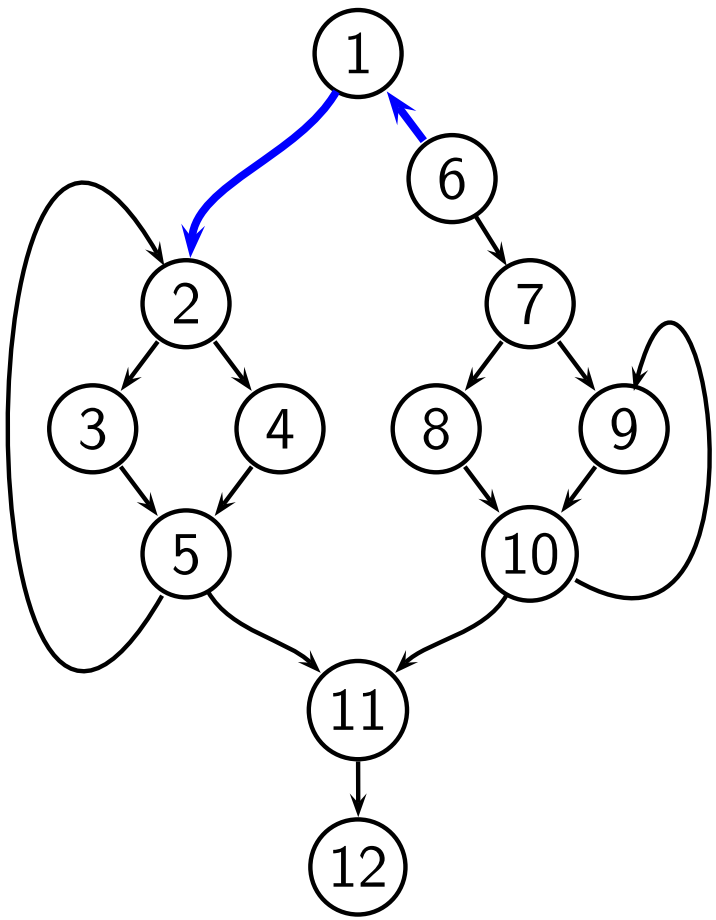

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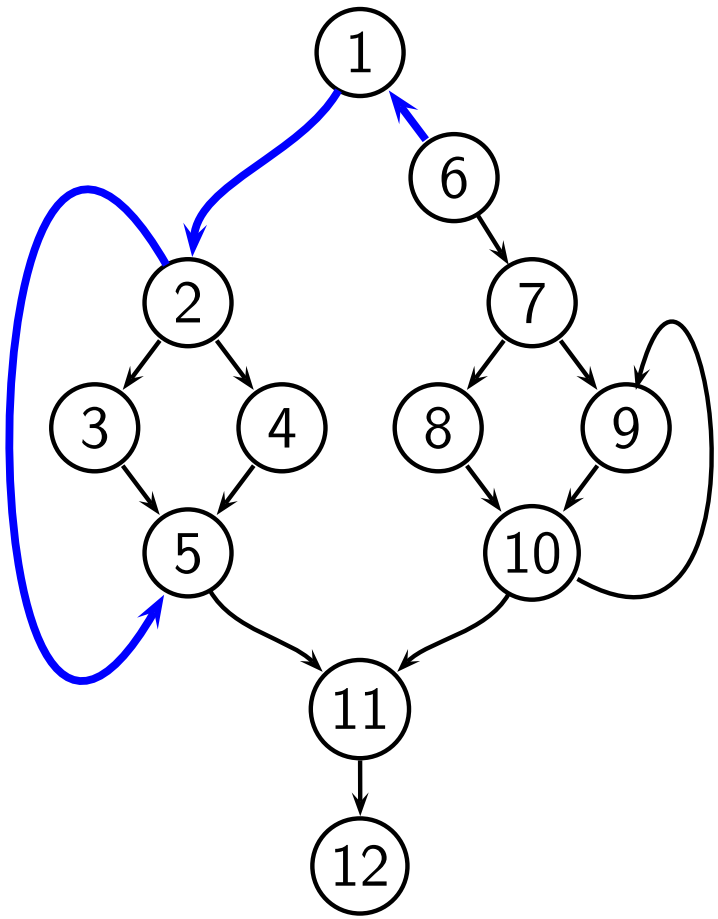

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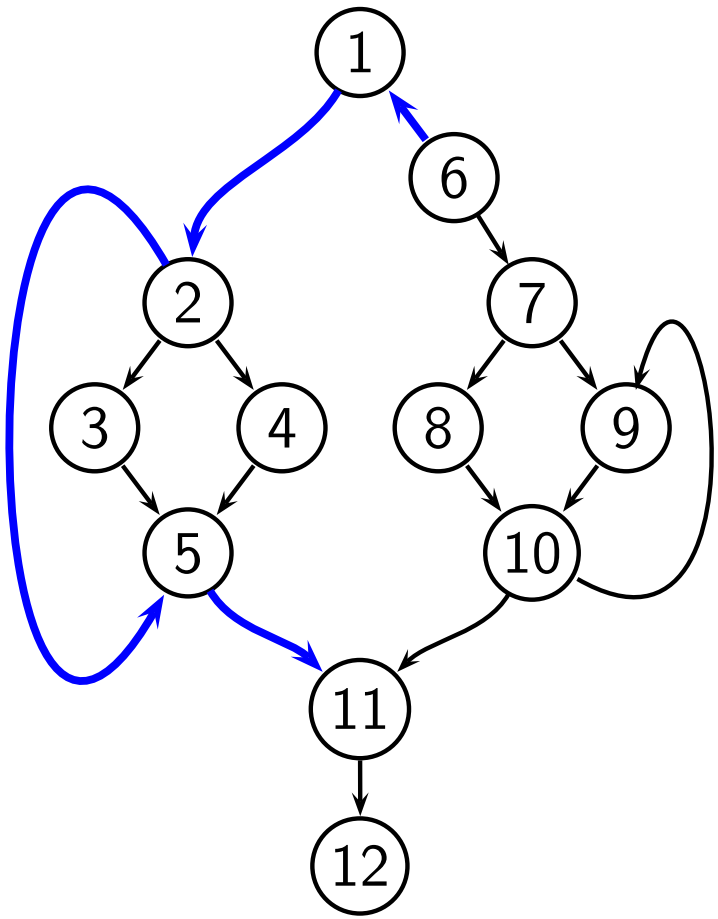

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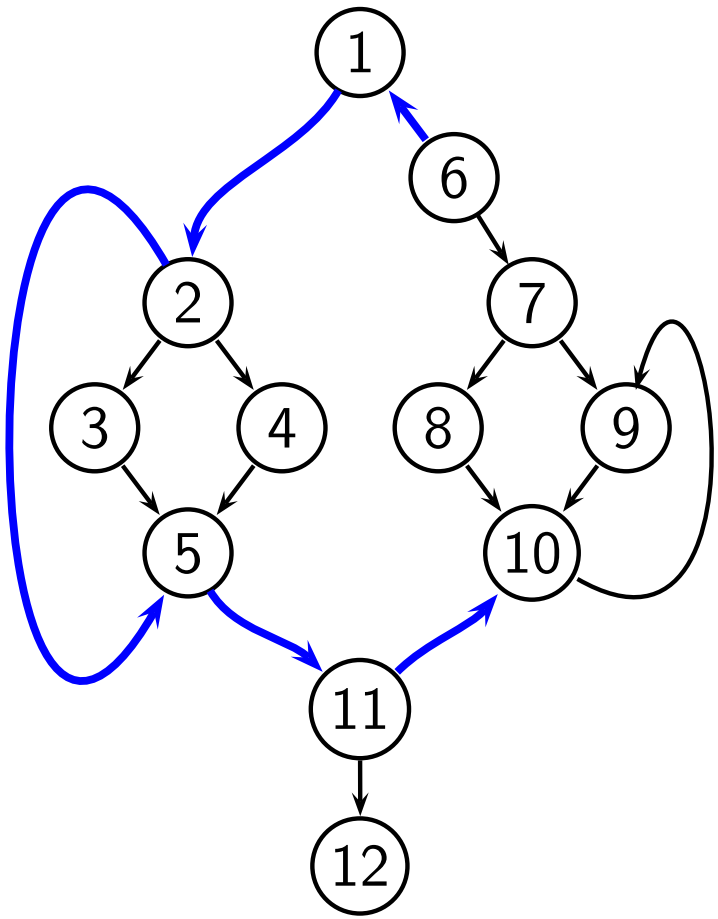

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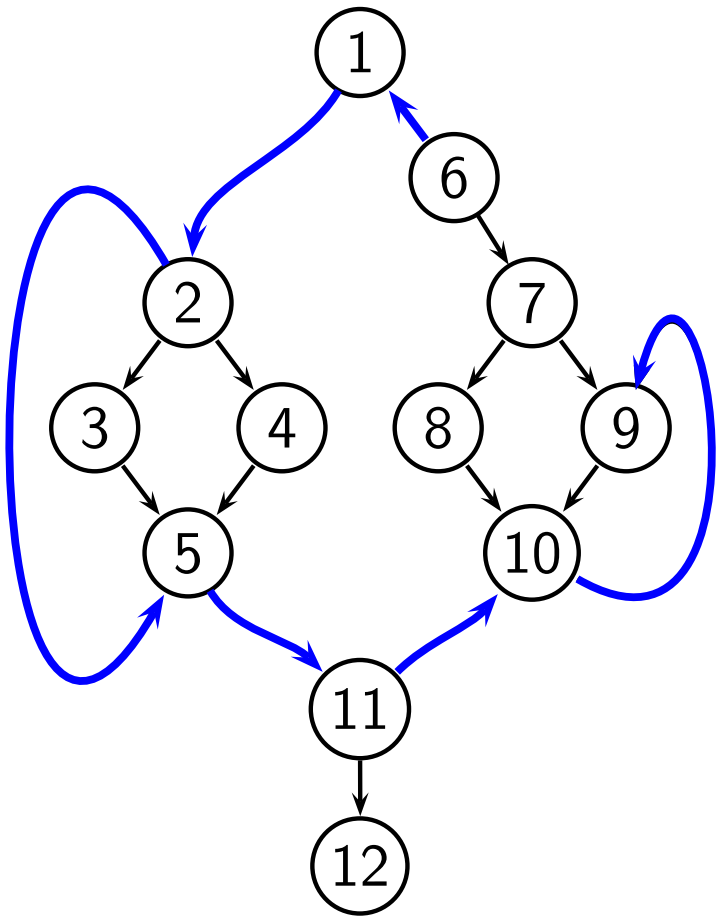

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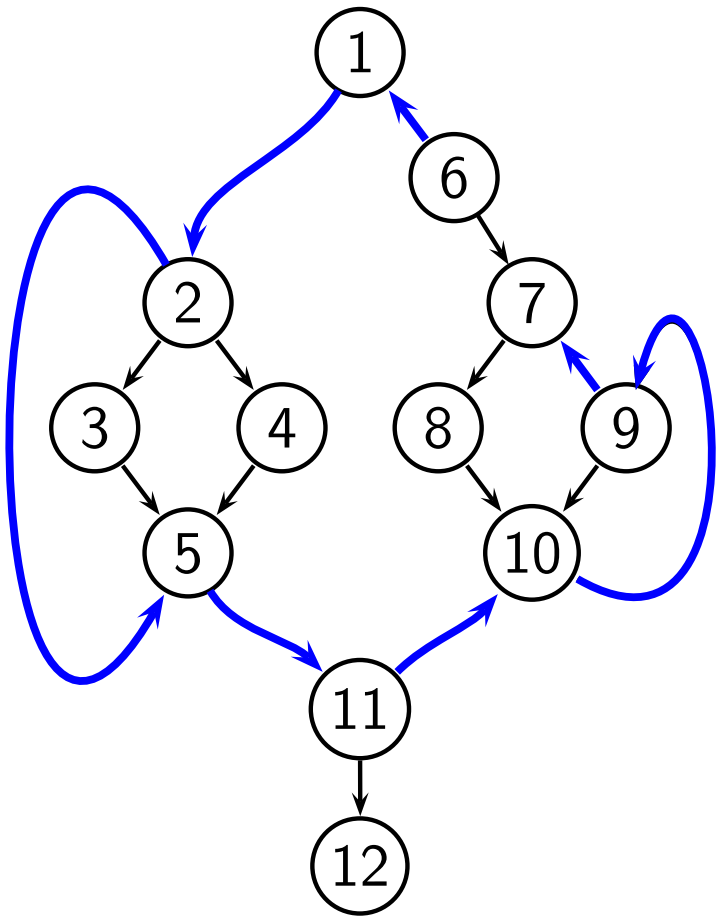

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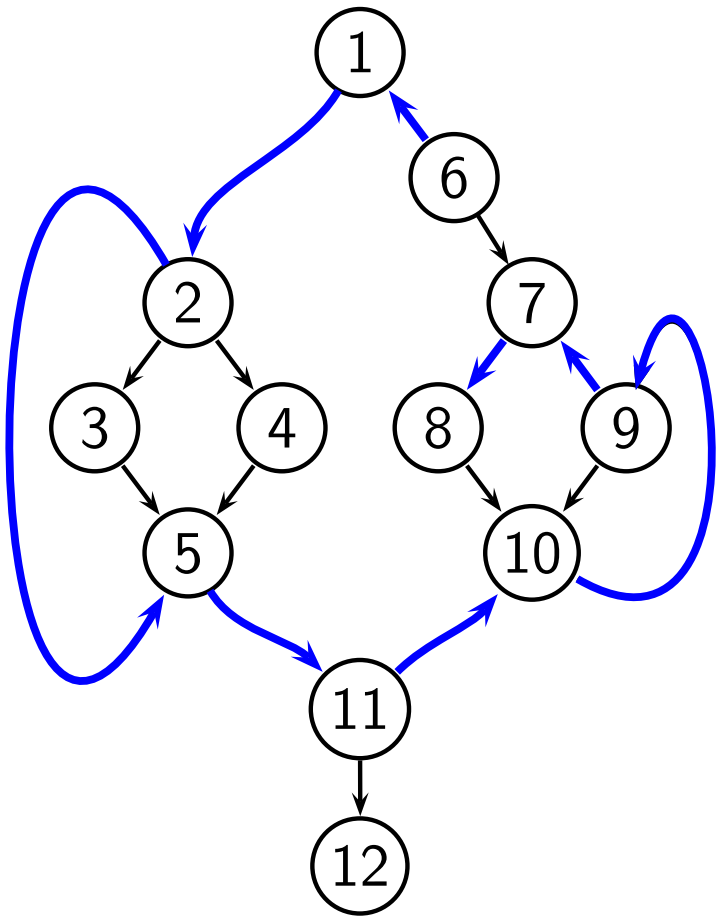
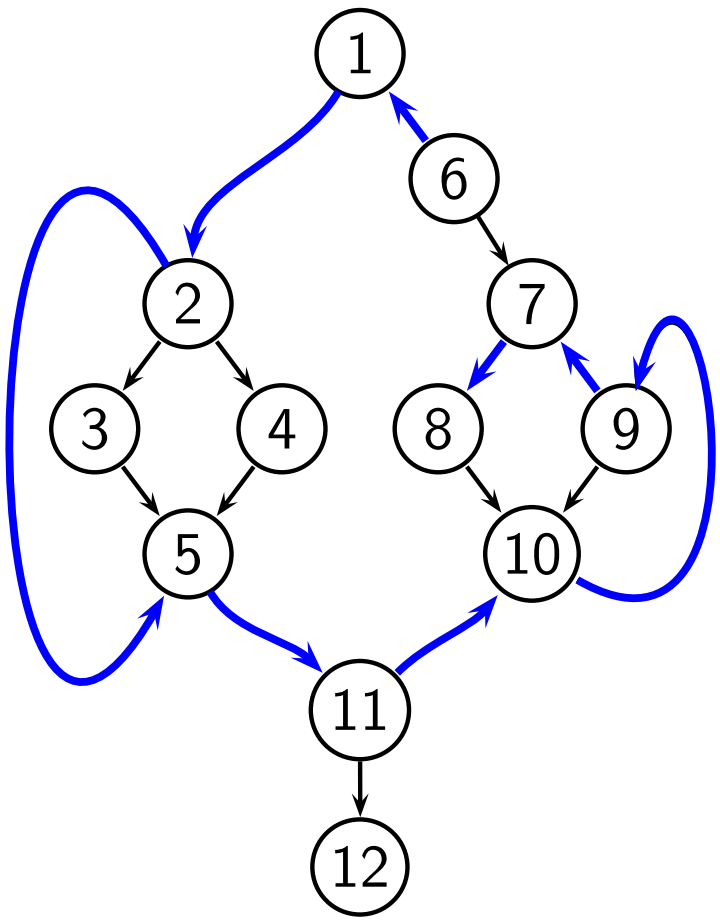


- Information could flow along arbitrary paths
- Theoretically predicted number : 144

Lacuna with PRE

Theoretical Complexity
Number of (fixed order) traversals in the worst case?



- Information could flow along arbitrary paths
- Theoretically predicted number : 144
- Actual iterations : 5

Lacuna with PRE: Complexity Measure

- Complexity $O(n^2)$ traversals

  Practical graphs may have upto 50 nodes

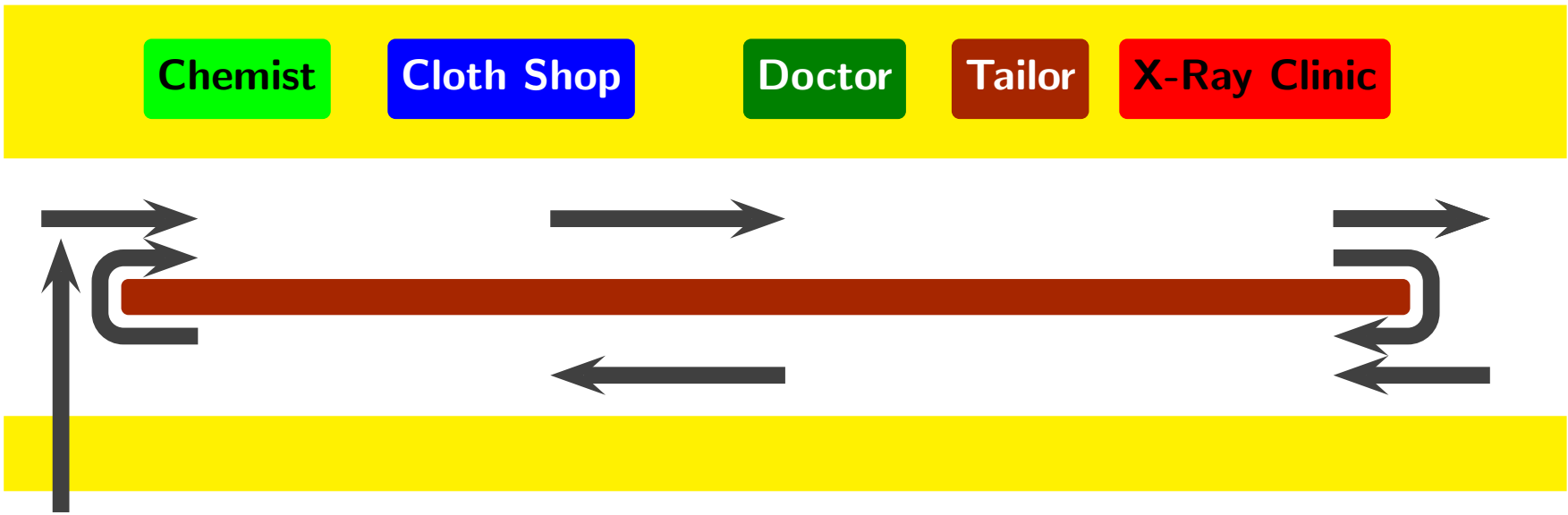
  - Predicted number of traversals : 2,500
  - Practical number of traversals : ≤ 5

- No explanation for about 14 years despite dozens of efforts
- Not much experimentation with performing advanced optimizations involving bidirectional dependency

The Story at IIT Bombay

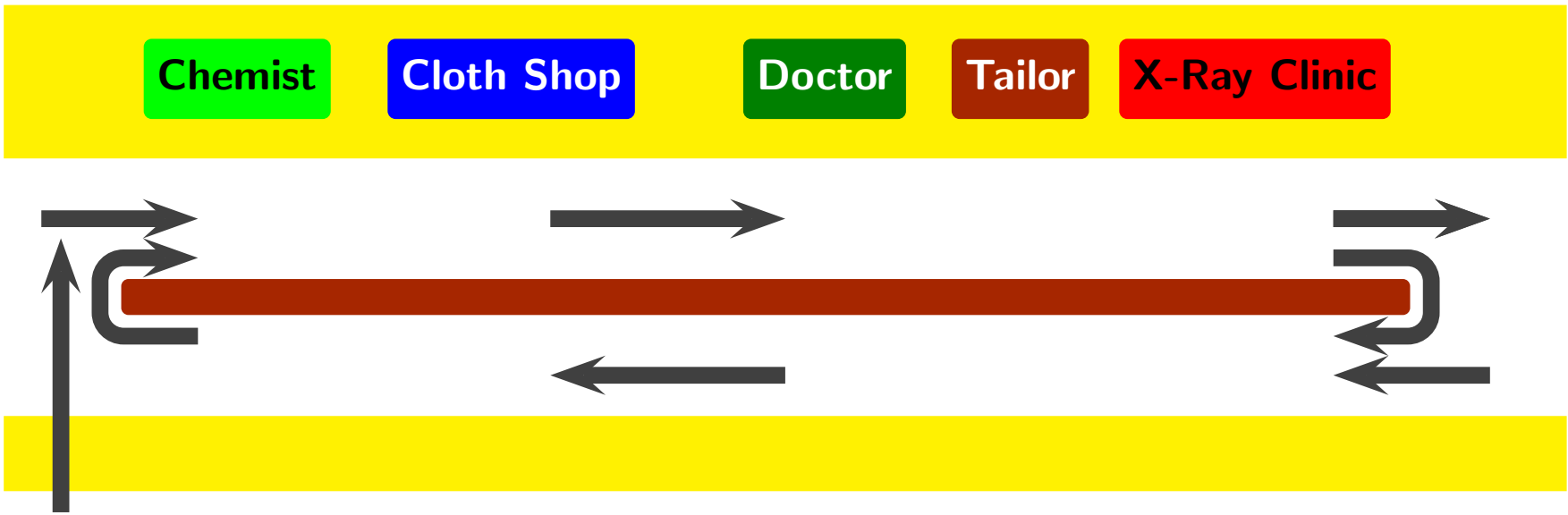
- The challenge of the professor
- The mysterious picture and the moment of reckoning

The Story at IIT Bombay : Mystery Solved



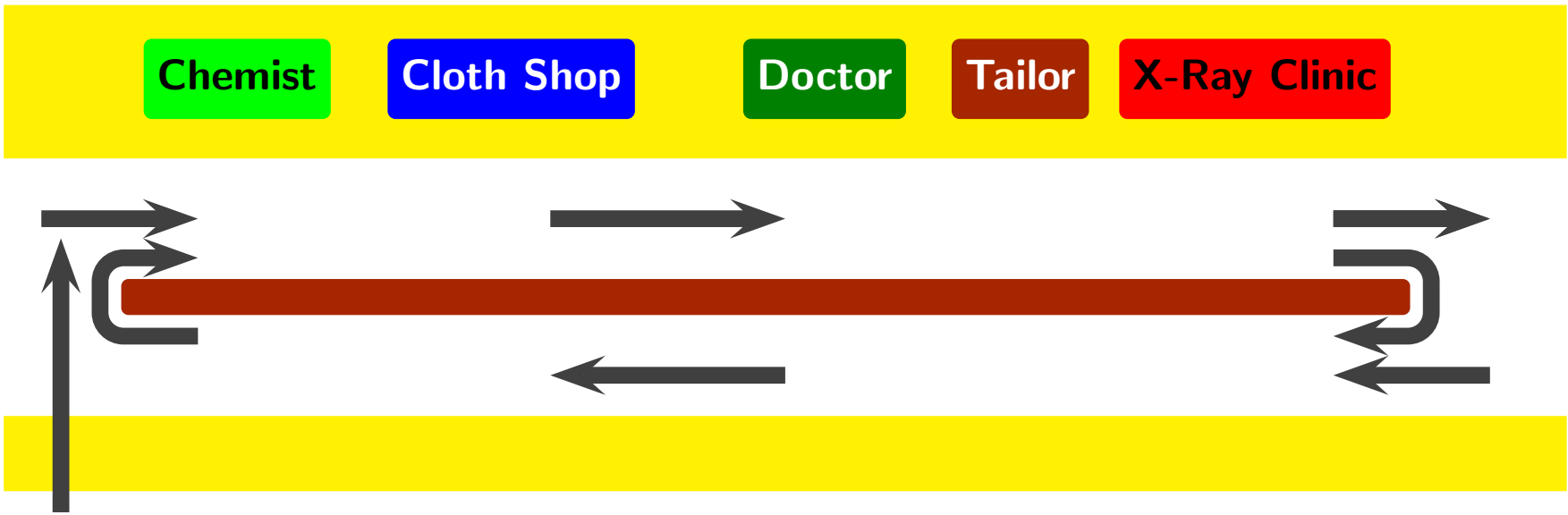
Task	U-Turns	Trips
Buy OTC (Over-The-Counter) medicine	None	1

