What is Research? (Talk I)

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Outline

- Why research?
- What is research?
- Where do good ideas come from?
- The process of research
- Richard Hamming on research ("*You and Your Research*")
- Conclusions

Disclaimers

- General concepts
- No "cook book" or "how to do it yourself"

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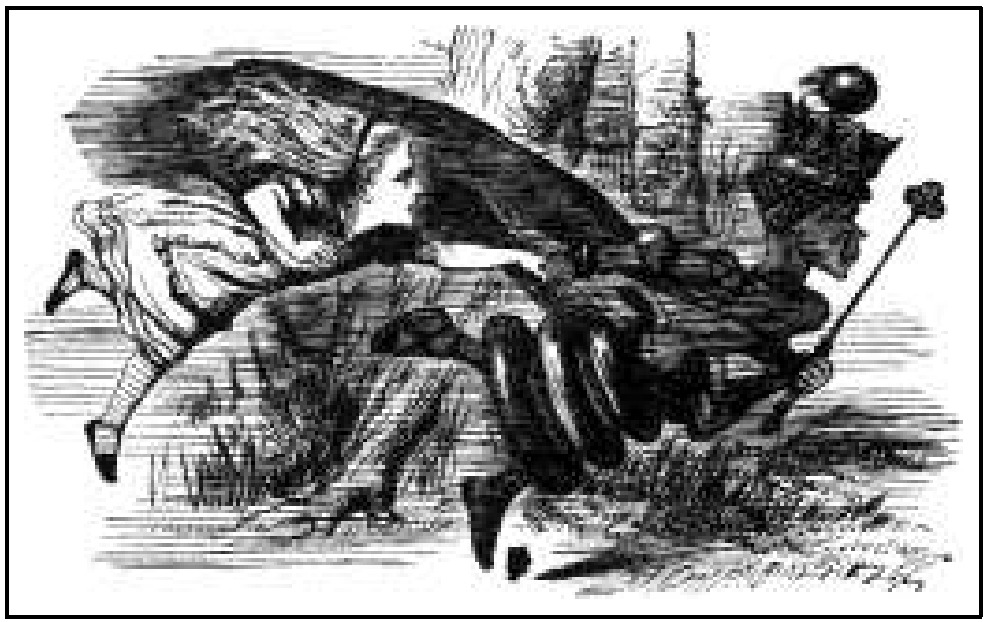
  - Views expressed through examples
  - Individual's perspective rather than an organization's perspective
  - Personal reflections and confessions ☺

Part 2

Why Research?

Alice's Adventures



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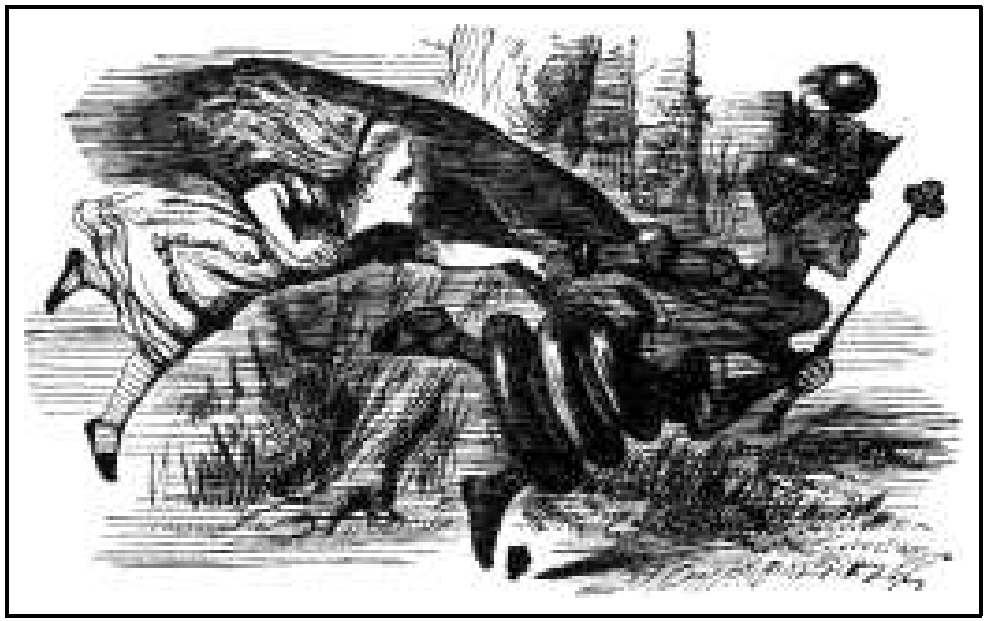