The Story at IIT Bombay : Mystery Solved



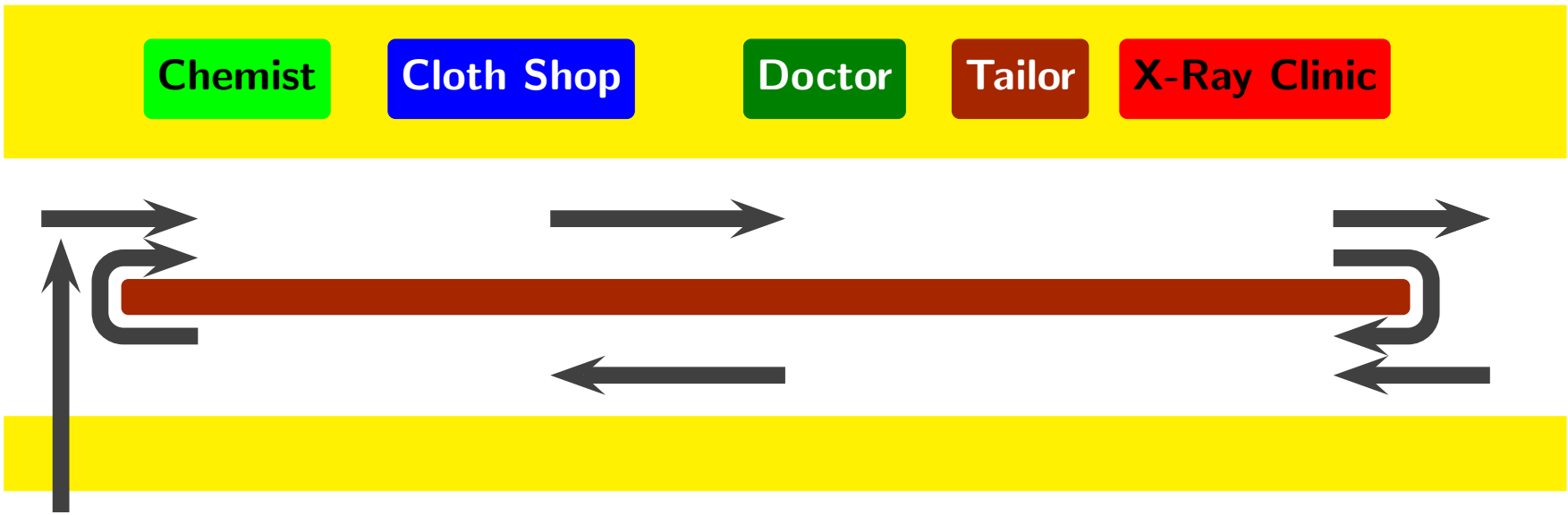
Task	U-Turns	Trips
Buy OTC (Over-The-Counter) medicine	None	1
Buy cloth. Give it to the tailor for stitching	None	1

The Story at IIT Bombay : Mystery Solved



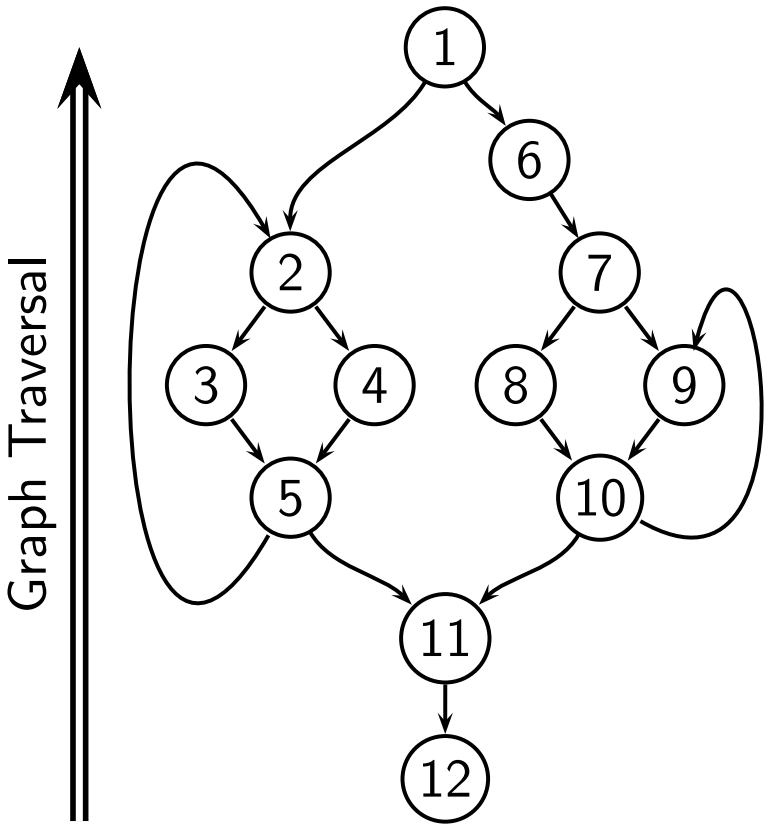
Task	U-Turns	Trips
Buy OTC (Over-The-Counter) medicine	None	1
Buy cloth. Give it to the tailor for stitching	None	1
Buy medicine with doctor's prescription	1	2

The Story at IIT Bombay : Mystery Solved



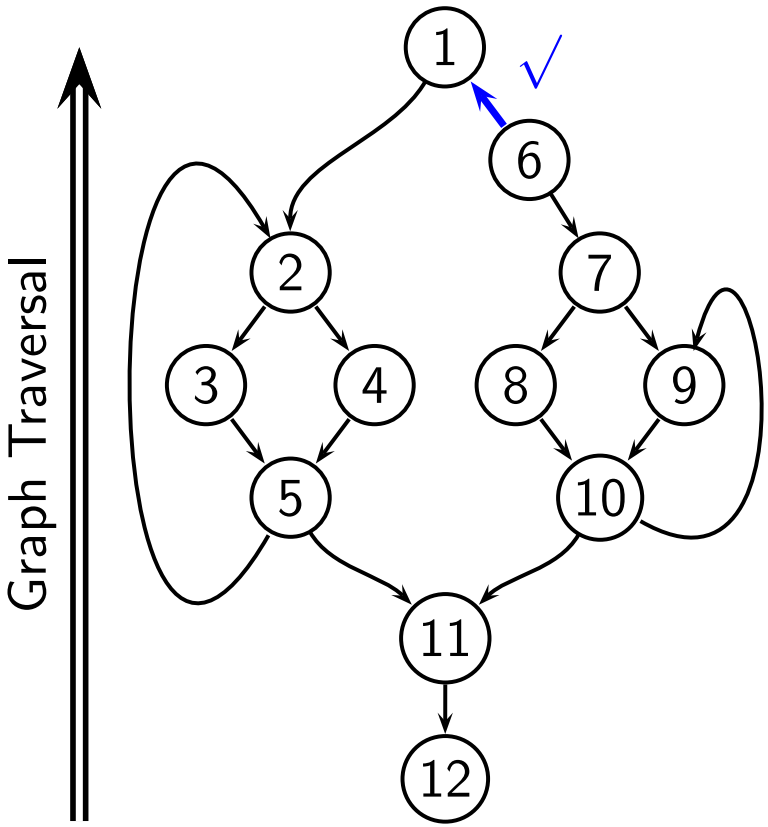
Task	U-Turns	Trips
Buy OTC (Over-The-Counter) medicine	None	1
Buy cloth. Give it to the tailor for stitching	None	1
Buy medicine with doctor's prescription	1	2
Buy medicine with doctor's prescription The diagnosis requires X-Ray	2	3

The Story at IIT Bombay : Mystery Solved



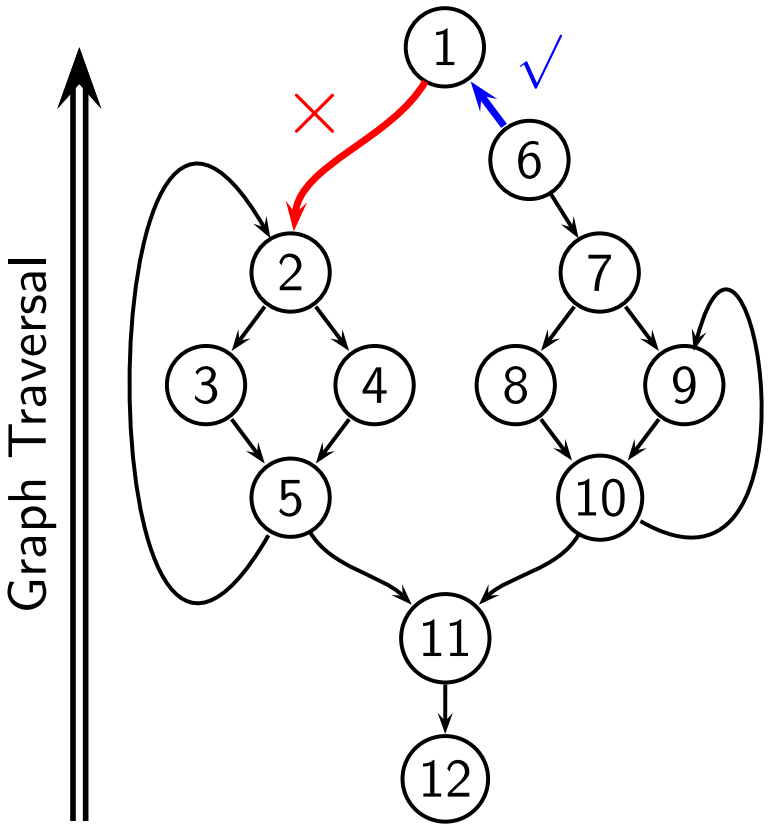
- Every "incompatible" edge traversal
  $\Rightarrow$ **One additional graph traversal**

The Story at IIT Bombay : Mystery Solved



- Every "incompatible" edge traversal ⇒ **One additional graph traversal**
- Max. Incompatible edge traversals = *Width* of the graph = **0?**
- Maximum number of traversals = 1 + Max. incompatible edge traversals

The Story at IIT Bombay : Mystery Solved



- Every "incompatible" edge traversal ⇒ **One additional graph traversal**
- Max. Incompatible edge traversals = *Width* of the graph = **1?**
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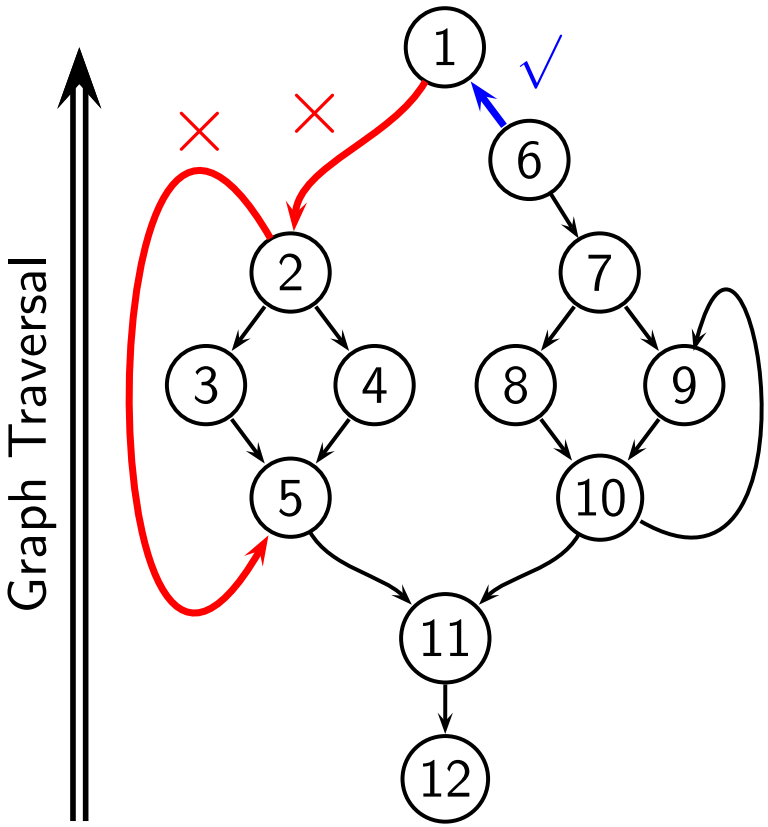
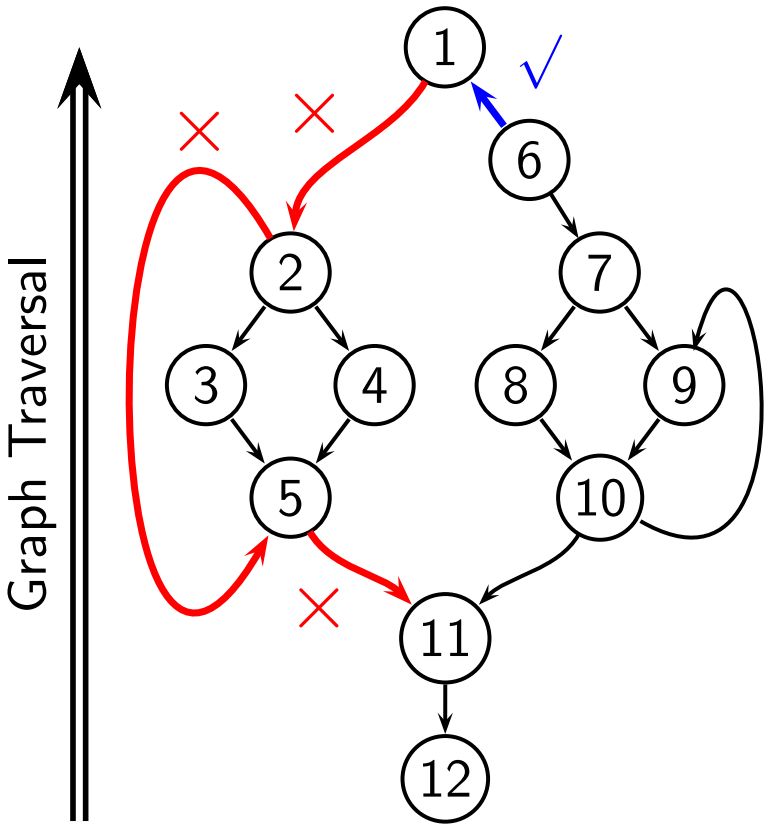
The Story at IIT Bombay : Mystery Solved



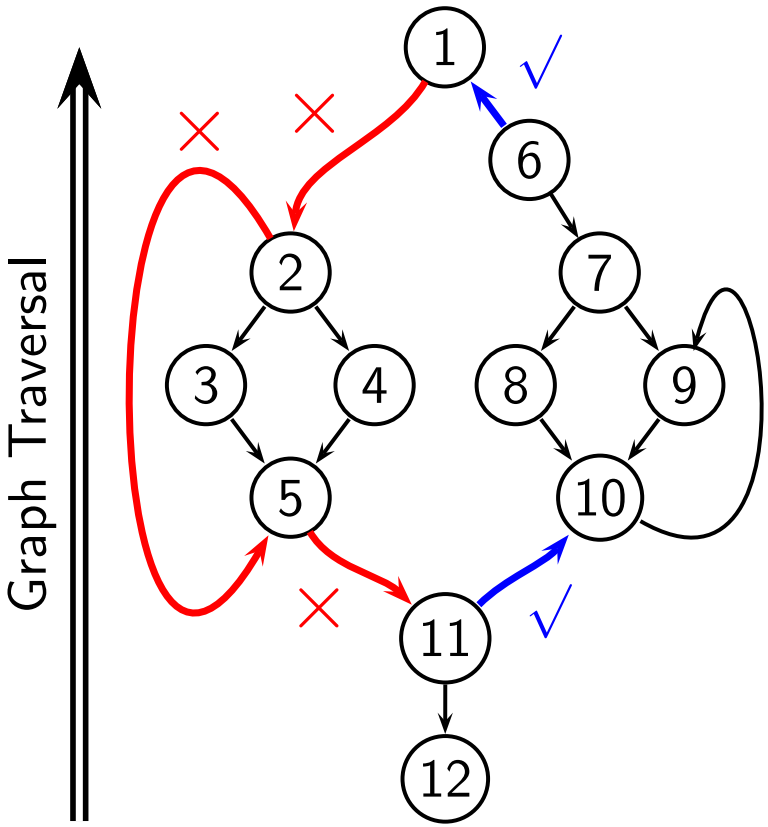
- Every "incompatible" edge traversal ⇒ **One additional graph traversal**
- Max. Incompatible edge traversals = *Width* of the graph = **2?**
- Maximum number of traversals = 1 + Max. incompatible edge traversals

The Story at IIT Bombay : Mystery Solved



- Every "incompatible" edge traversal ⇒ **One additional graph traversal**
- Max. Incompatible edge traversals = *Width* of the graph = **3?**
- Maximum number of traversals = 1 + Max. incompatible edge traversals

The Story at IIT Bombay : Mystery Solved



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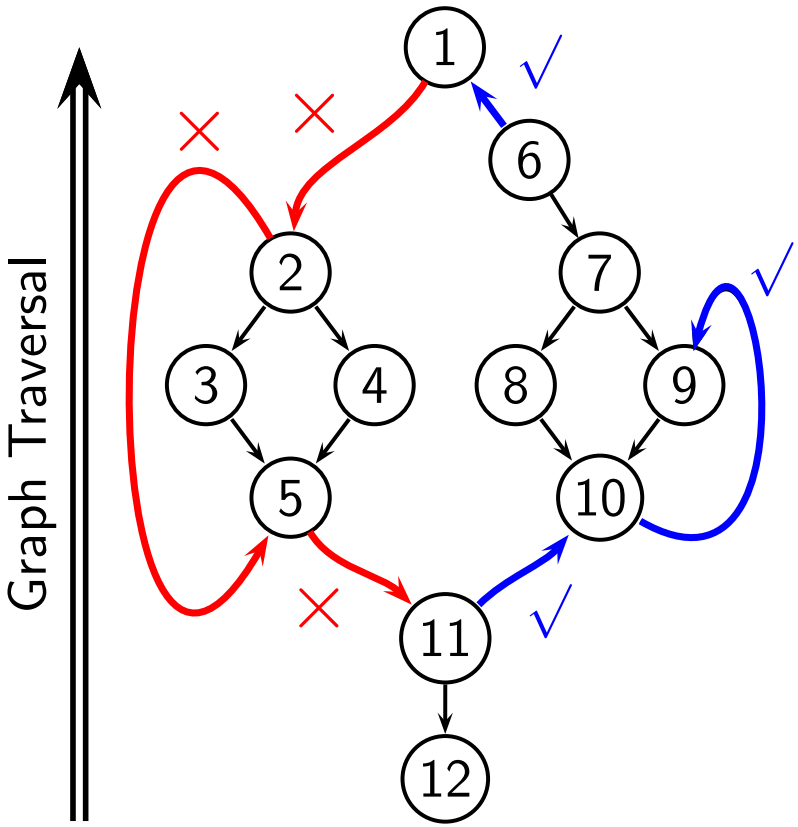

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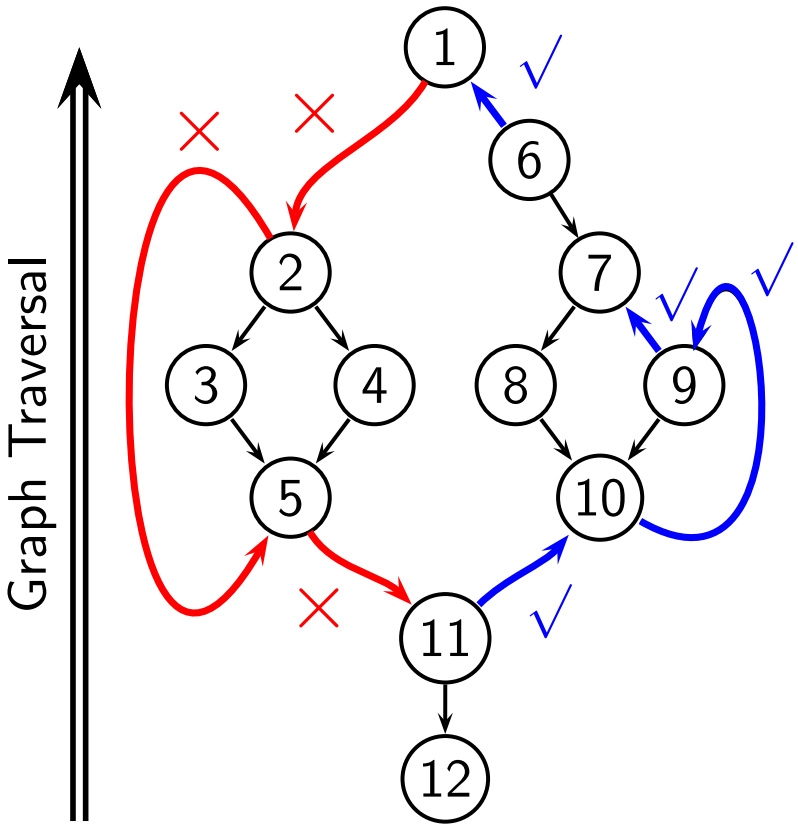

- Every "incompatible" edge traversal ⇒ **One additional graph traversal**
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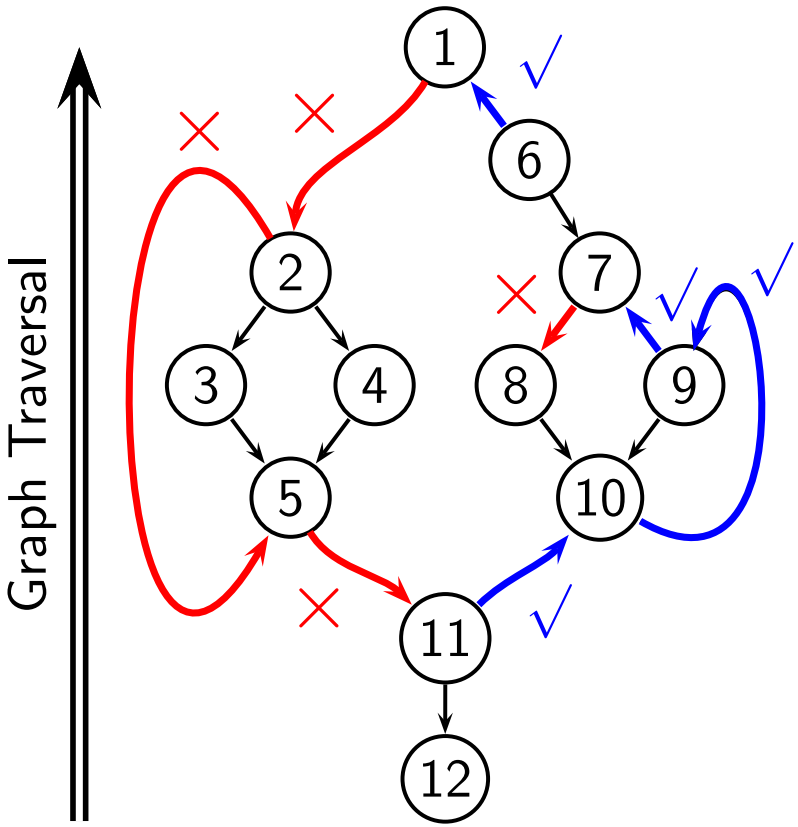
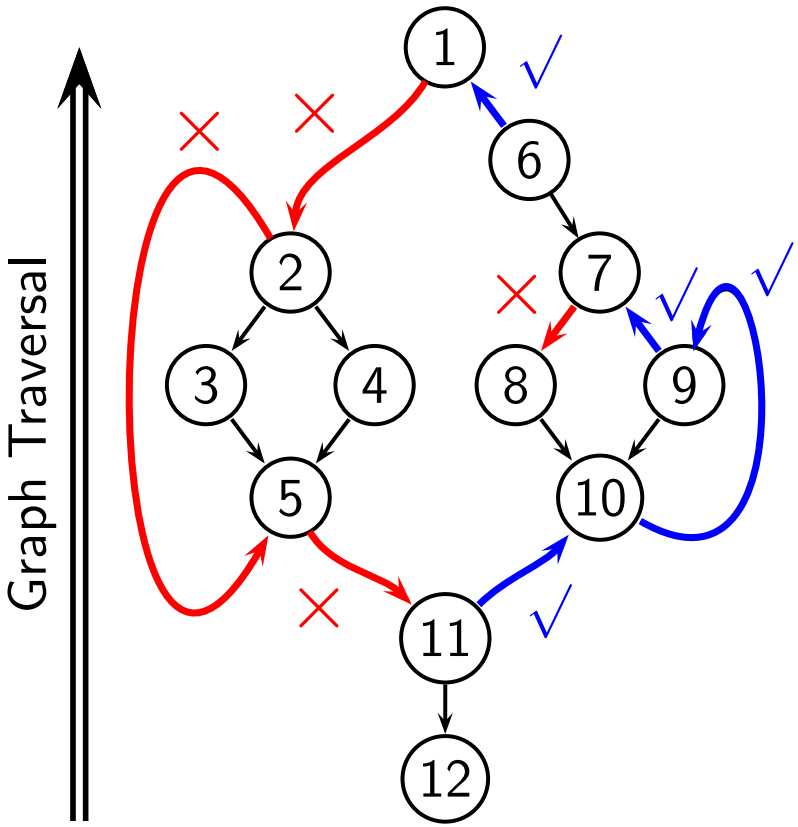
The Story at IIT Bombay : Mystery Solved



- Every "incompatible" edge traversal ⇒ **One additional graph traversal**
- Max. Incompatible edge traversals = *Width* of the graph = **4**
- Maximum number of traversals = 1 + Max. incompatible edge traversals

The Story at IIT Bombay : Mystery Solved



- Every "incompatible" edge traversal $\Rightarrow$ **One additional graph traversal**
- Max. Incompatible edge traversals = *Width* of the graph = **4**
- Maximum number of traversals = $1 + 4 = 5$

Looking Back

Key Idea	Its Significance
A partial redundancy can be converted to total redundancy	Subsumes loop invariant movement without having to detect loops
The compatibility or a lack or it, between the order of dependence and the order of traversal determines the number of traversals	Bridges the gap between theoretical prediction and practical observation

Part 4

The Process of Research

The Spirit of Inquiry (1)

Very few of us know,

how much we have to know,

in order to know,

how little we know

The Spirit of Inquiry (1)

Very few of us know,

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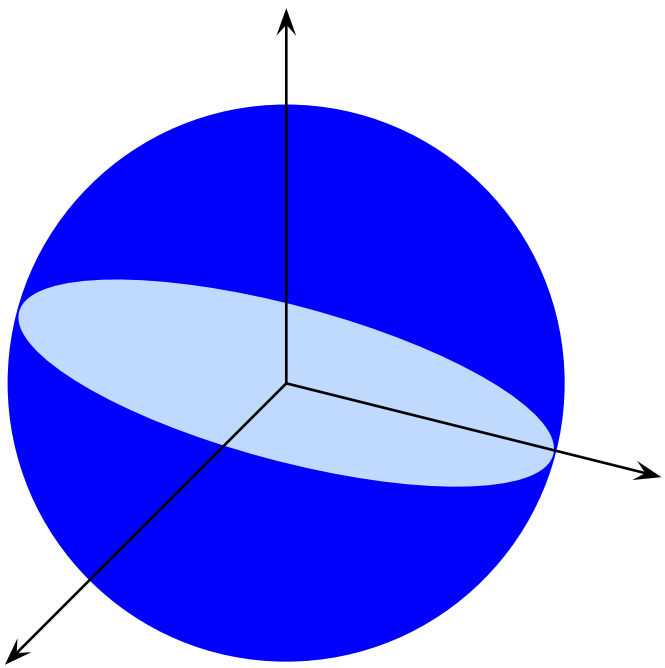

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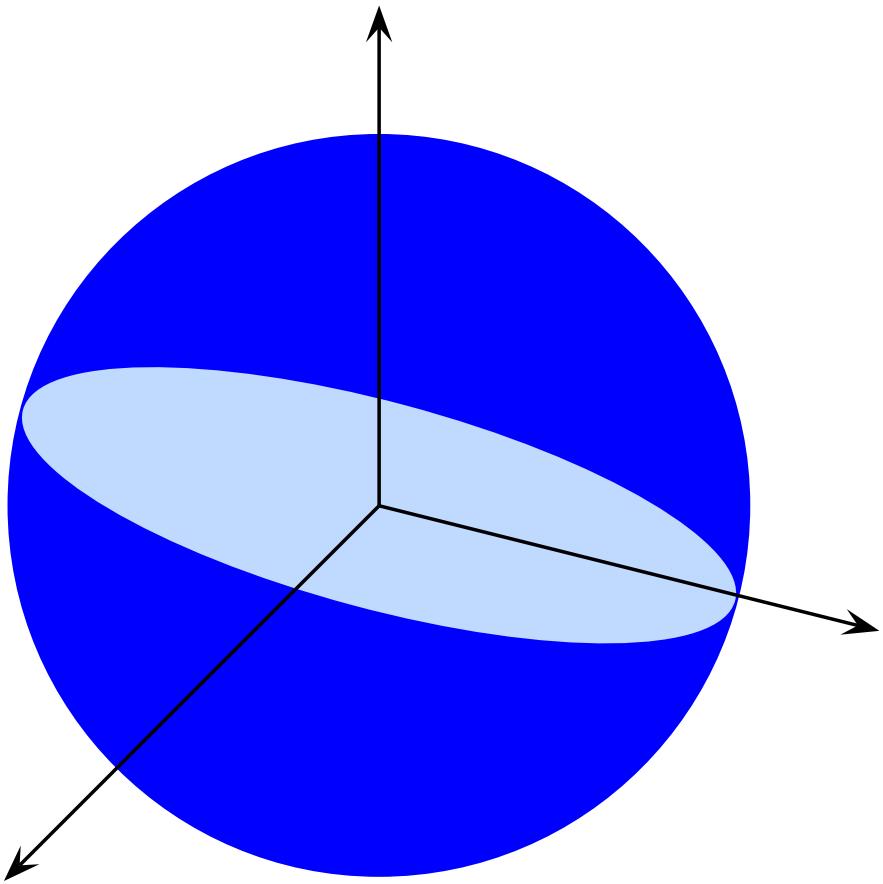

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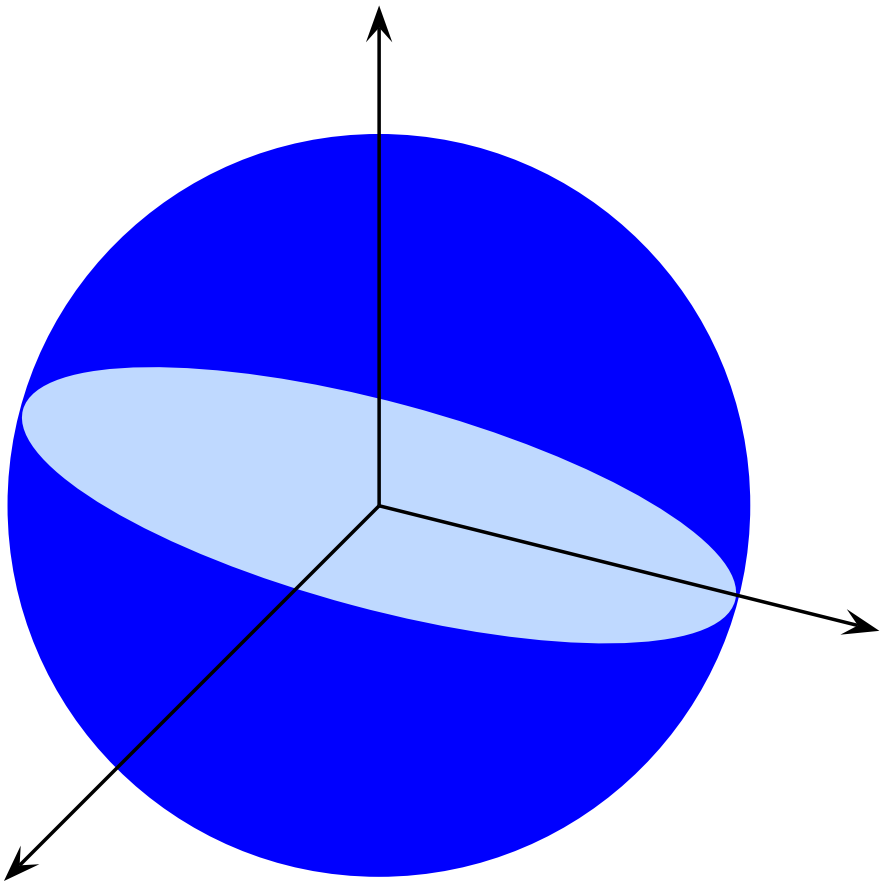

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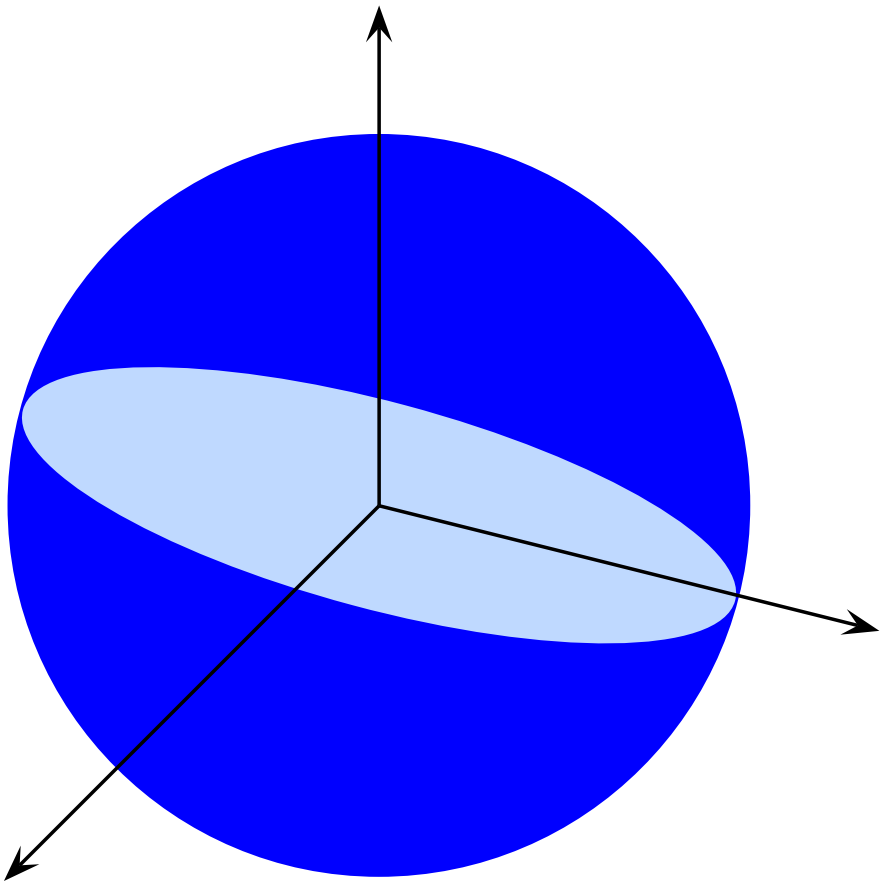

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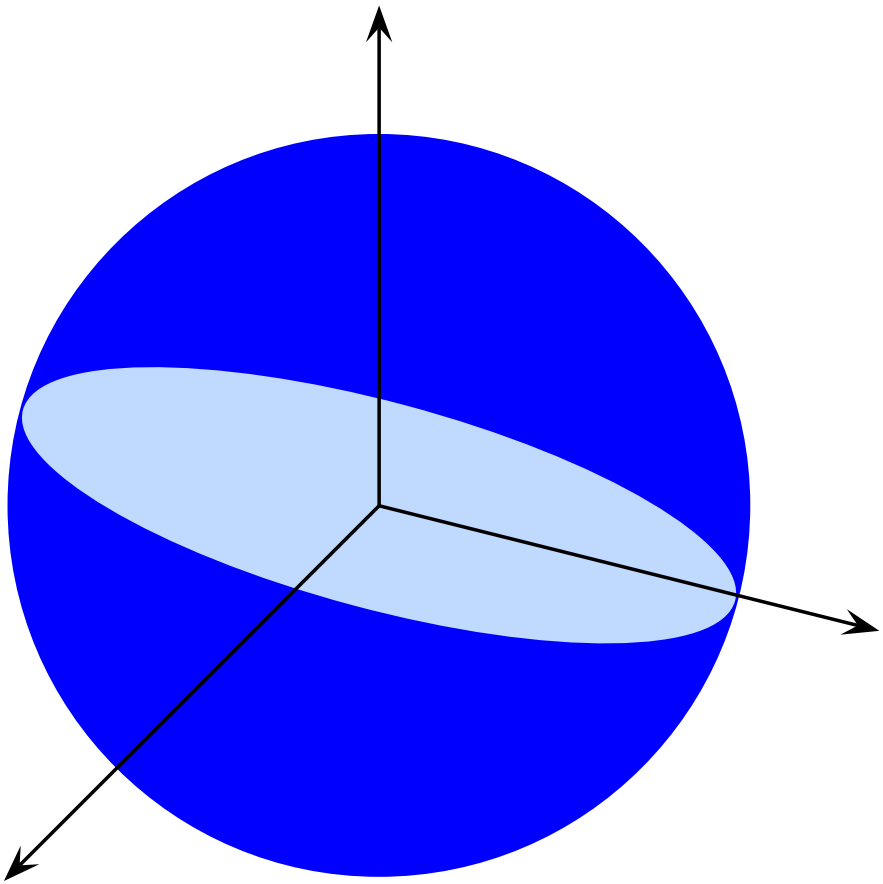

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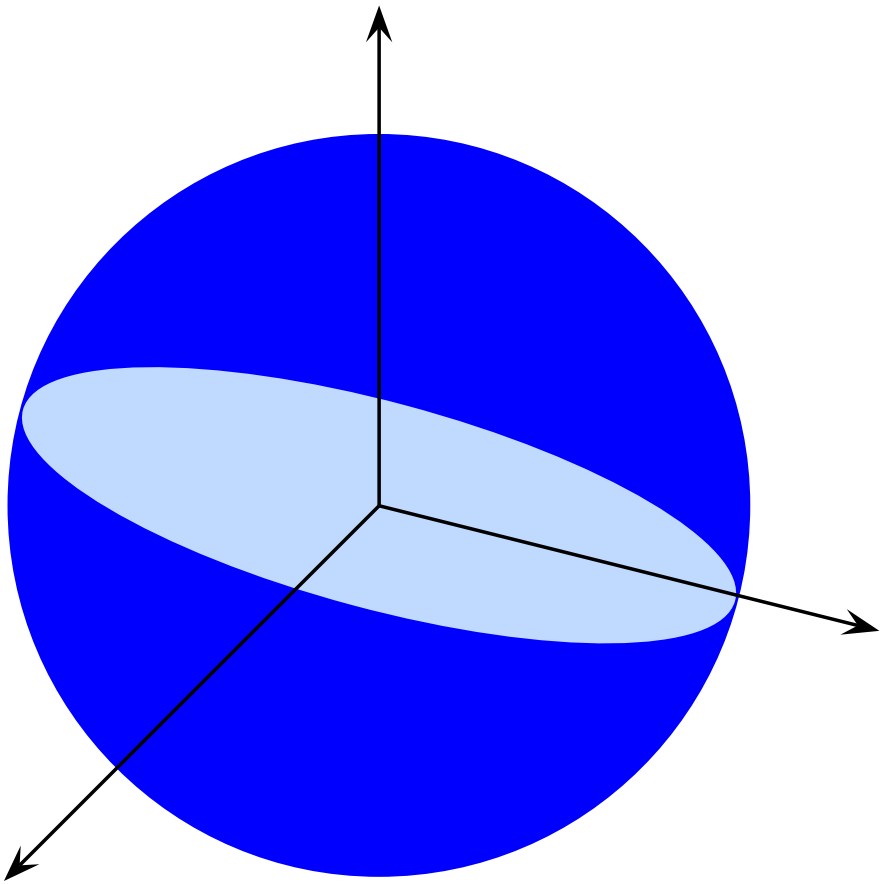

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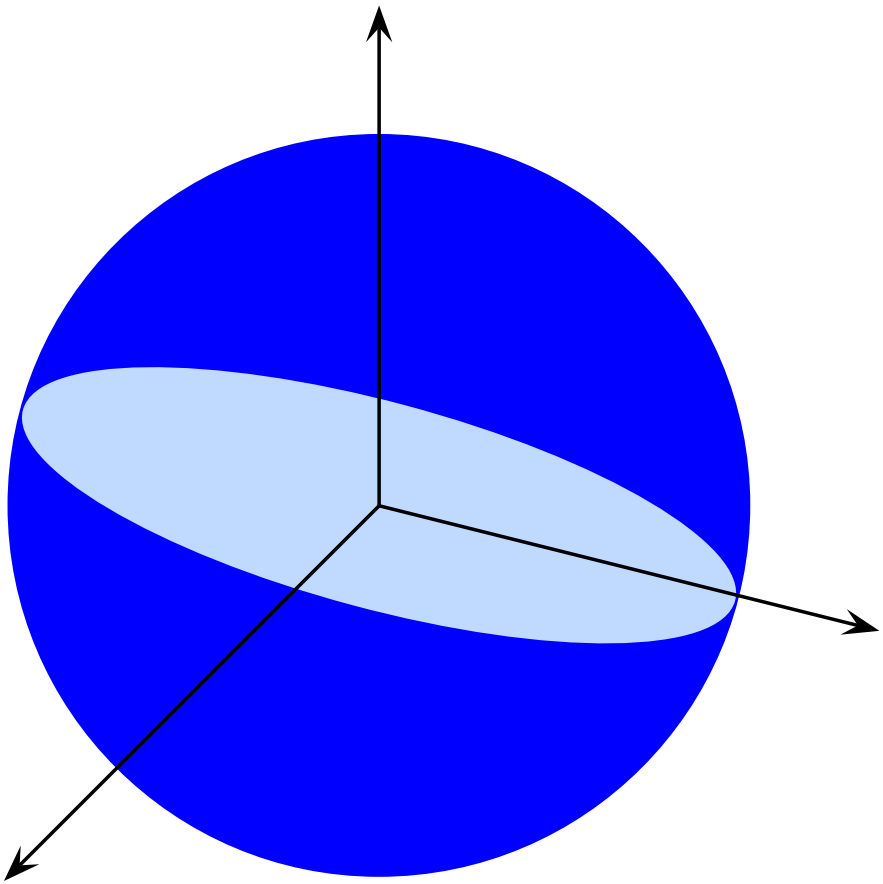

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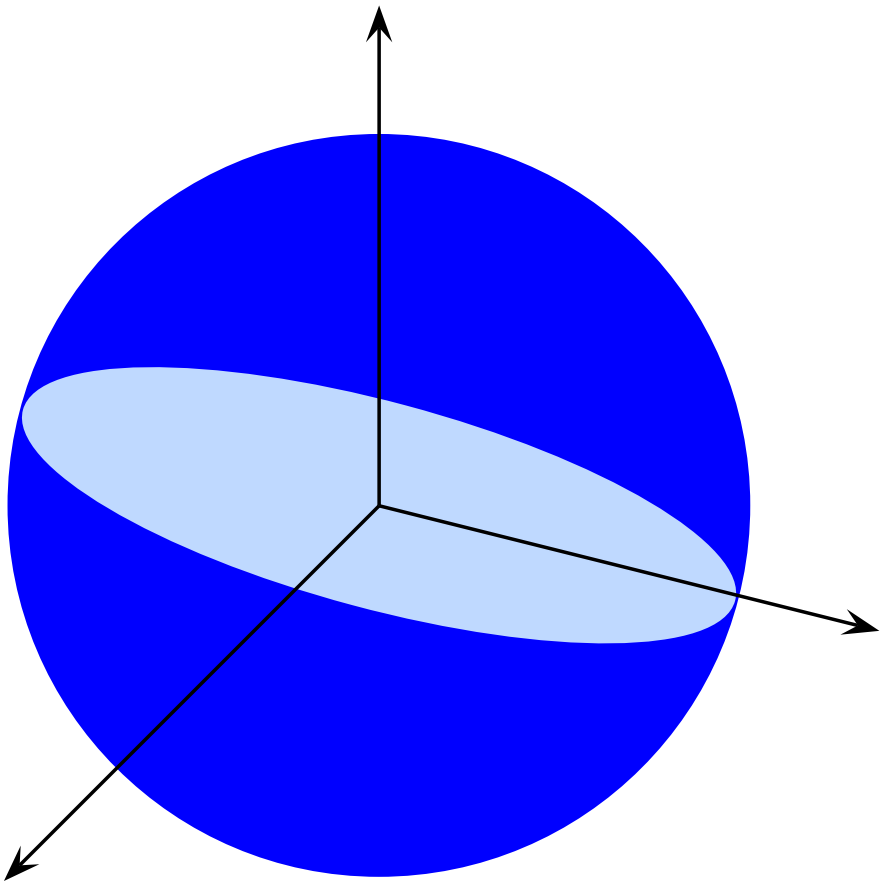

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It's important to know what we know and what we don't and be comfortable with it

The Spirit of Inquiry (2)

- Is asking questions disrepectful?
- Is independent thinking disrepectful?
- Does repsect require obedience of thoughts?

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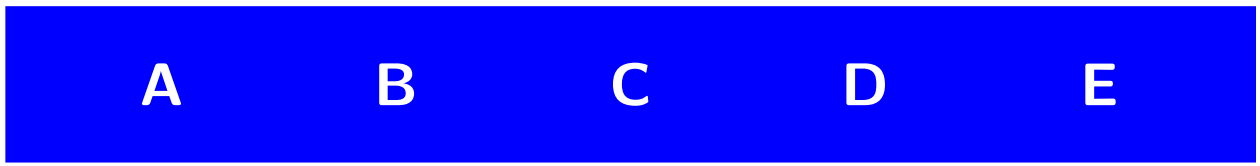
We end up mixing criticism of an idea with criticism of the person 

Breadth Vs. Depth



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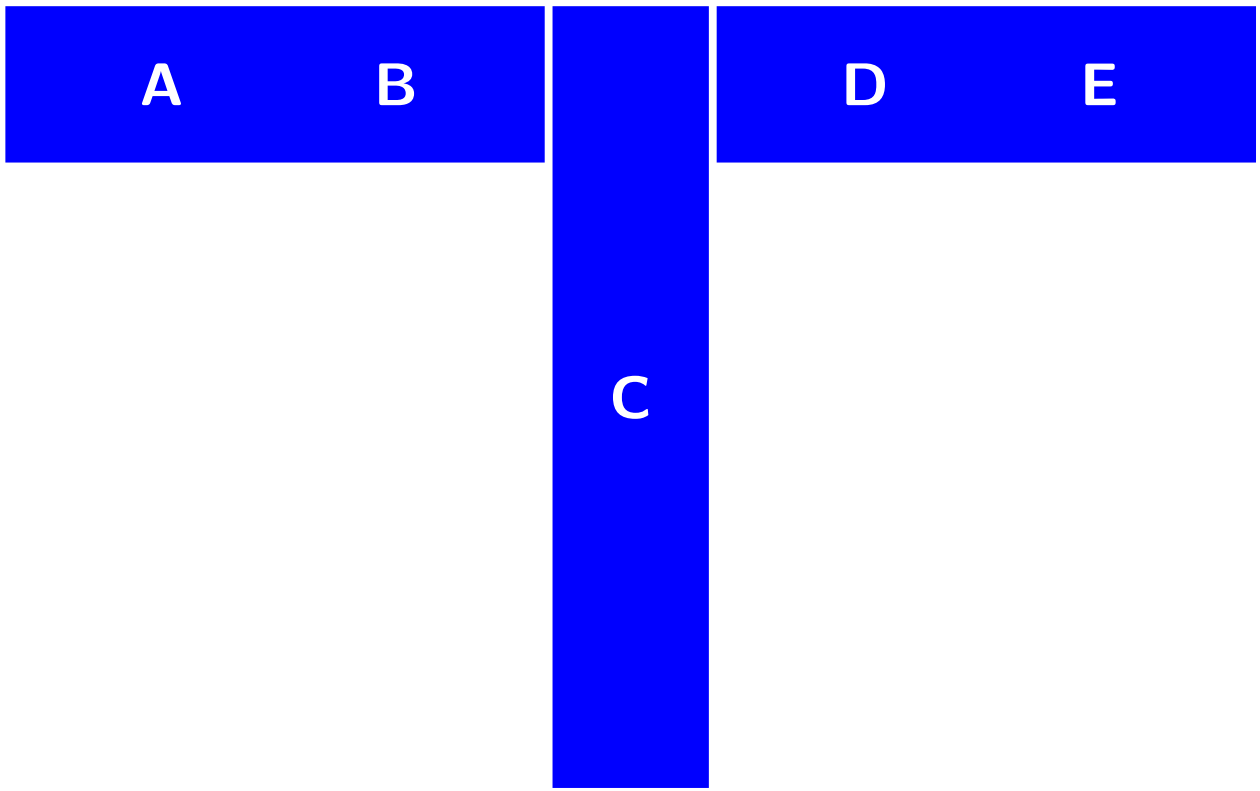

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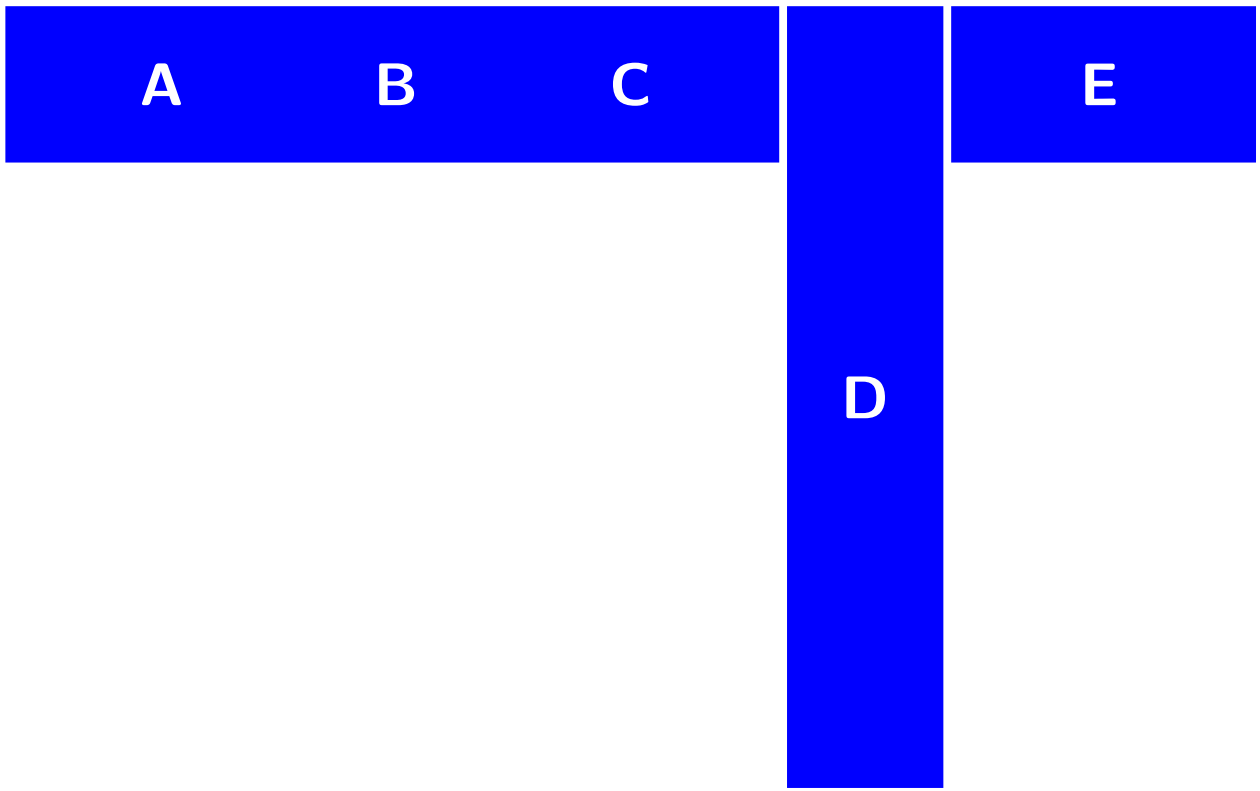

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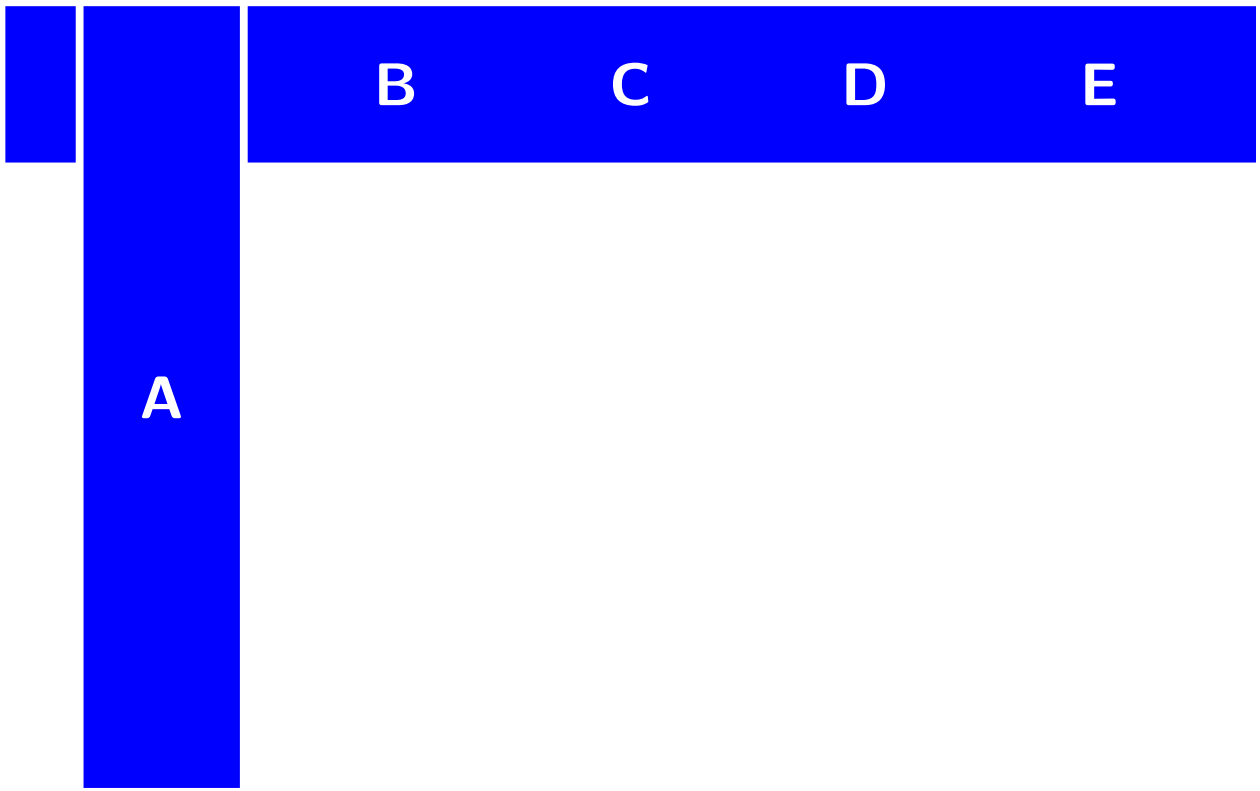

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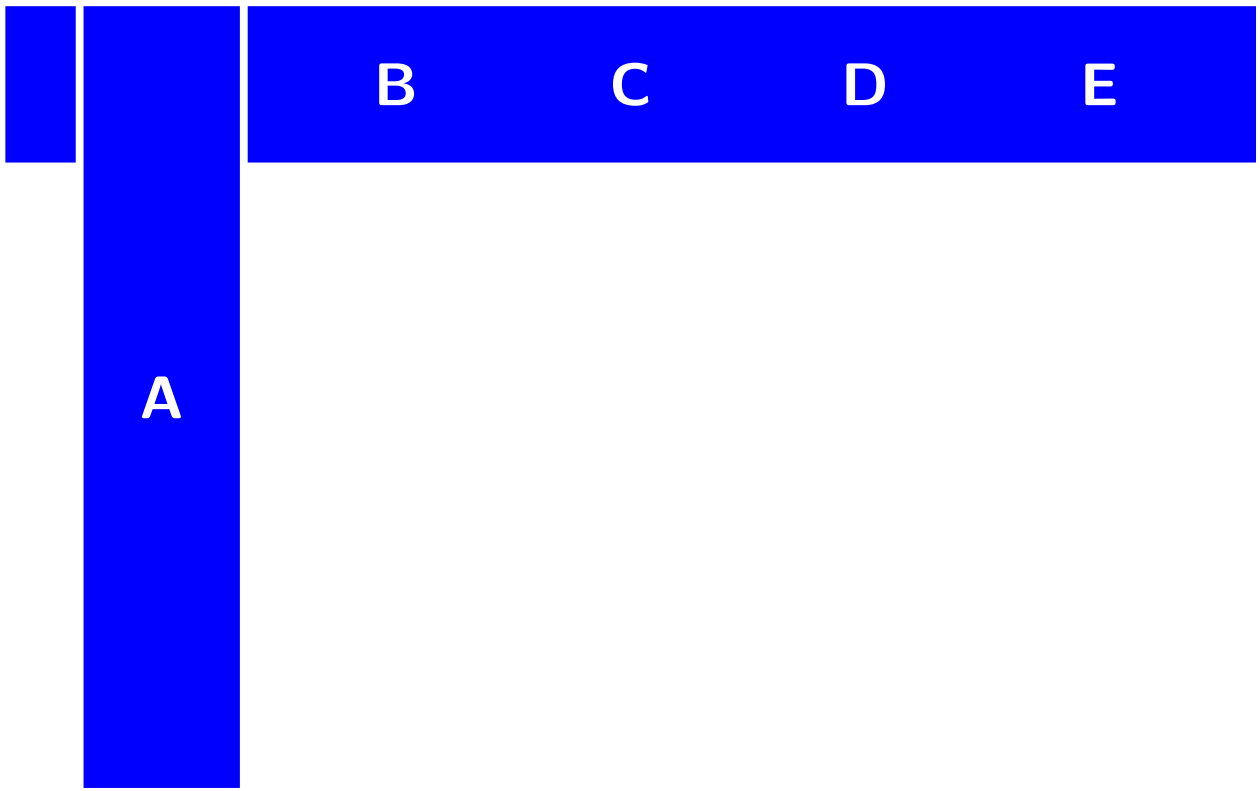
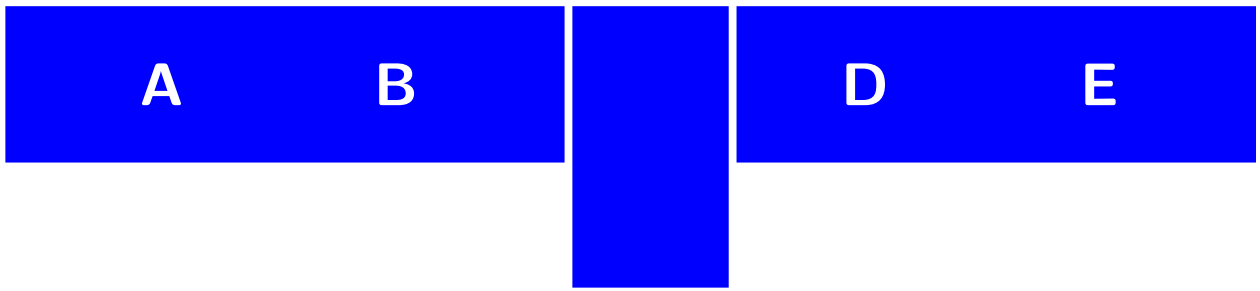


Breadth or Depth?

Breadth Vs. Depth

Achieve depth in one area and overall breadth

Breadth Vs. Depth



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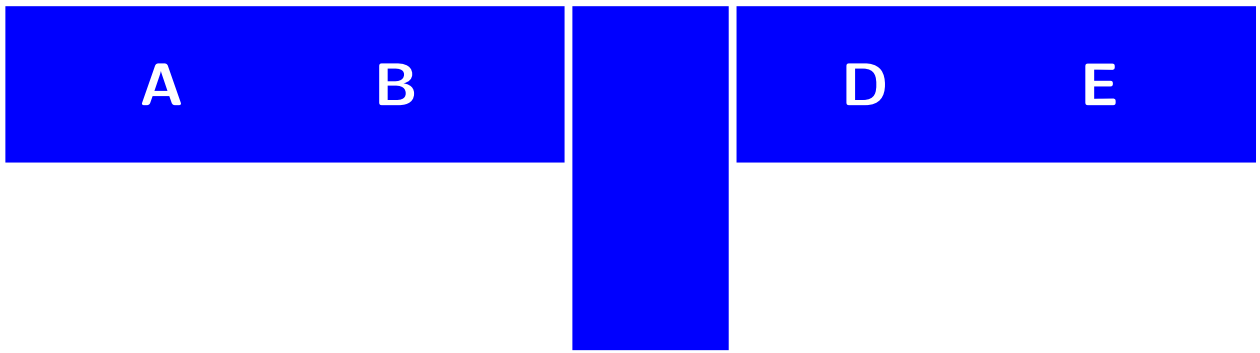

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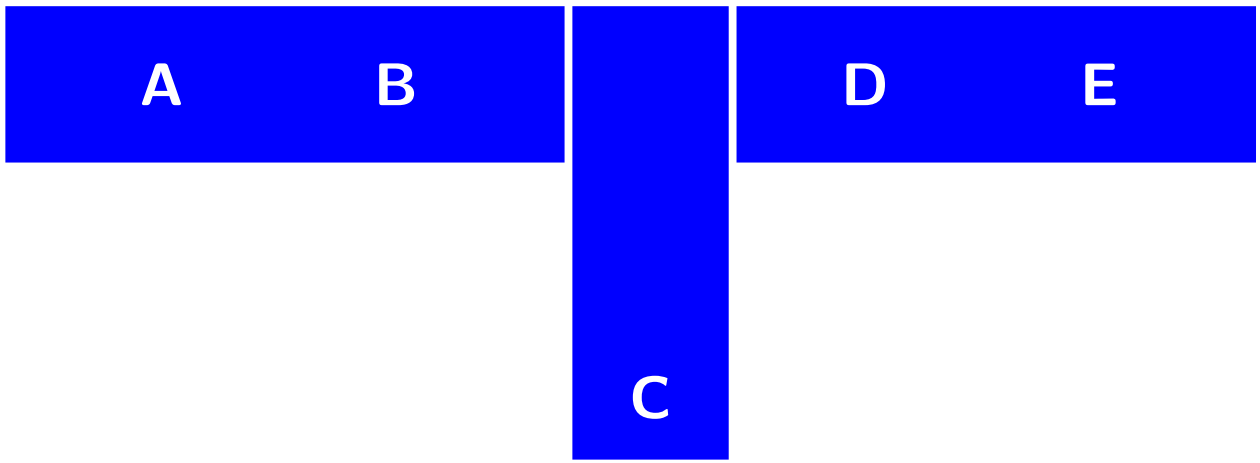

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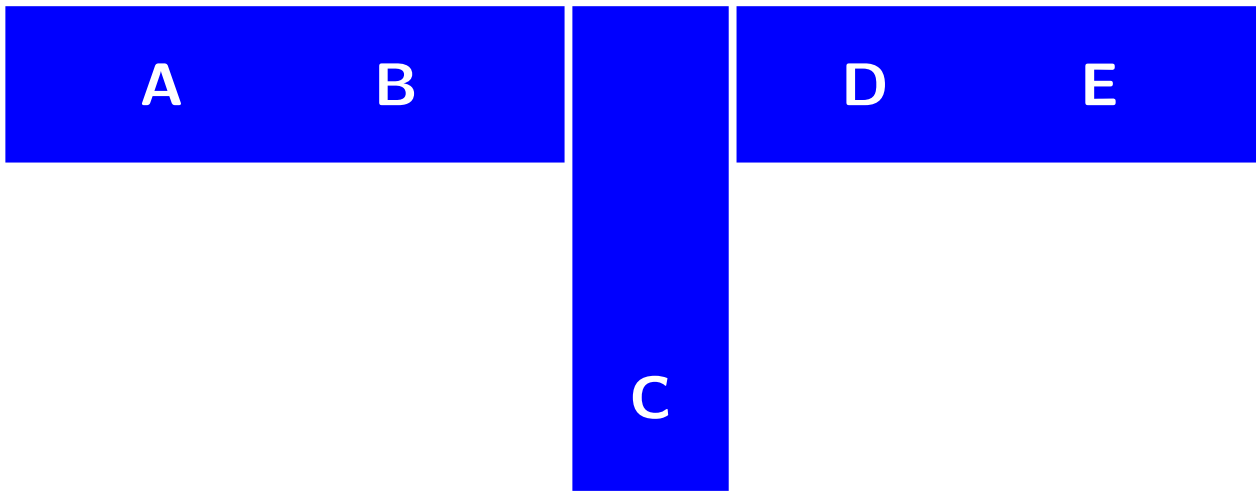

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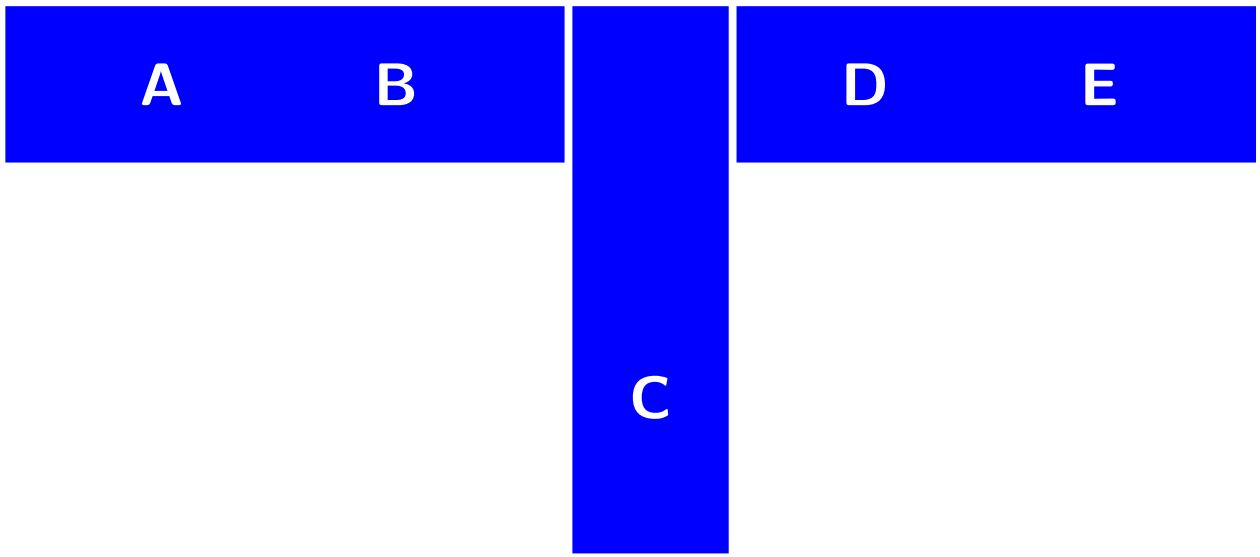

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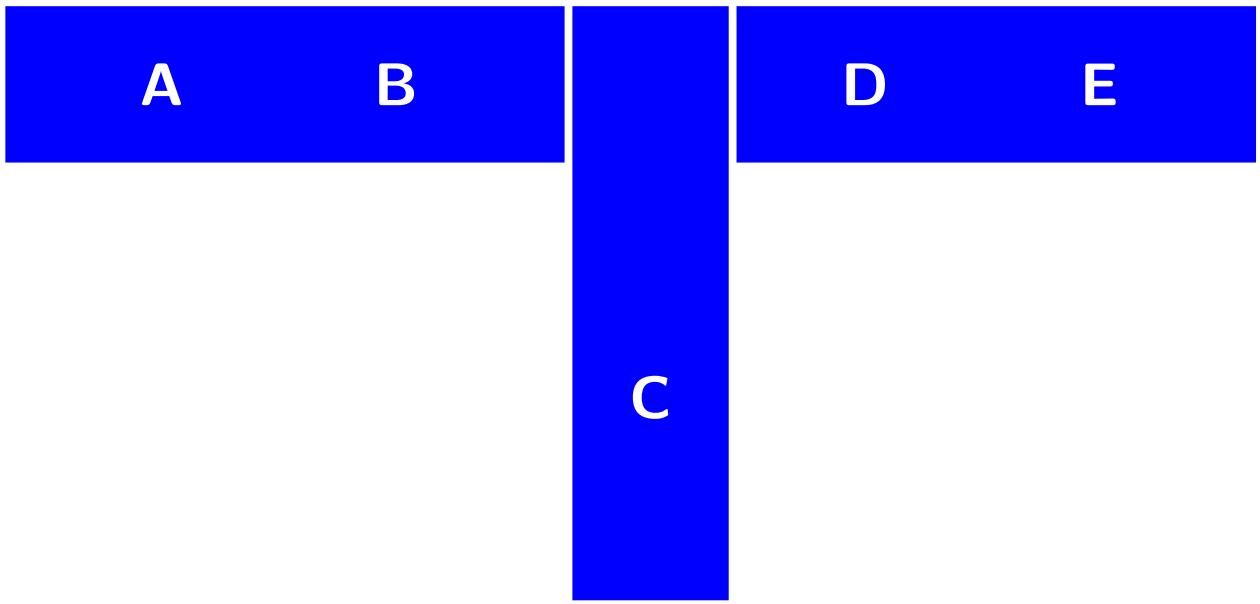

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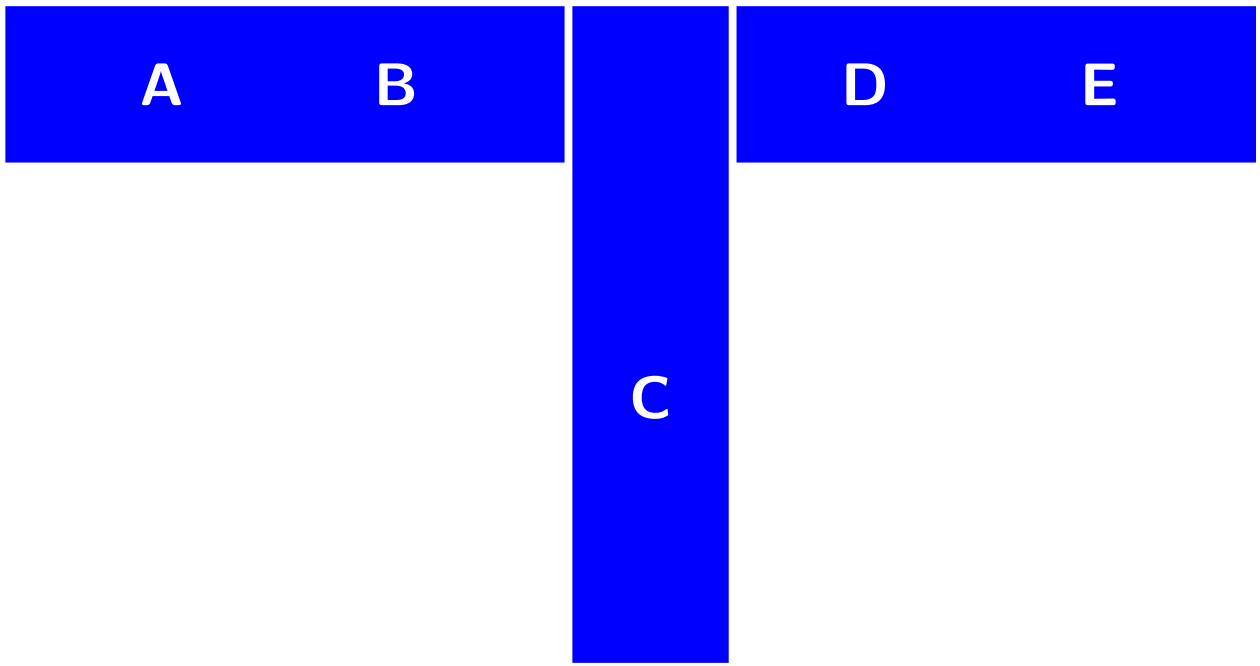

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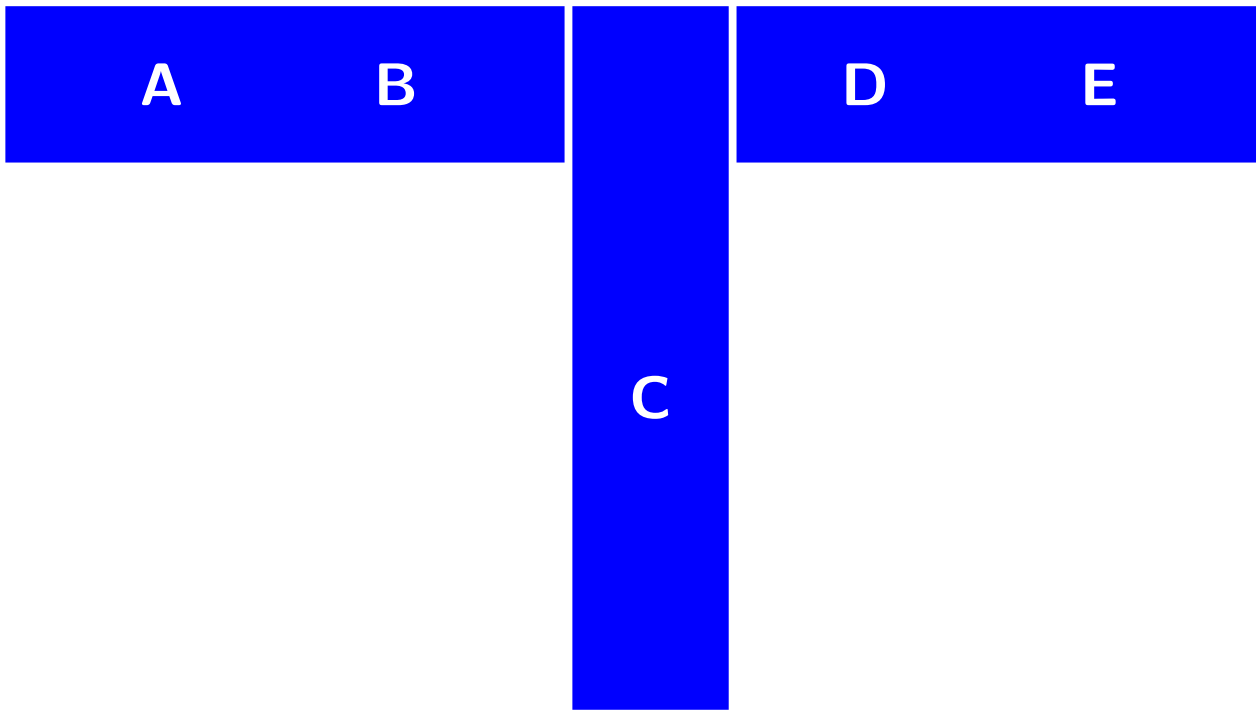

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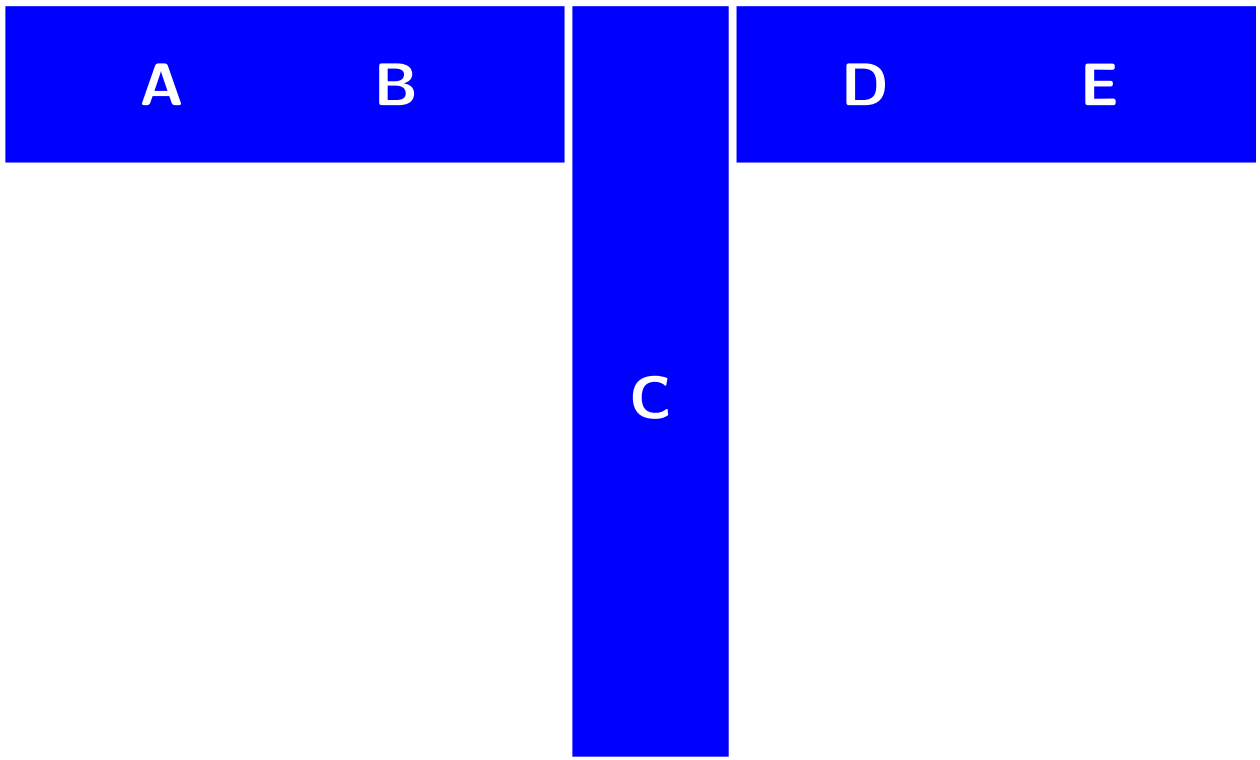

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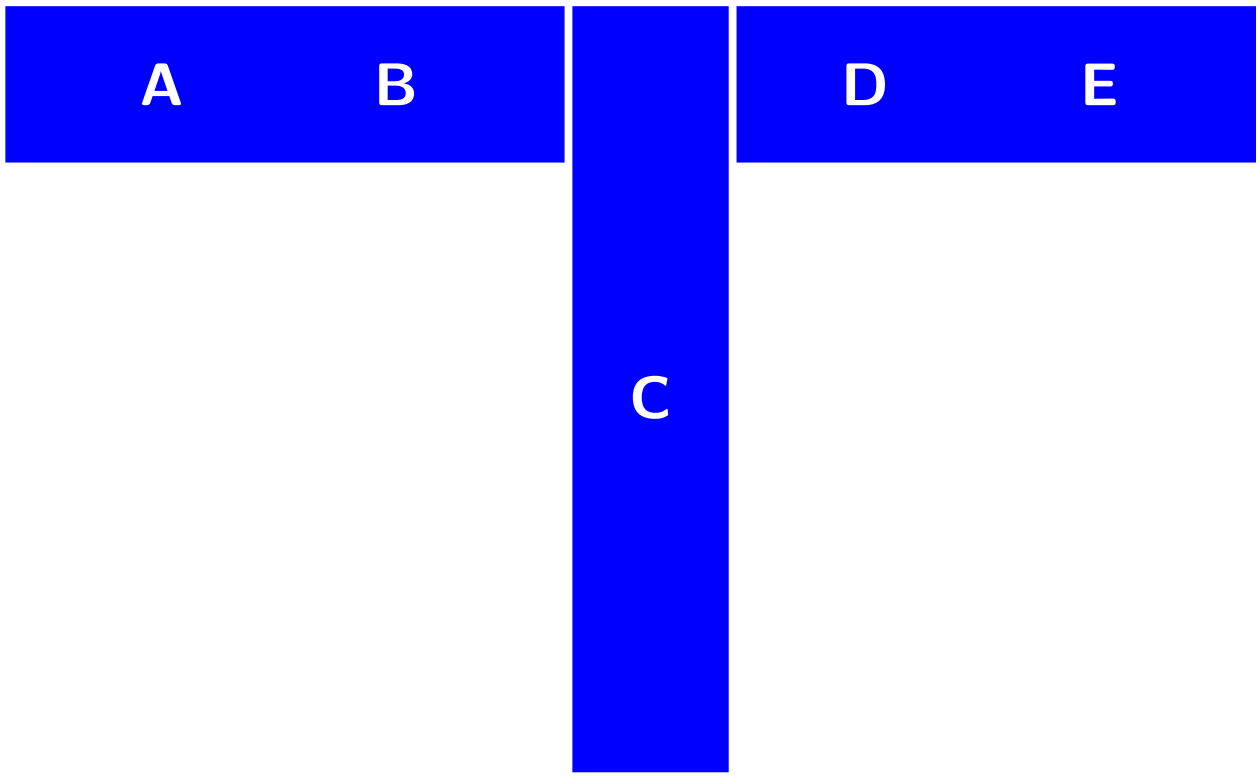

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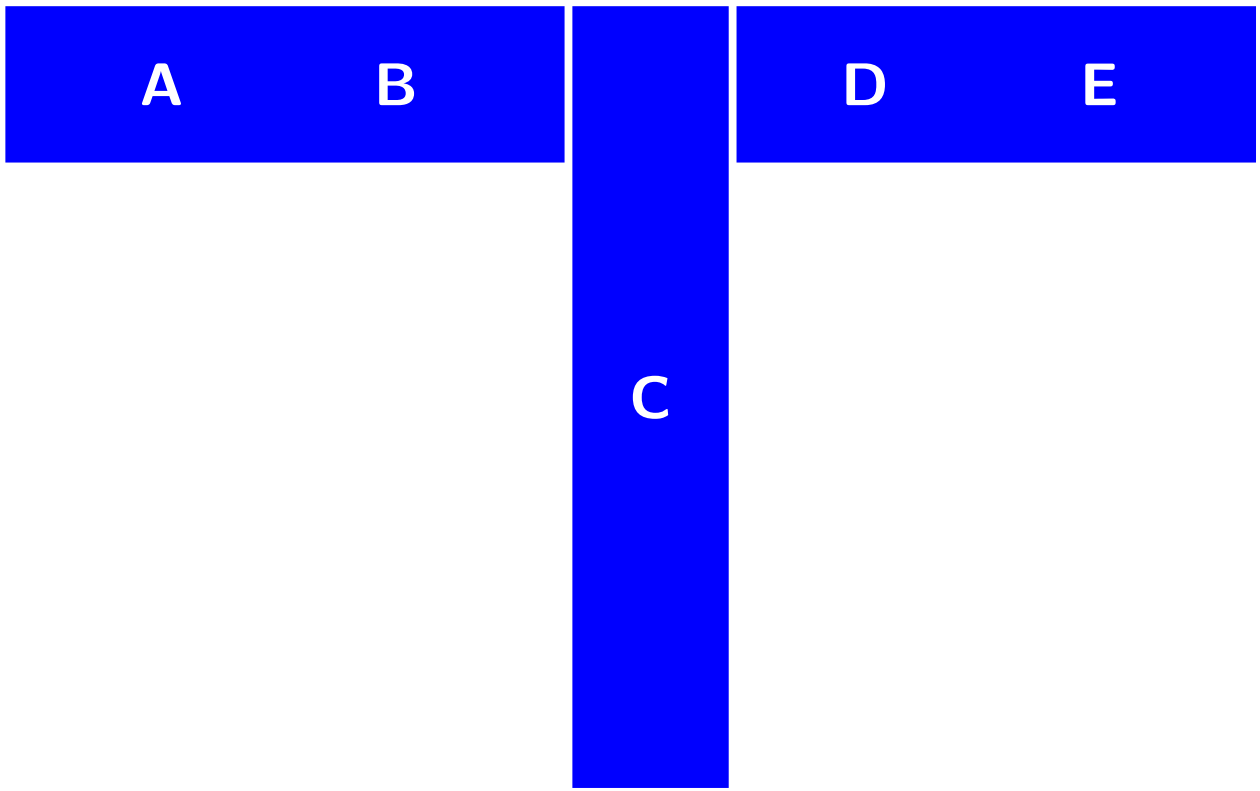

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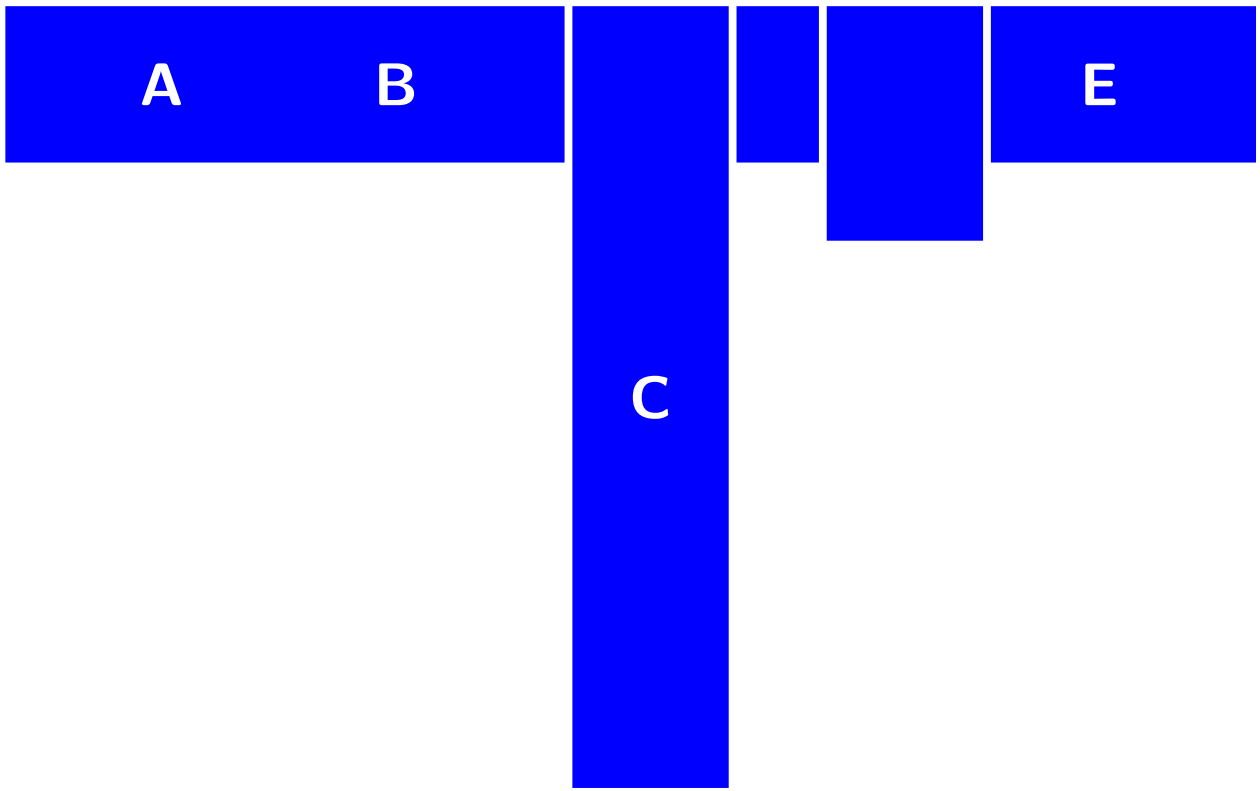

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Other areas can be understood on need basis relatively quickly

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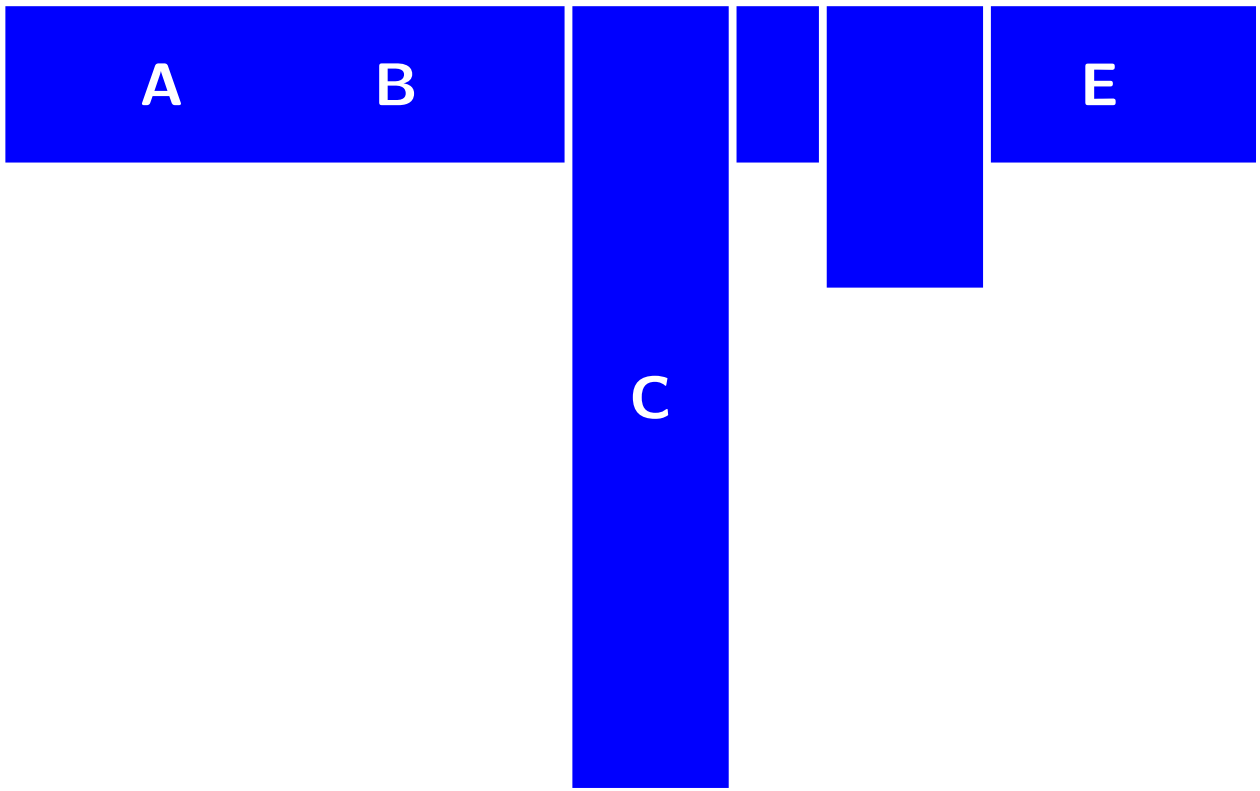

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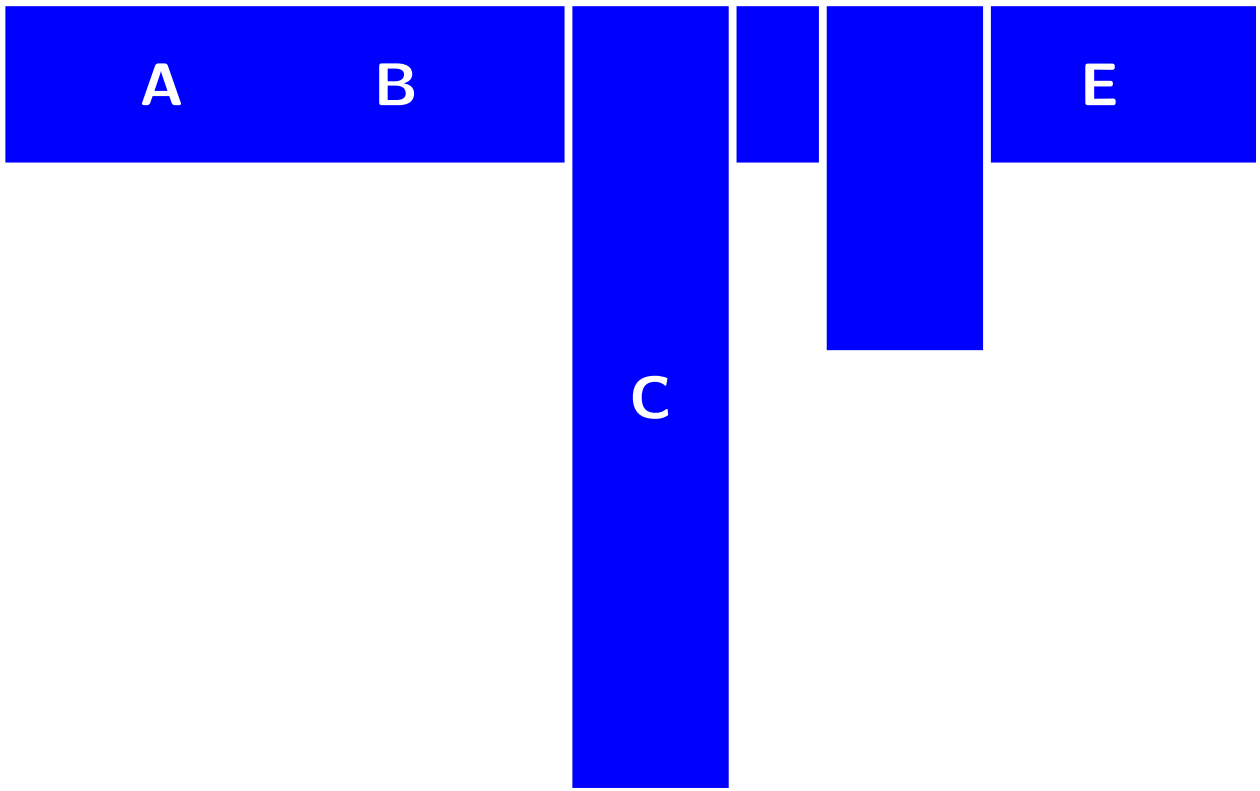

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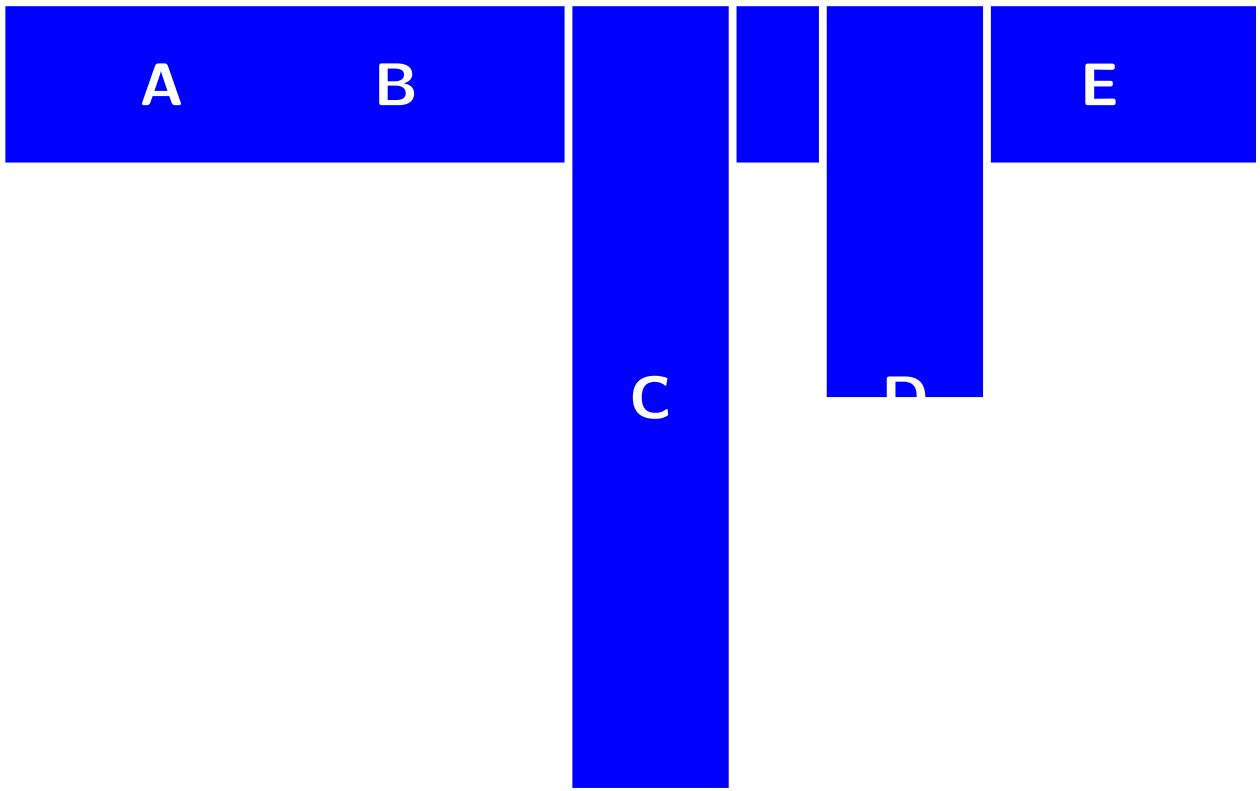

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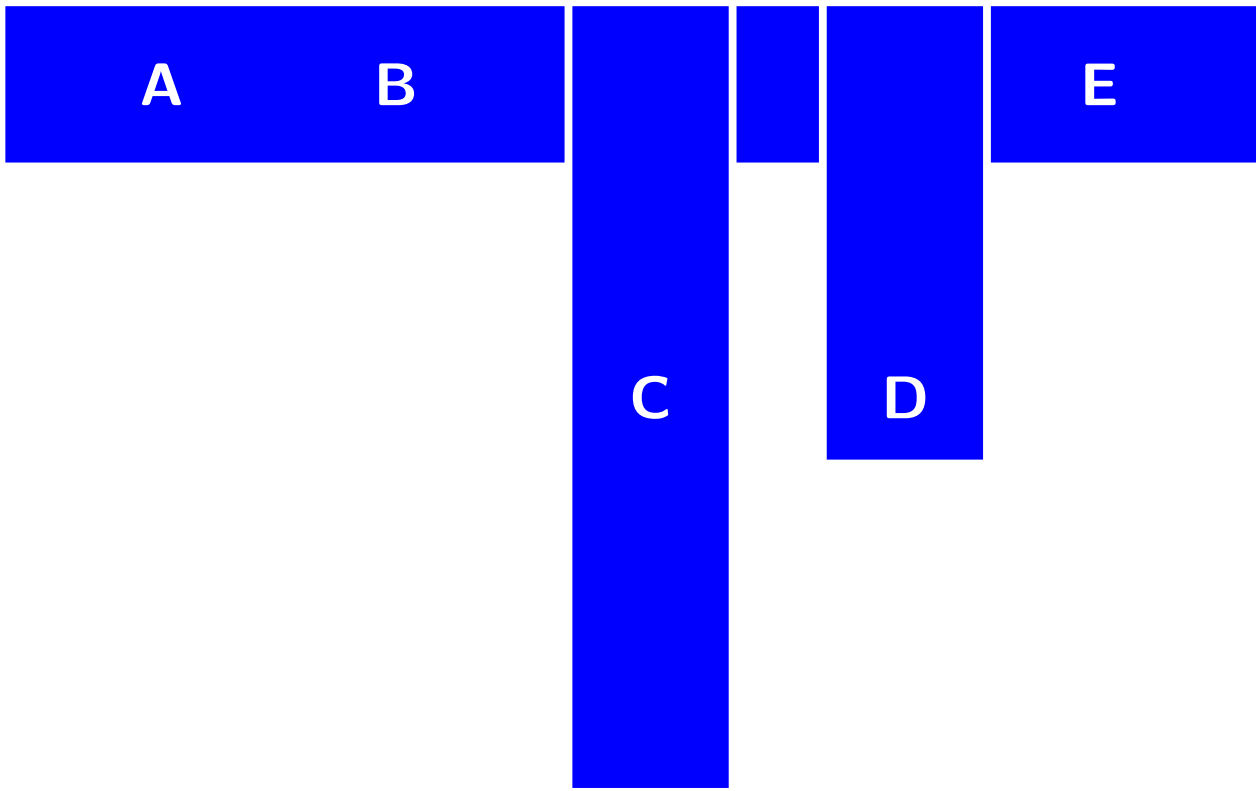

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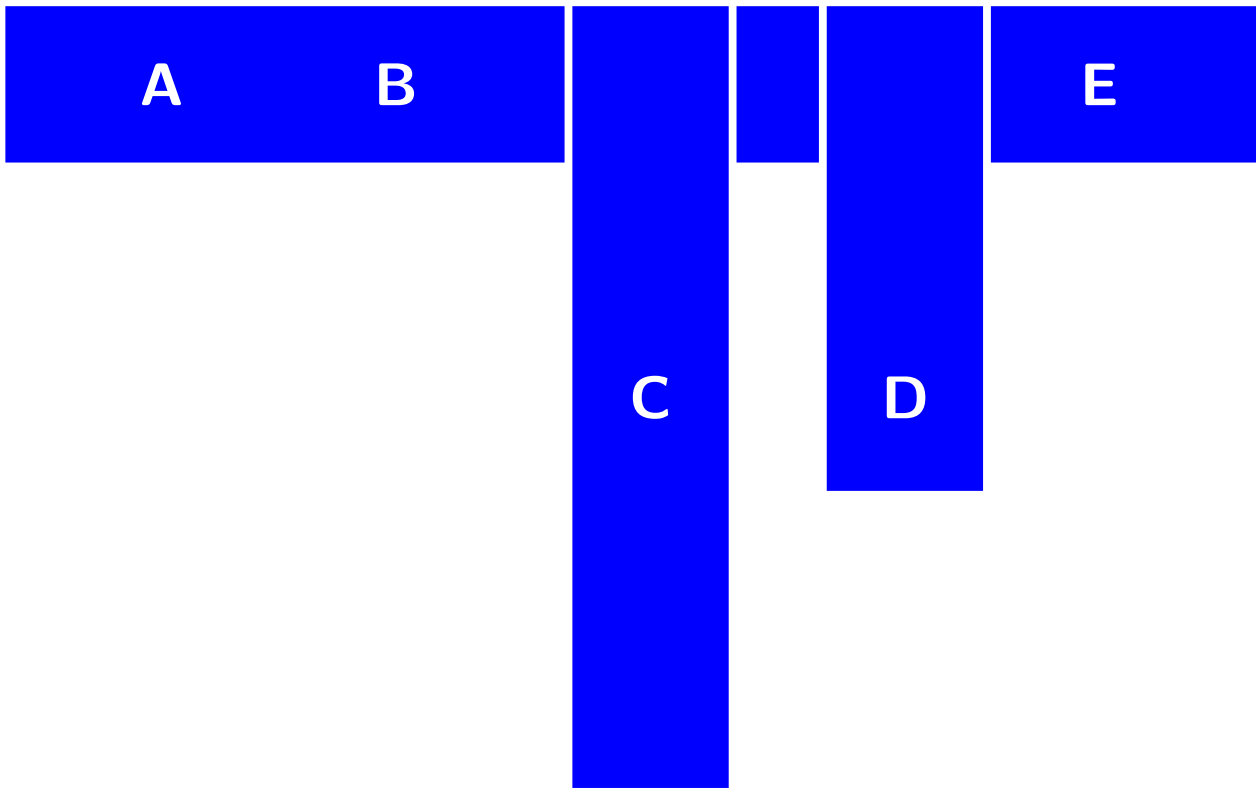

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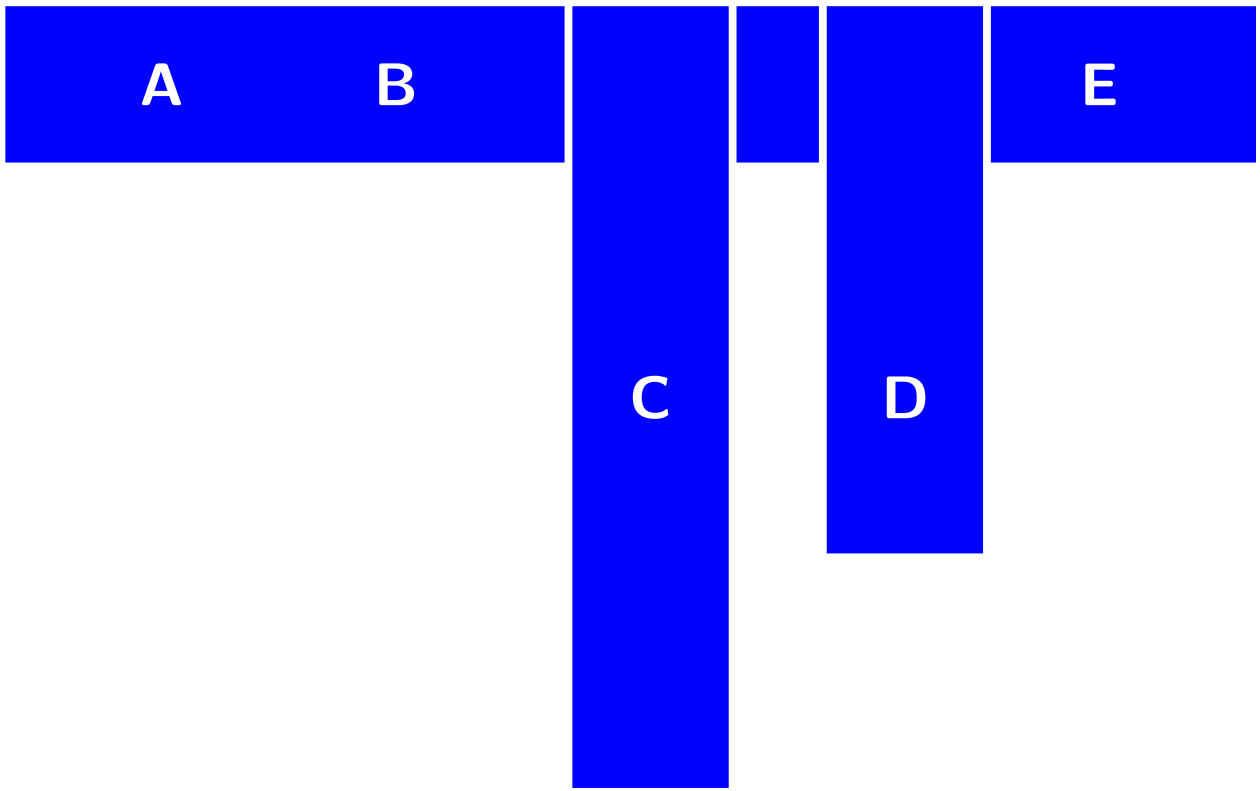

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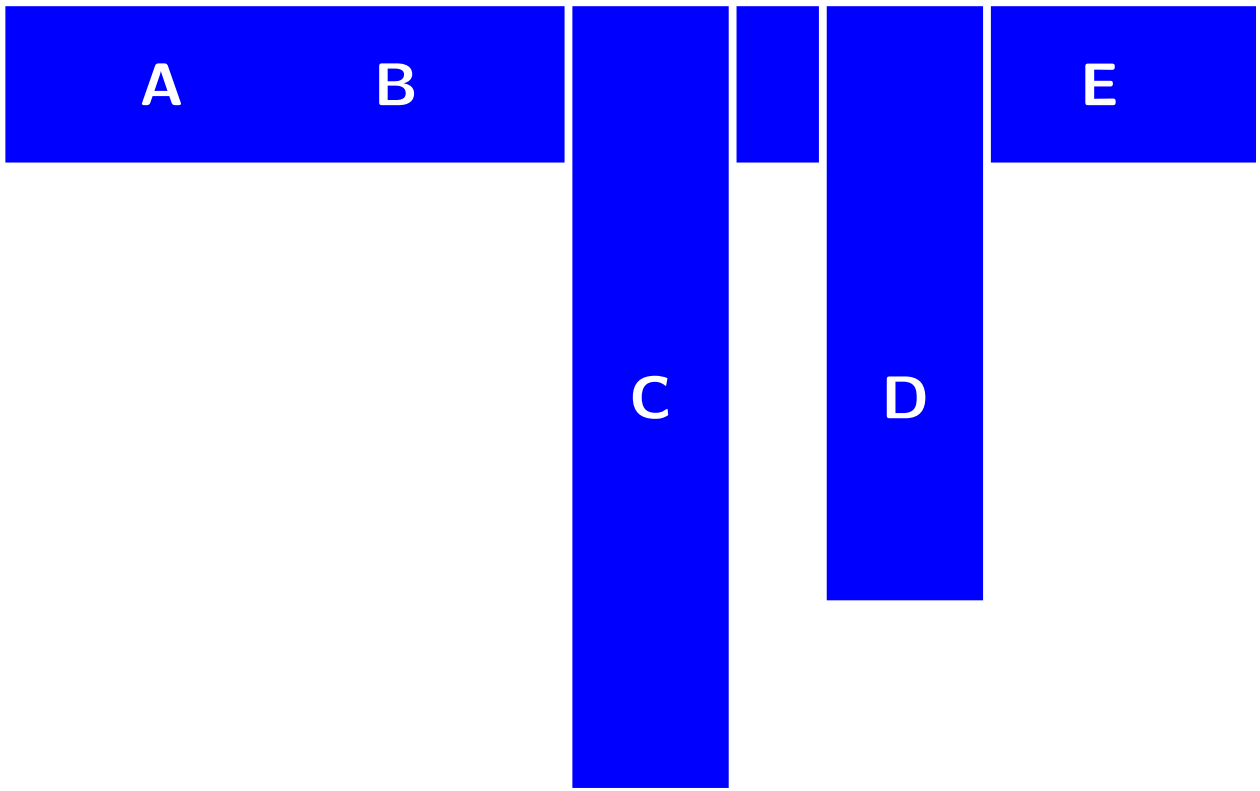

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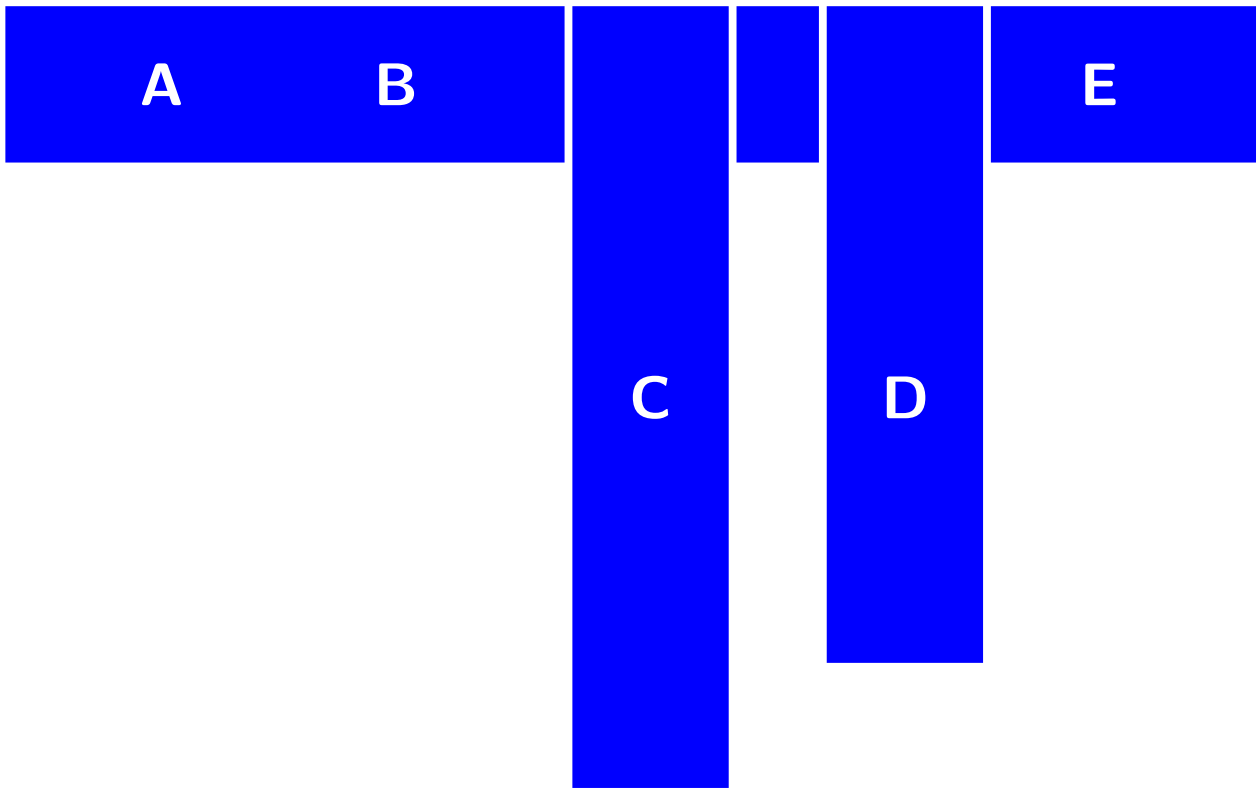

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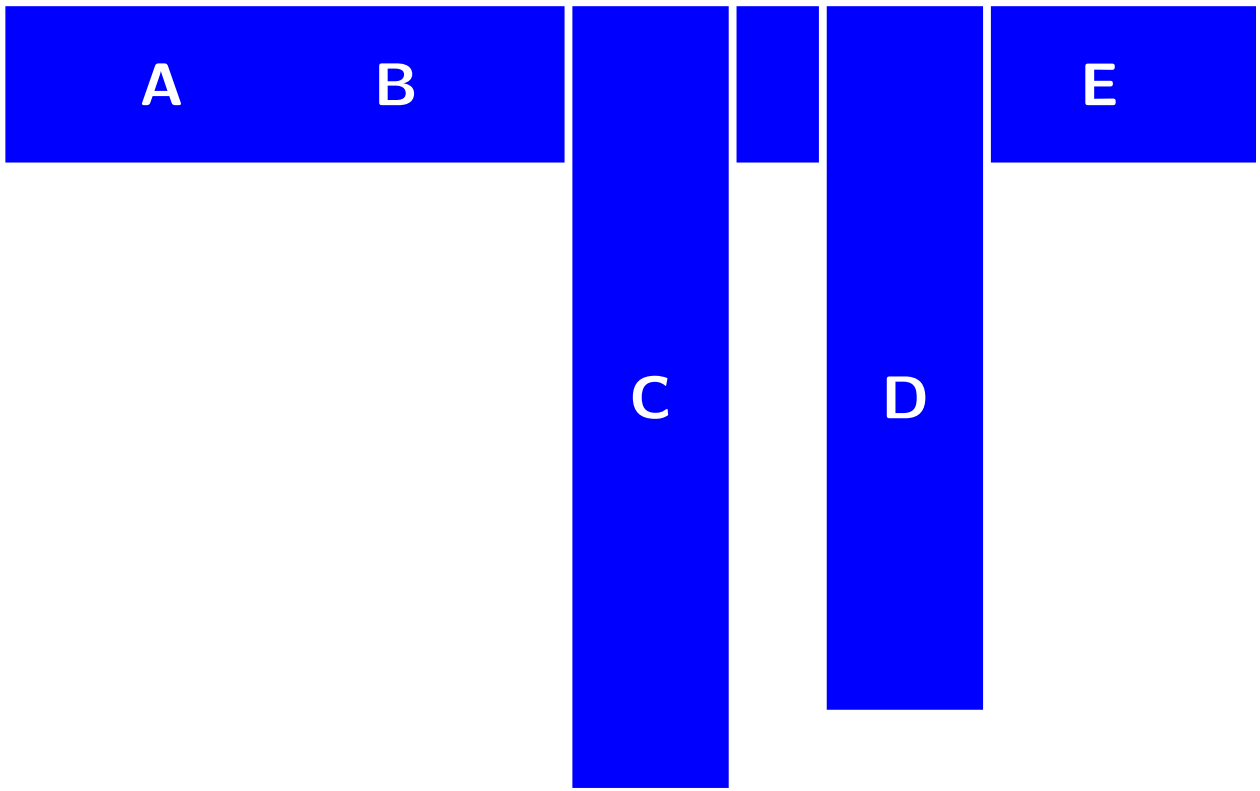

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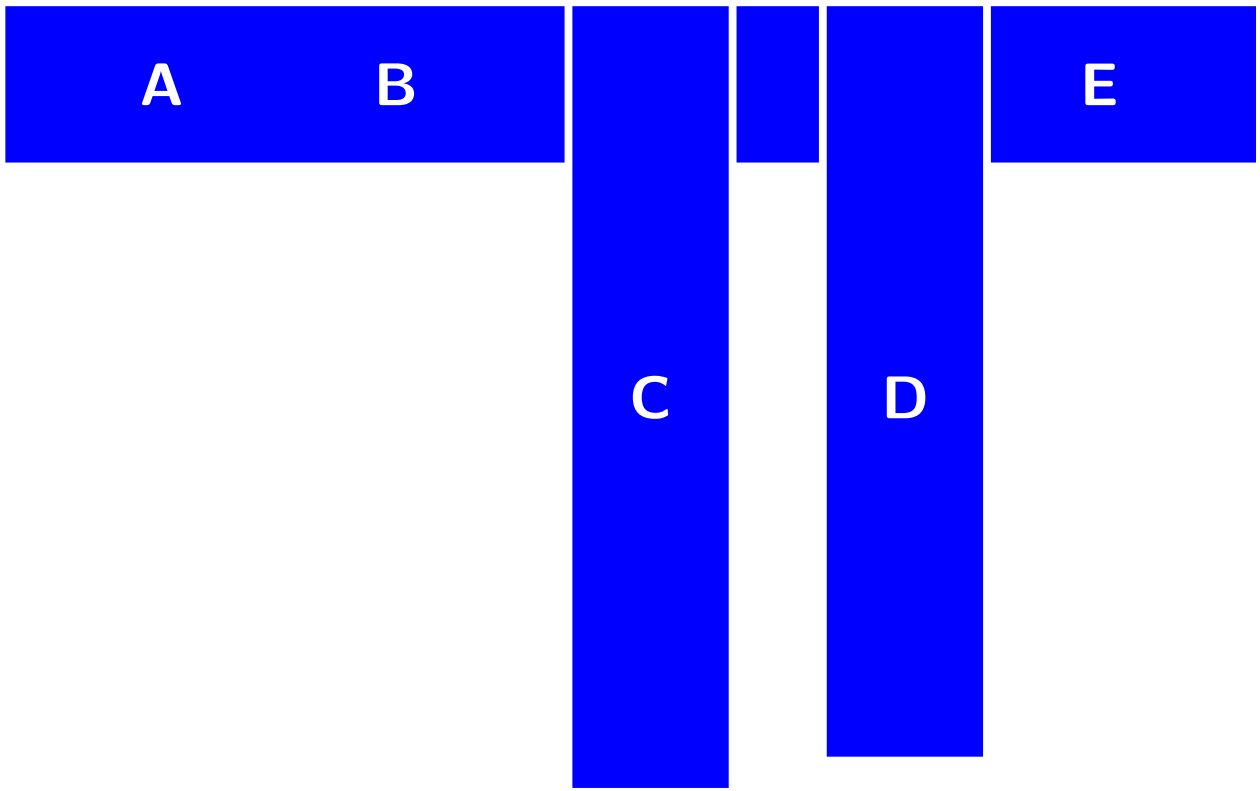

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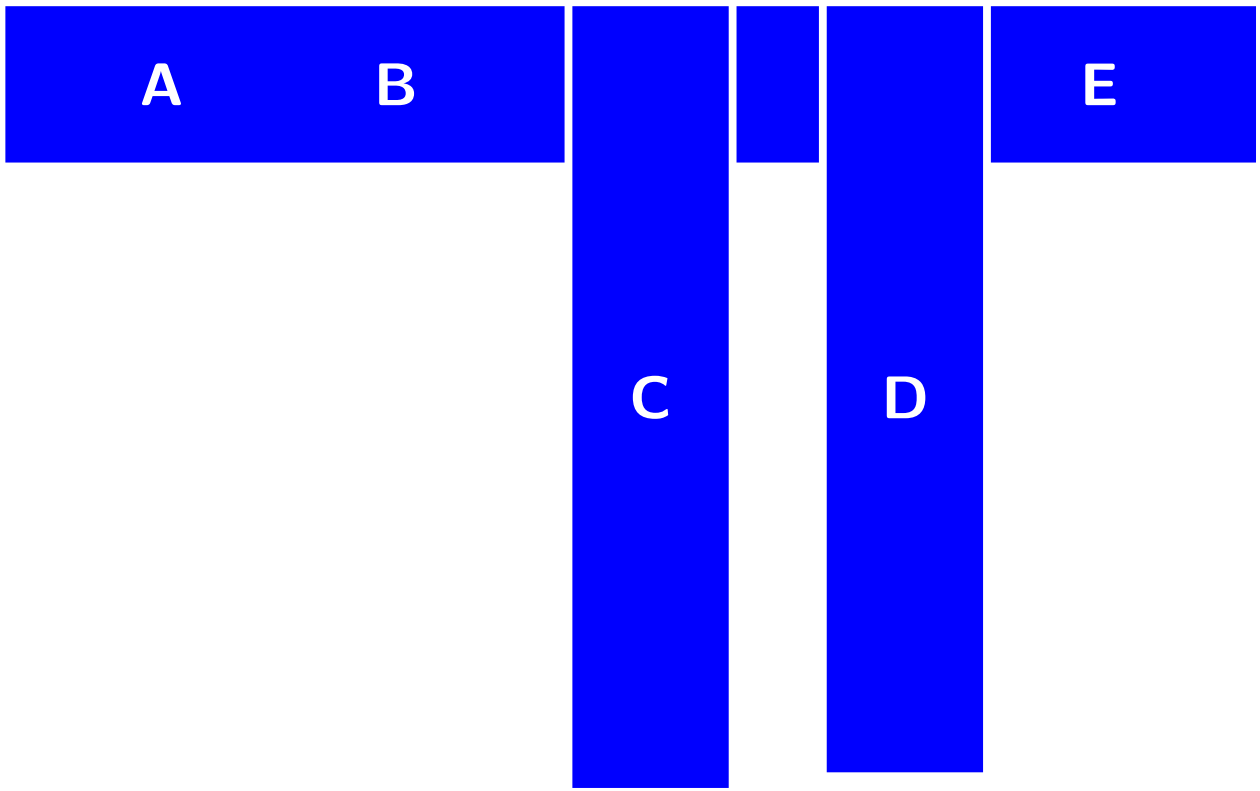

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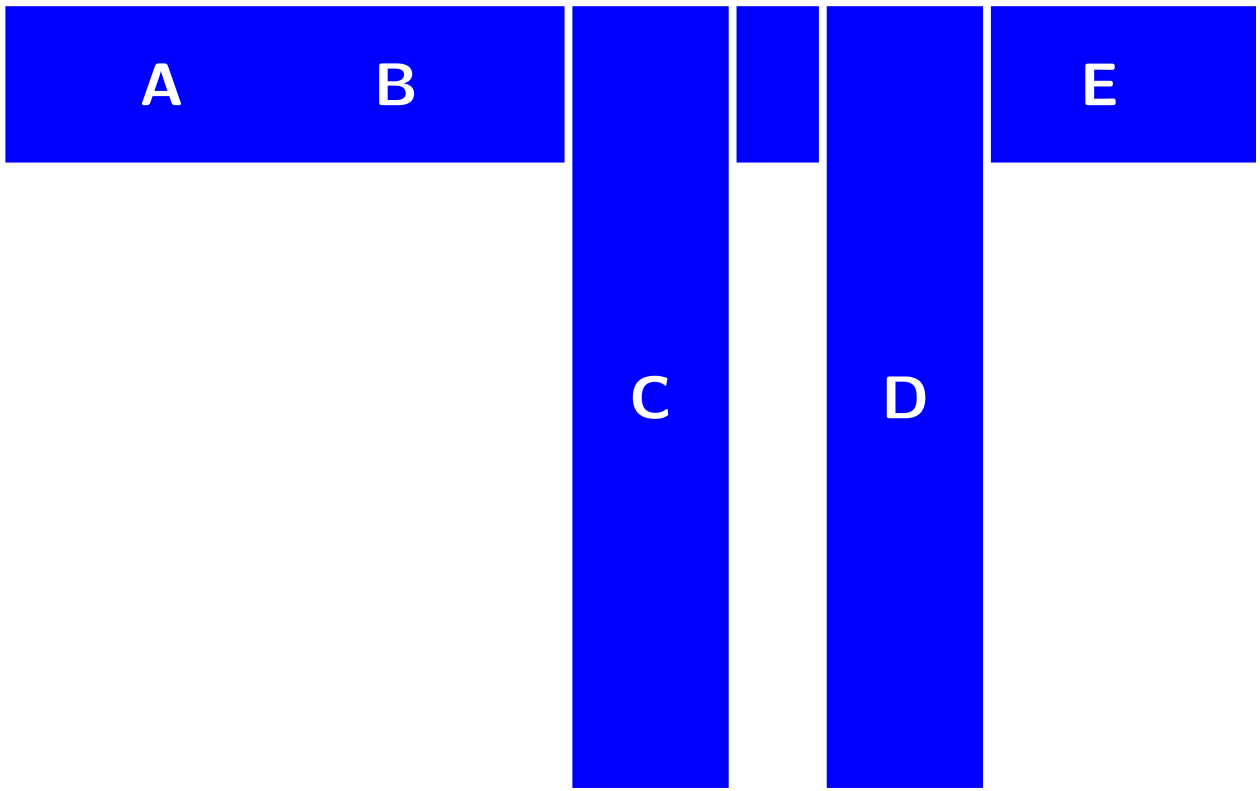

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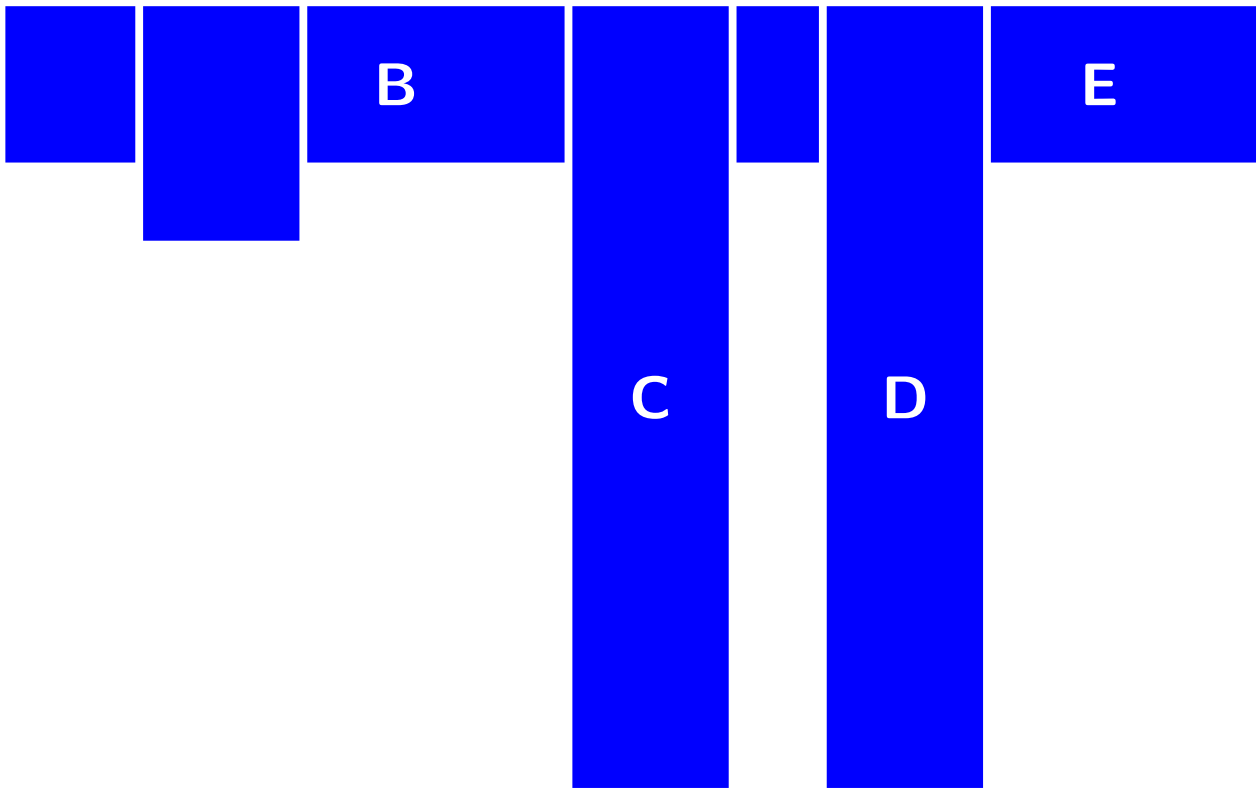

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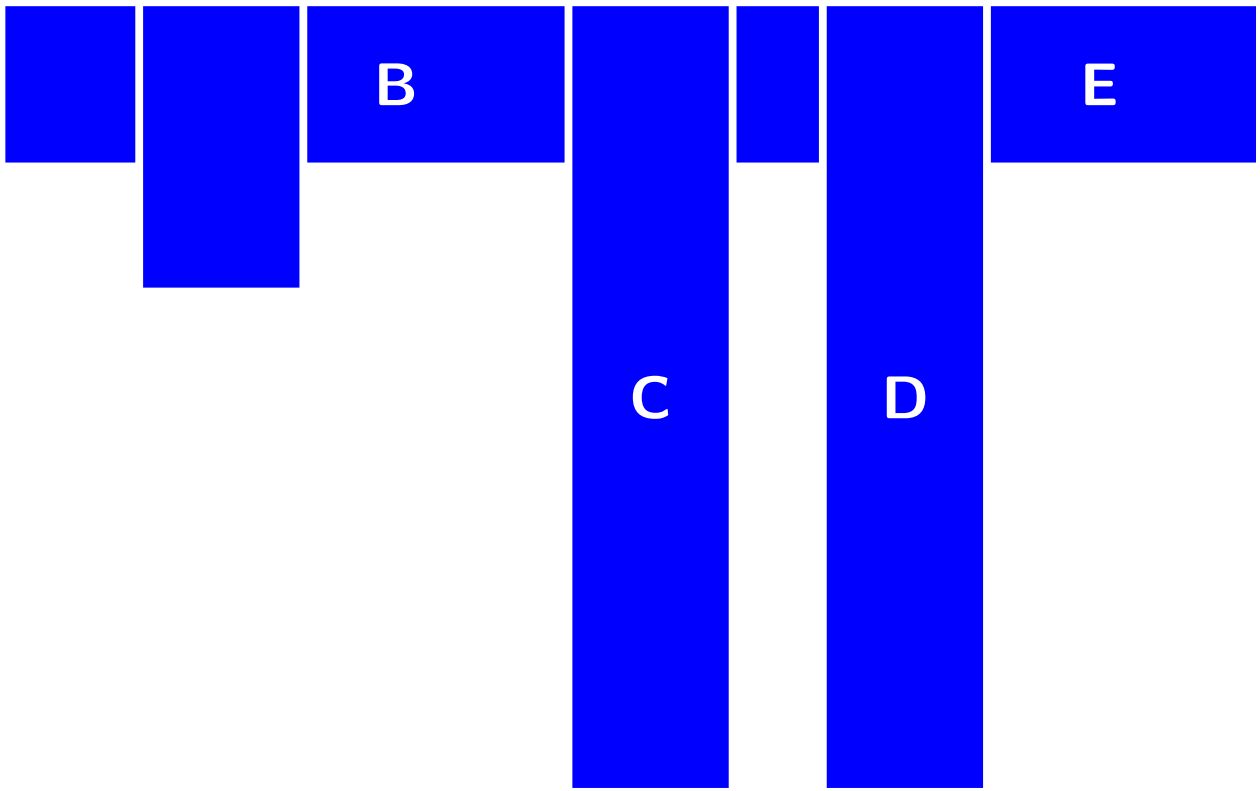

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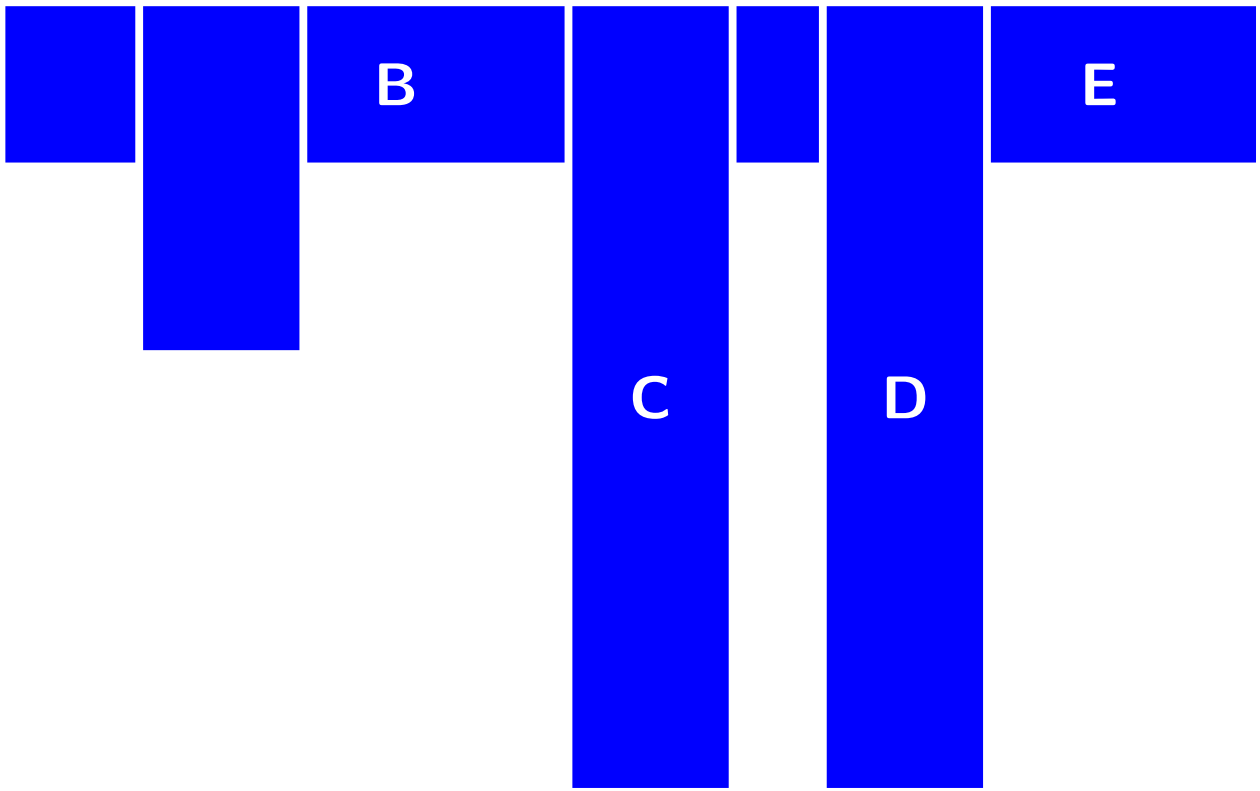

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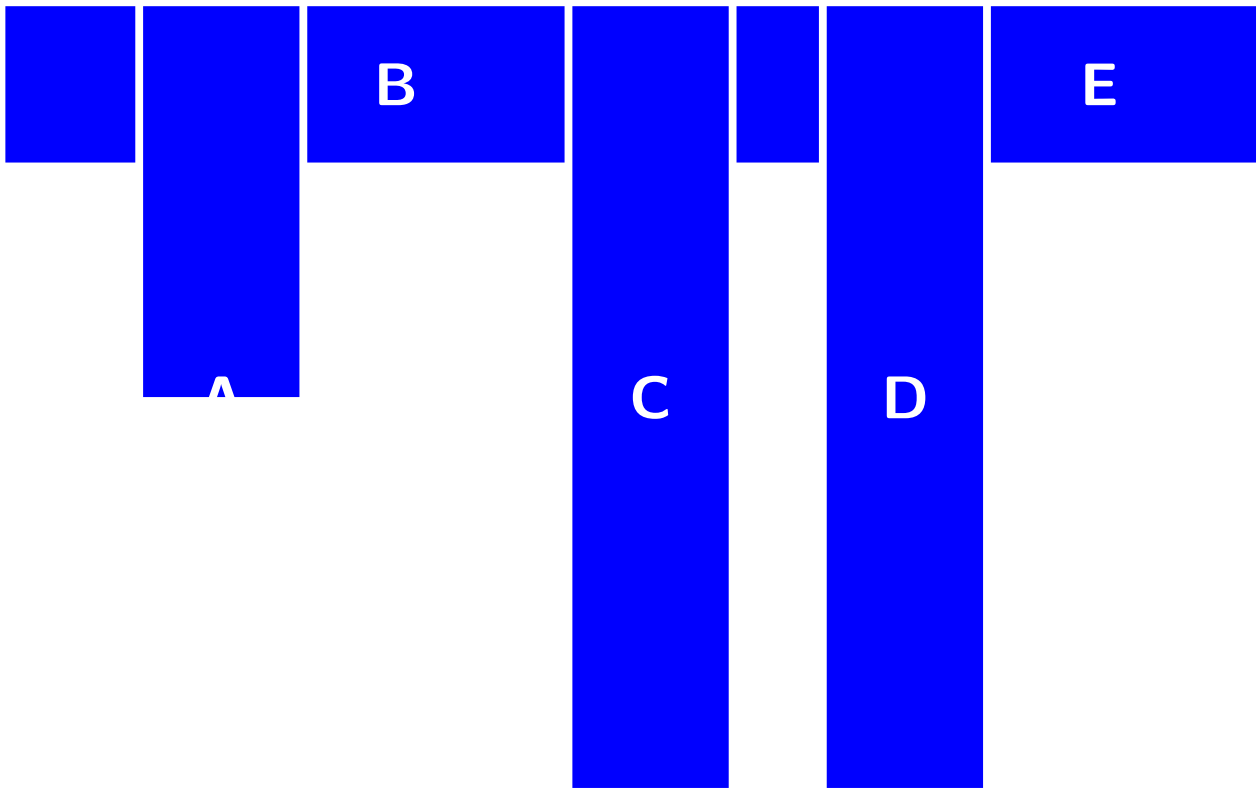

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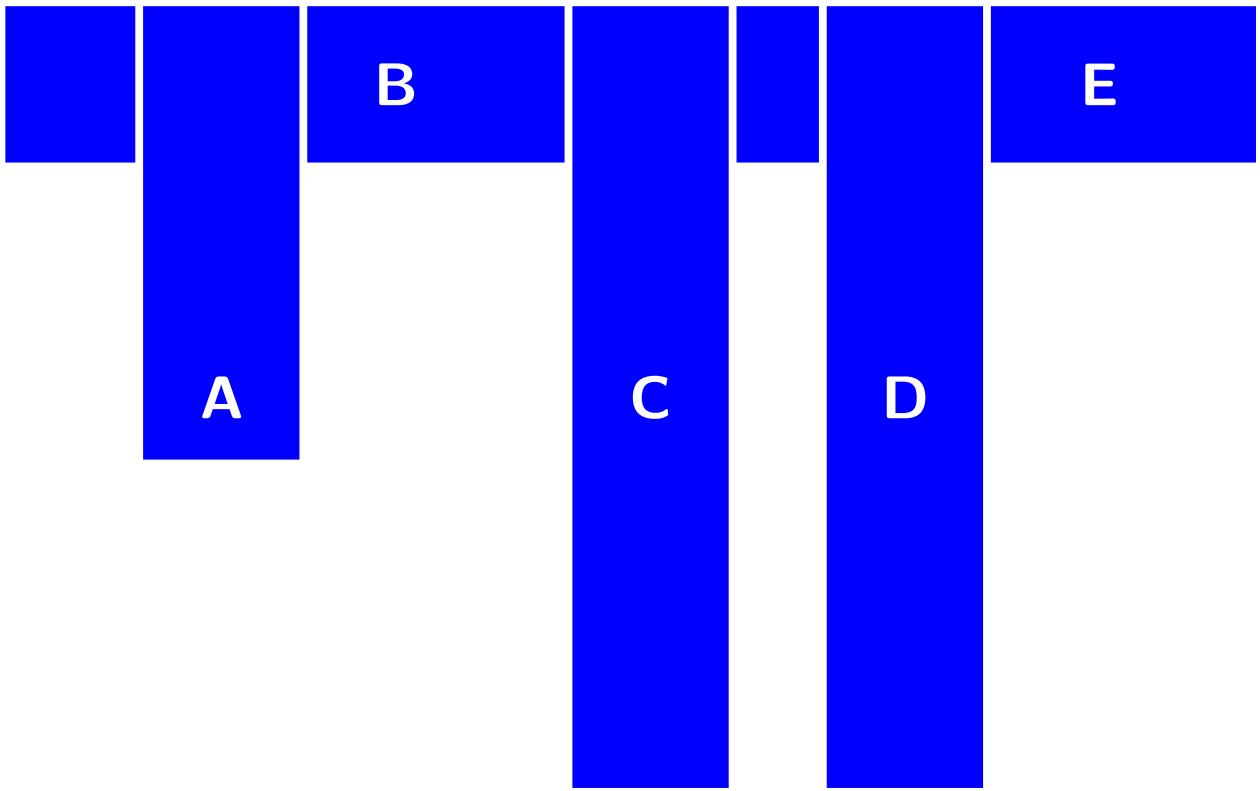

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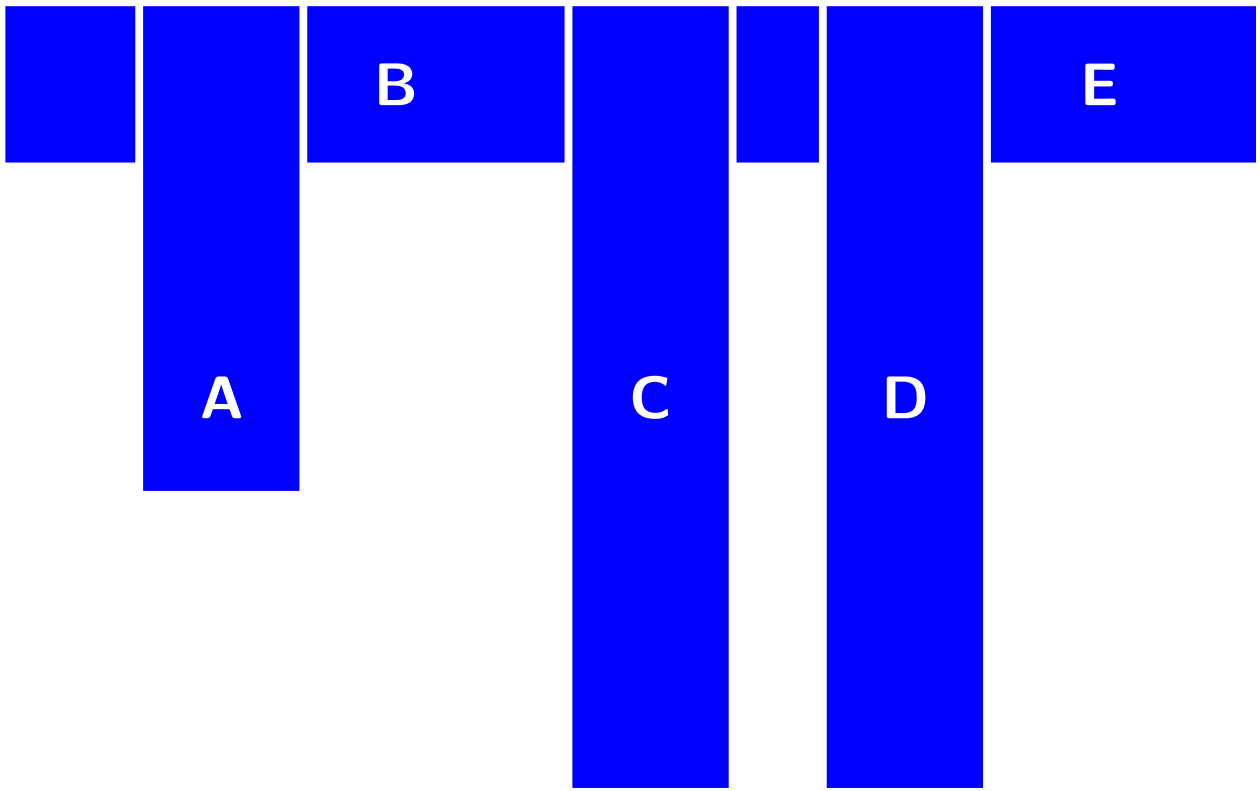

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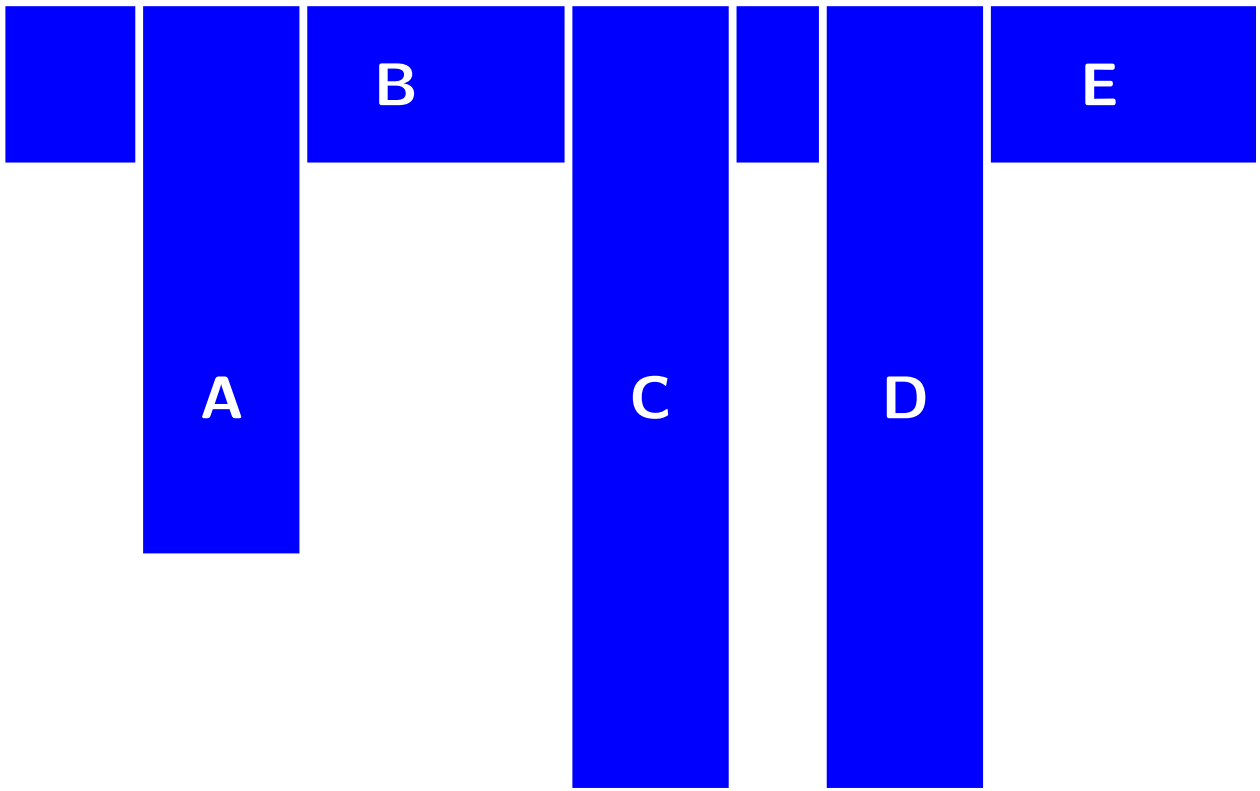

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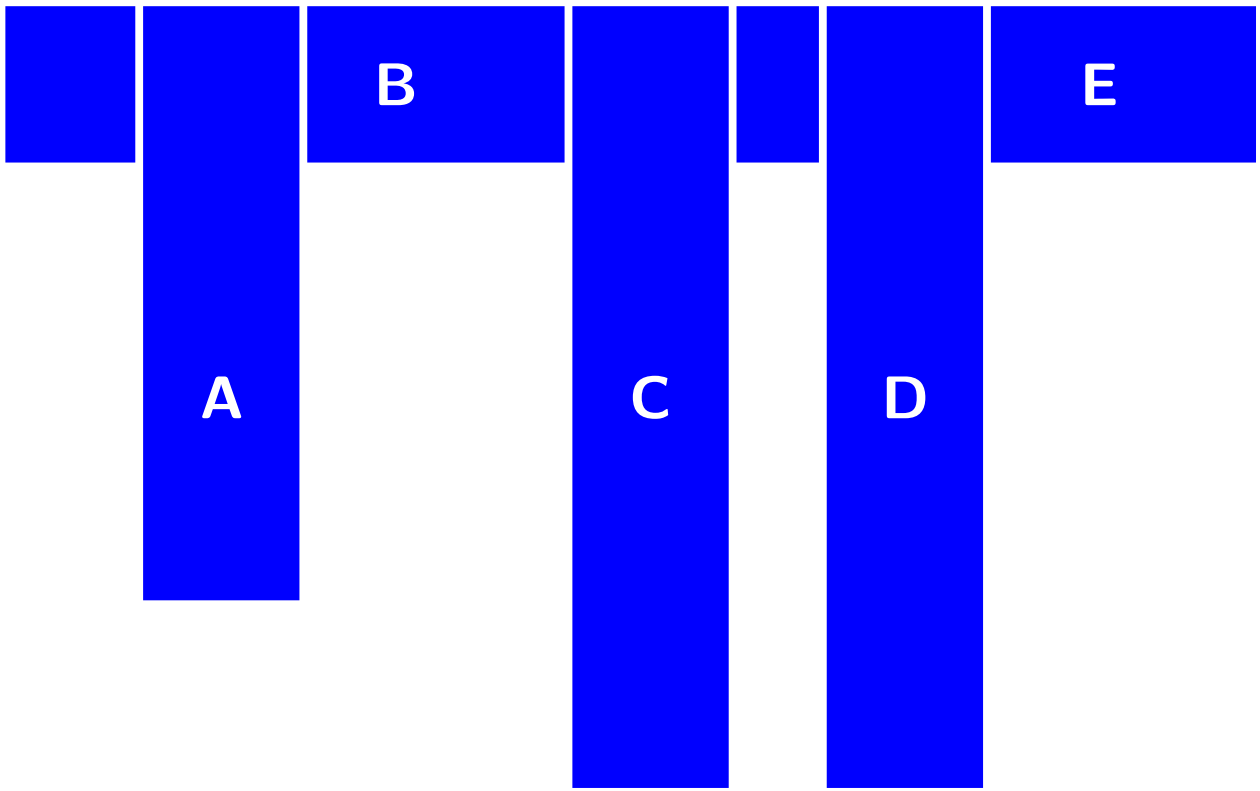

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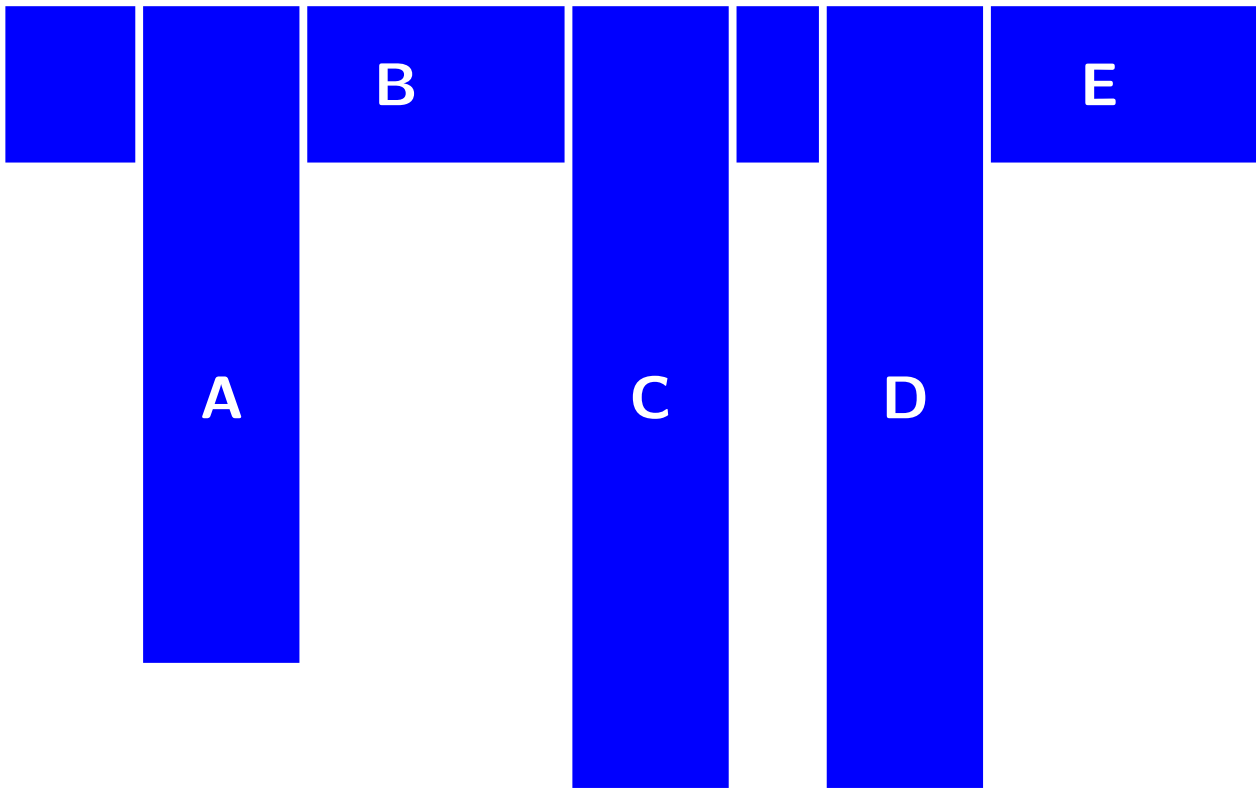

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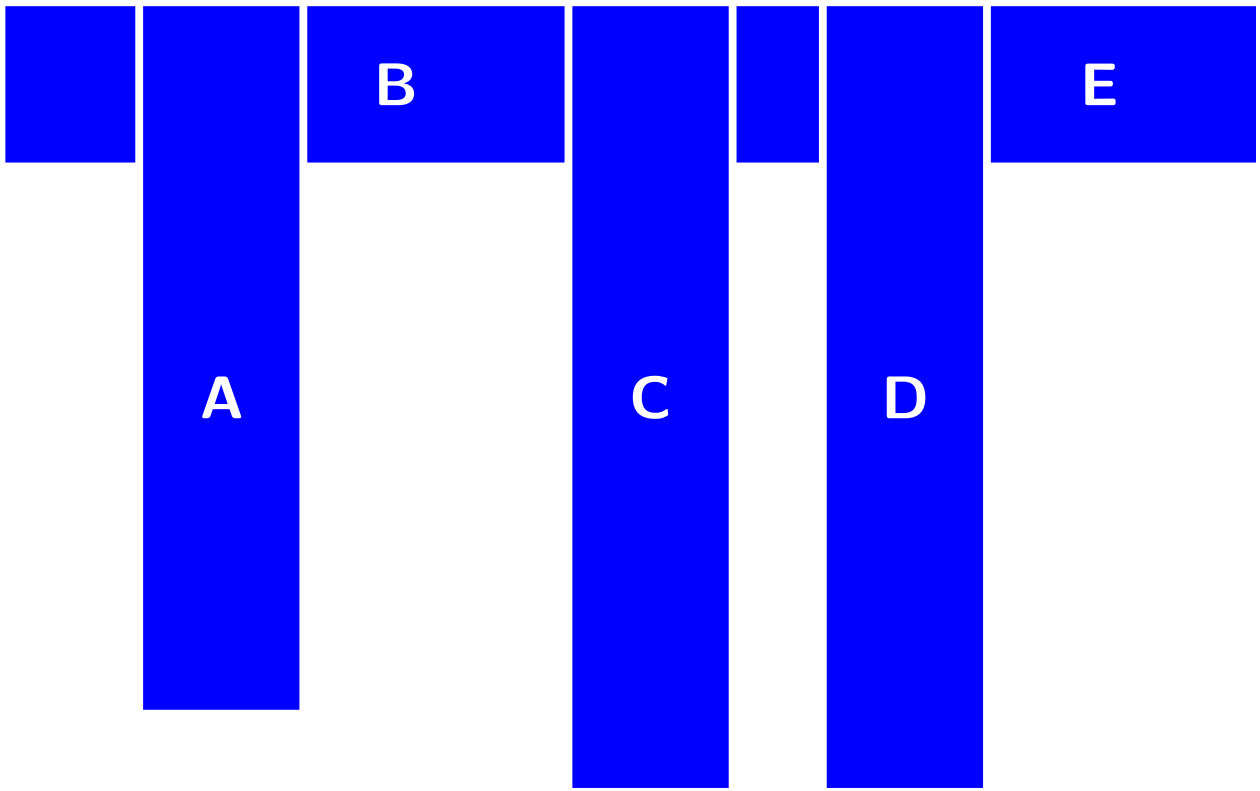

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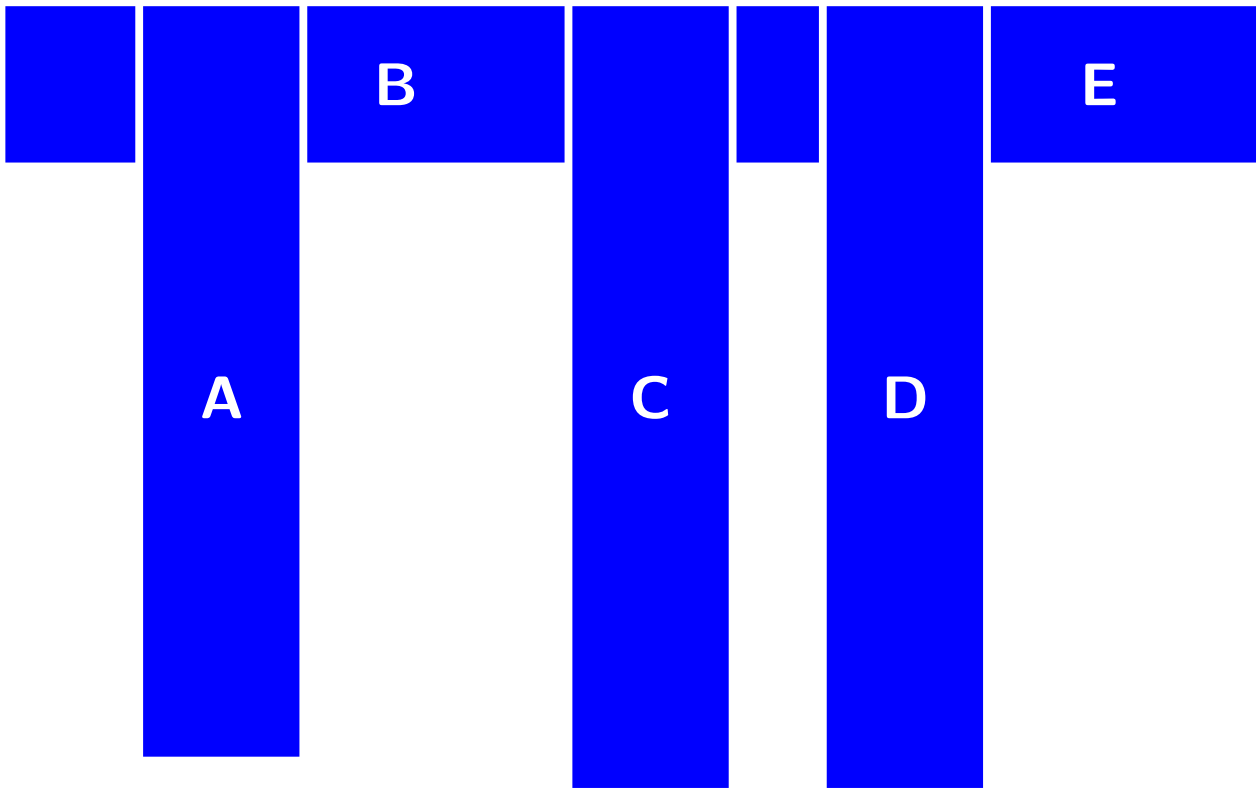

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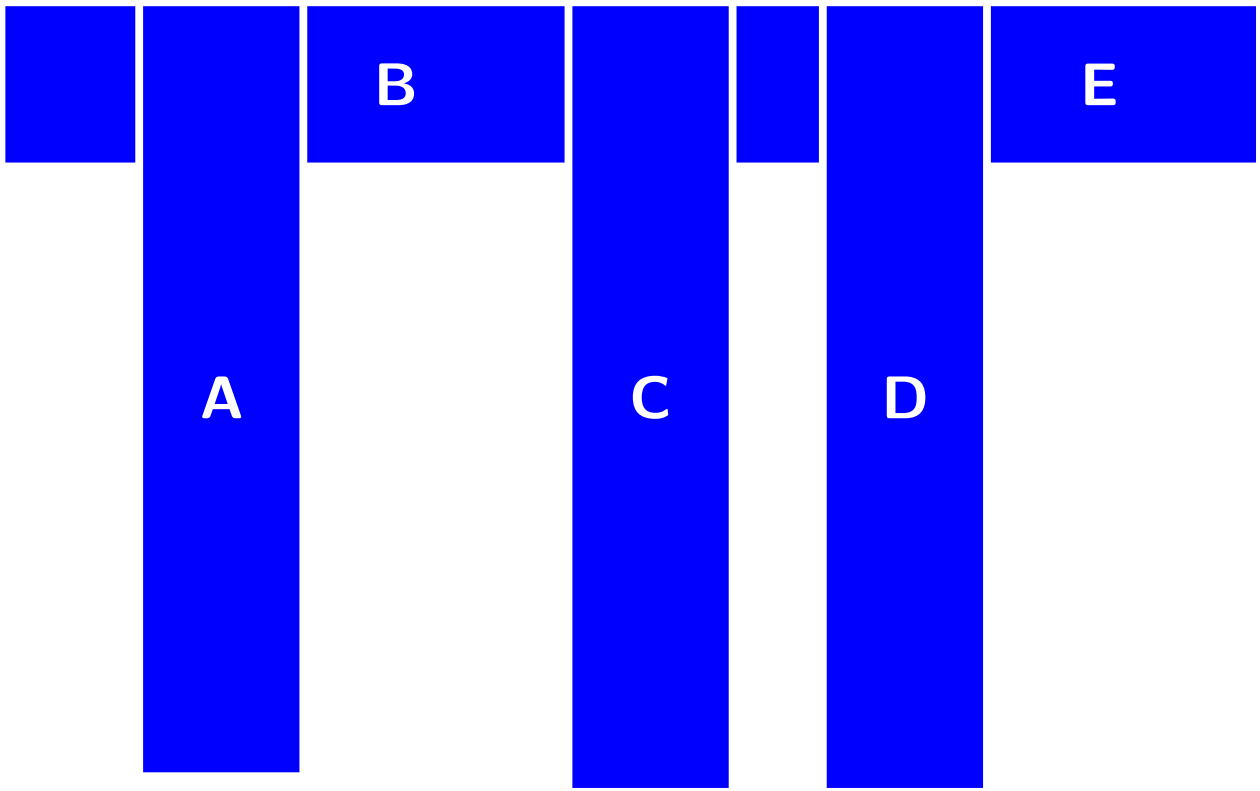

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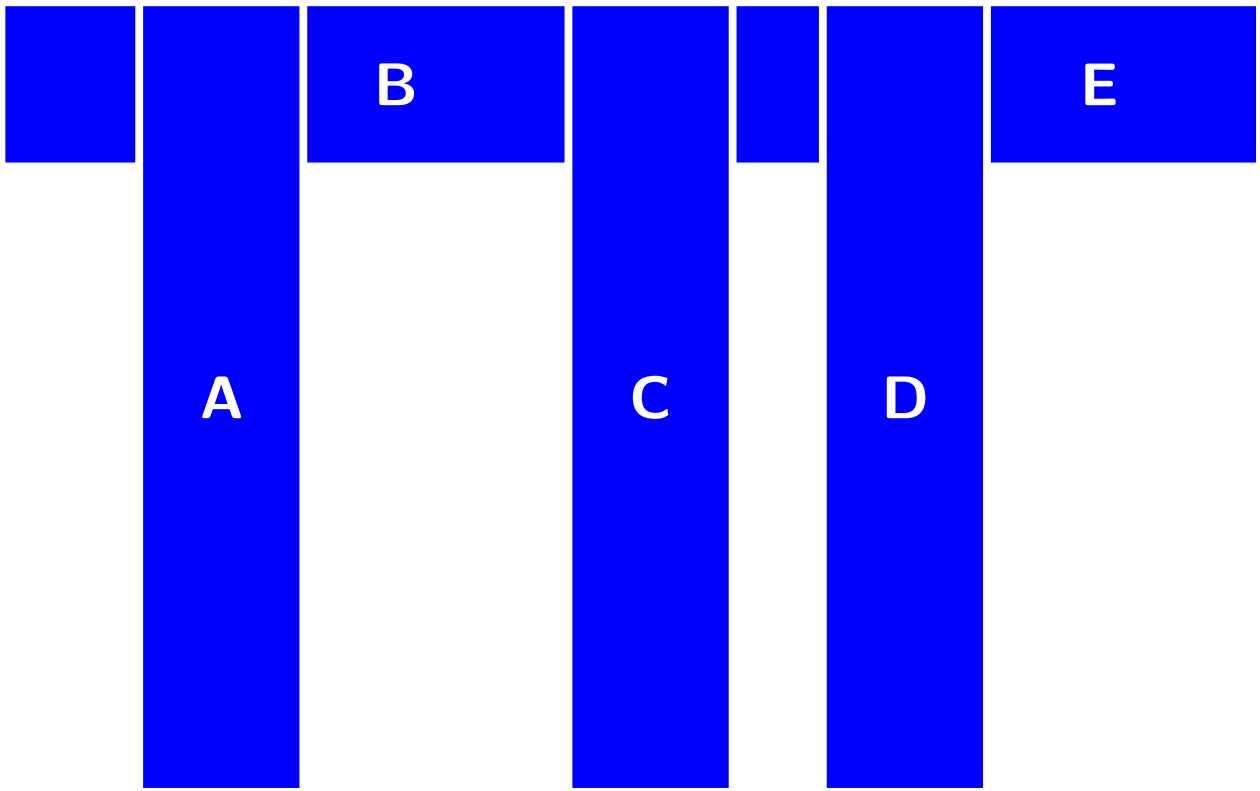
Breadth Vs. Depth



Achieve depth in one area and overall breadth

Other areas can be understood on need basis relatively quickly

Ability to Abstract and Modularize

- Different levels of abstraction and different granularities of modularization

  Example : Describing a car to

  - a person who wants to travel in a car
  - a person who wants to drive a car
  - a person who wants to repair a car
  - a person who wants to design a car

Each of the above views is **correct** and **complete** w.r.t to chosen level of abstraction

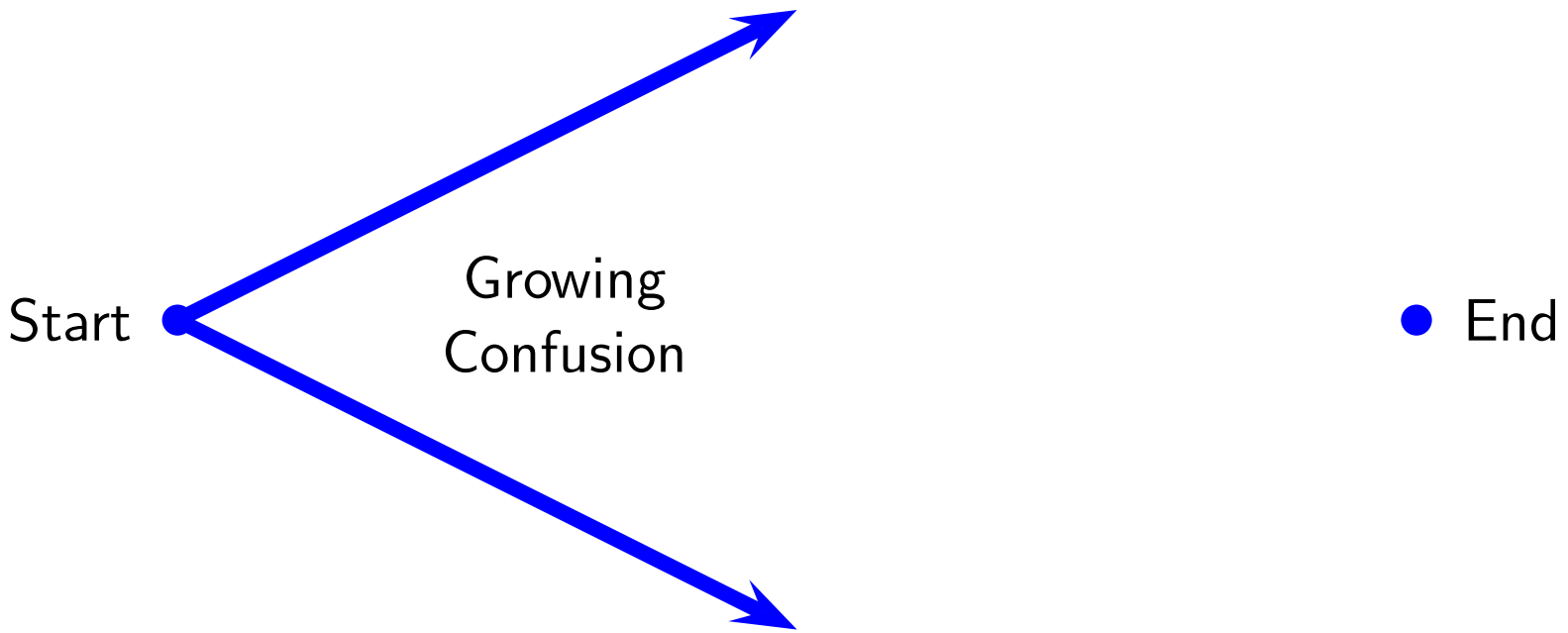
From Confusion to Conviction

Start • • End

From Confusion to Conviction

Start • Growing Confusion • End

From Confusion to Conviction



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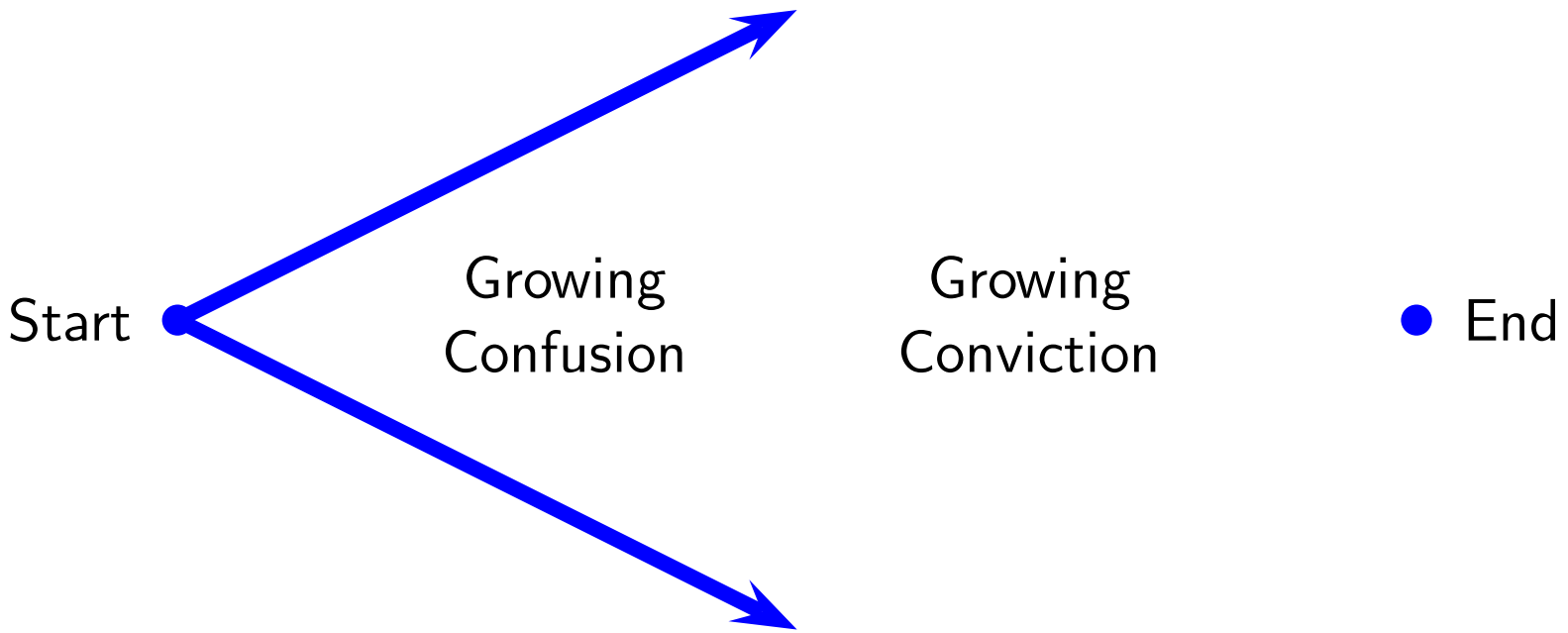

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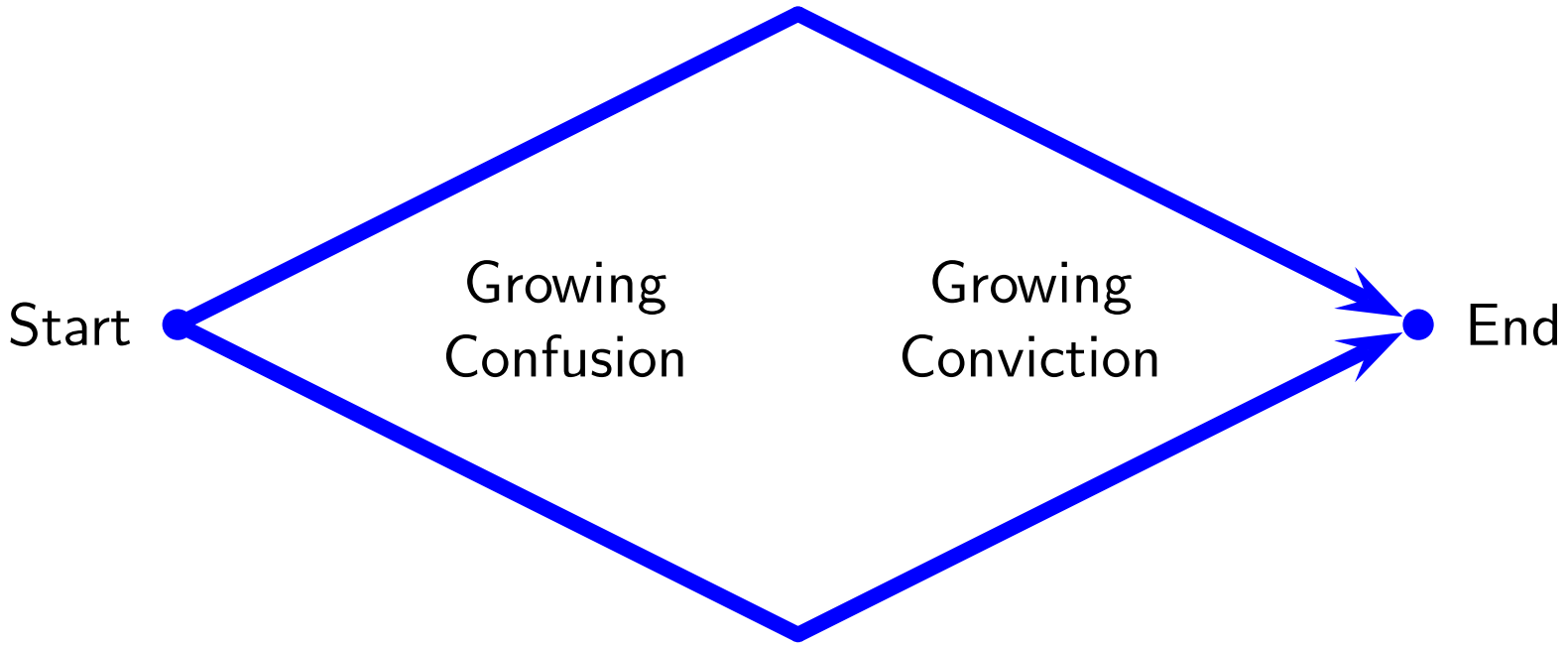
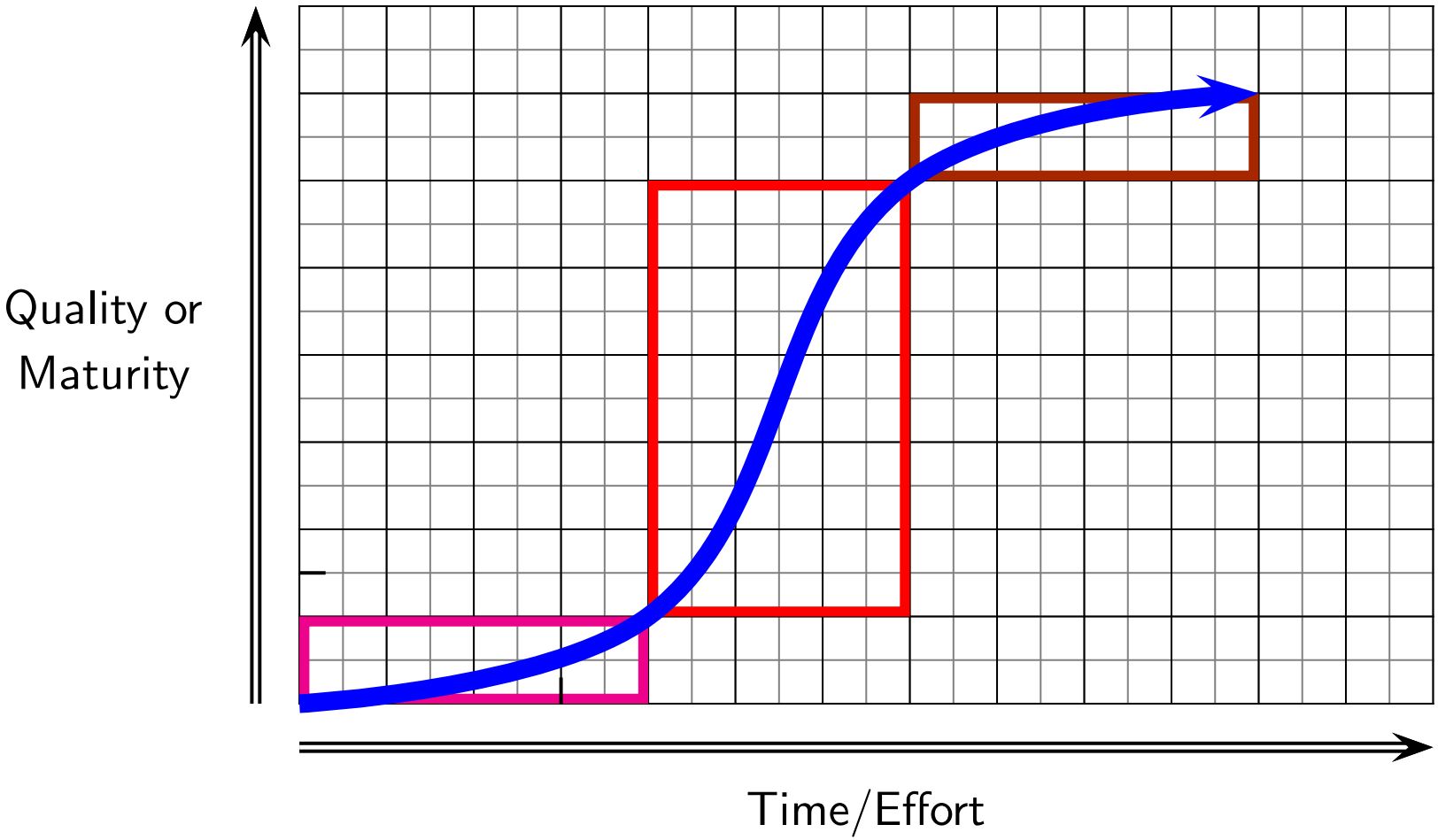


The "S" Curve of Research Life Cycle



Research in Industry Vs. Research in Academia

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  Deliverables exist but of a different nature

  Deadlines are usually as strict

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1. Seek extension of an earlier known solution

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Part 5

Richard Hamming on Research

On the Role of Luck in Research

Pasteur: "Luck favours a prepared mind."

Hamming: "Our society frowns on people who set out to do really good work. You're not supposed to; luck is supposed to descend on you and you do great things by chance. Well, that's a kind of dumb thing to say.

I spoke earlier about planting acorns so that oaks will grow. You can't always know exactly where to be, but you can keep active in places where something might happen.

A prepared mind sooner or later finds something important and does it. So yes, it is luck. *The particular thing you do is luck, but that you do something is not.* "

Luck is when preparation meets opportunity

Turning Difficulties into Opportunities in Research

Knowing right questions is the first step in knowing the answers

Hamming: "Often the great scientists, by turning the problem around a bit, changed a defect to an asset.

Hamming, you think the machines can do practically everything. Why can't you make them write programs?" What appeared at first to me as a defect forced me into automatic programming very early. What appears to be a fault, often, by a change of viewpoint, turns out to be one of the greatest assets you can have. "

The Role of Hard Work in Research

- Research is 1% inspiration and 99% perspiration

  Newton: "If others would think as hard as I did, they would get similar results."

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- Continuous consolidation works like compound interest

  Hamming: "Given two people of approximately the same ability and one person who works ten percent more than the other, the latter will more than twice outproduce the former. The more you know, the more you learn; the more you learn, the more you can do; the more you can do, the more the opportunity ..."

On the Role of Intelligence and Courage in Research

Hamming: "How about having lots of 'brains?' It sounds good. ... But great work is something else than mere brains.

One of the characteristics you see, and many people have it including great scientists, is that usually when they were young they had independent thoughts and had the courage to pursue them.

Once you get your courage up and believe that you can do important problems, then you can. If you think you can't, almost surely you are not going to. ... That is the characteristic of great scientists; they have courage. They will go forward under incredible circumstances; they think and continue to think. "

On the Role of Drive and Commitment in Research

Hamming: "Well, one of the reasons is drive and commitment. The people who do great work with less ability but who are committed to it, get more done that those who have great skill and dabble in it, who work during the day and go home and do other things and come back and work the next day. They don't have the deep commitment that is apparently necessary for really first-class work. "

On the Role of Commitment and Creativity in Research

Hamming: "If you are deeply immersed and committed to a topic, day after day after day, your subconscious has nothing to do but work on your problem. And so you wake up one morning, or on some afternoon, and there's the answer. For those who don't get committed to their current problem, the subconscious goofs off on other things and doesn't produce the big result.

So ... you don't let anything else get the center of your attention - you keep your thoughts on the problem. Keep your *subconscious starved so it has to work on your problem, so you can sleep peacefully and get the answer in the morning, free.* "

Committment, Hard Work, and Preparation Enhance Creativity

- Keep your antennas tuned
- You never know when and where the signals come from

On the Role of Uncertainty in Research

Hamming: "Most people like to believe something is or is not true. Great scientists tolerate ambiguity very well. They believe the theory enough to go ahead; they doubt it enough to notice the errors and faults so they can step forward and create the new replacement theory. If you believe too much you'll never notice the flaws; if you doubt too much you won't get started. It requires a lovely balance. But most great scientists are well aware of why their theories are true and they are also well aware of some slight misfits which don't quite fit and they don't forget it. "

Incremental Research Vs. Fundamental Research

Hamming: "Most great scientists know many important problems. They have something between 10 and 20 important problems for which they are looking for an attack. And when they see a new idea come up, one hears them say 'Well that bears on this problem.'

The great scientists, when an opportunity opens up, get after it and they pursue it. They drop all other things. They get rid of other things and they get after an idea because they had already thought the thing through. Their minds are prepared; they see the opportunity and they go after it. "

Part 6

Conclusions

The Role of Research in Long Satisfying Technical Career

- In a rapidly changing field like CS/IT, quick self learning is the most important ability
- Quick self learning is enhanced significantly by exposure to research
- Research experience is likely to become more and more important in future

The Essence of Research

- Research is a game of innovative ideas that are significant
  Even an experimental research begins with an observation and speculation
- The significance of ideas could lie in any of the following:
  - Beauty
  - Utility
  - Enhancement of knowledge
- Research is often a cycle of:

  Speculate, design, apply/perform experiment, observe, interpret, infer and repeat

Ingredients of Good Research

- Innovation
- Aesthetics
- Other important aspects :
  - Completeness
  - Rigour
  - Empirical demonstration
  - Effective communication

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- What we all may already possess

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  Strong Background

  Enhances the effectiveness of all the above traits, particularly when time is a crucial factor

To Be or Not To Be? That is the Question!

- Research is fun!
- Research makes a researcher a much better learner
- Research enables better consolidation of skills
  - Depth of skills
  - The "skill" of applying various skills!

    One gets involved with all aspects of solving a particular problem

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Research takes us to a different state of mind!

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- Solving intellectually challenging problems

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- However, the questions addressed may not be new

  (May be new to the person but not to some others)
- Research addresses questions that have not been addressed before

  (Or have not been addressed adequately before)

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The Ten Commandments of Success in Research

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2. Work on multiple problems
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5. Get emotionally involved
6. Remain committed
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9. Don't depend on luck
10. Handle uncertainty and disappointments

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Also applicable to

- A practising engineer
- A student
- A teacher

and almost all walks of life!

Last But Not the Least

Thank You!

Last But Not the Least

Thank You!

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