Through the Looking Glass
Author: Lewis Carroll
Illustration: John Tenniel

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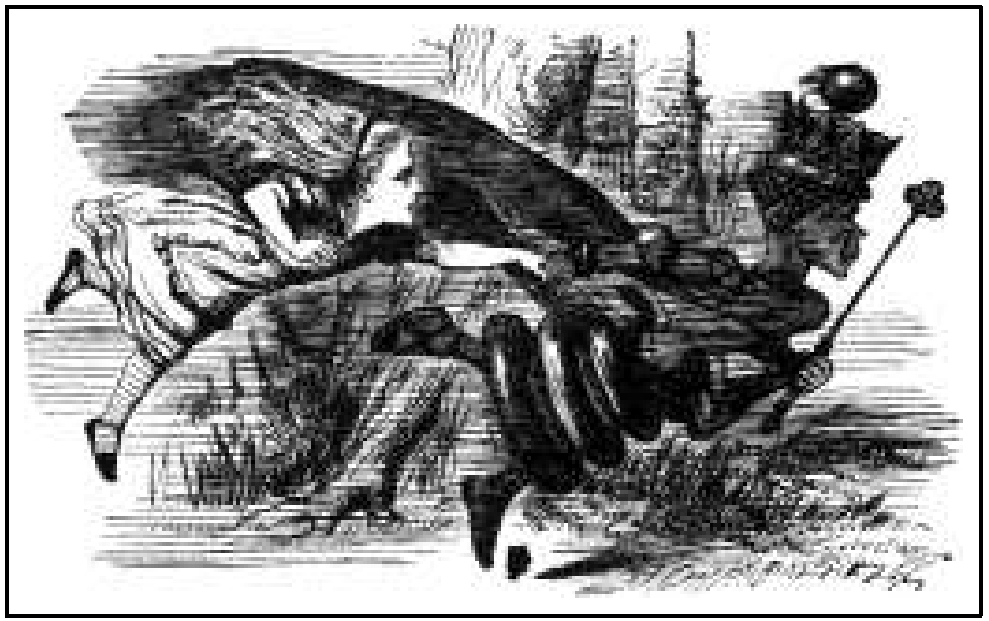

Through the Looking Glass
Author: Lewis Carroll
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'Well, in our country,' said Alice, still panting a little, 'you'd generally get to somewhere else – if you ran very fast for a long time, as we've been doing.'

'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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  - **Better sculptors**

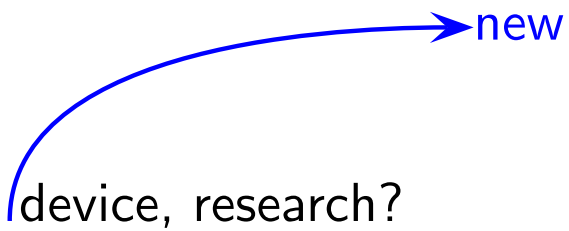
In Search of Research?

- 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



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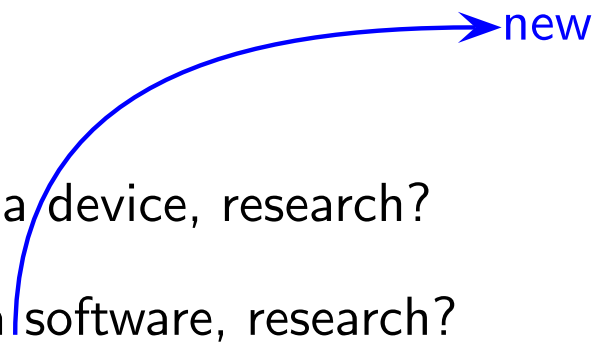

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Research could involve any of the above, or none of the above

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Important disclaimer

Neither this talk nor any of my works has been sponsored by a certain mobile service provider!

Ingredients of Good Research

- Innovation

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- Aesthetics

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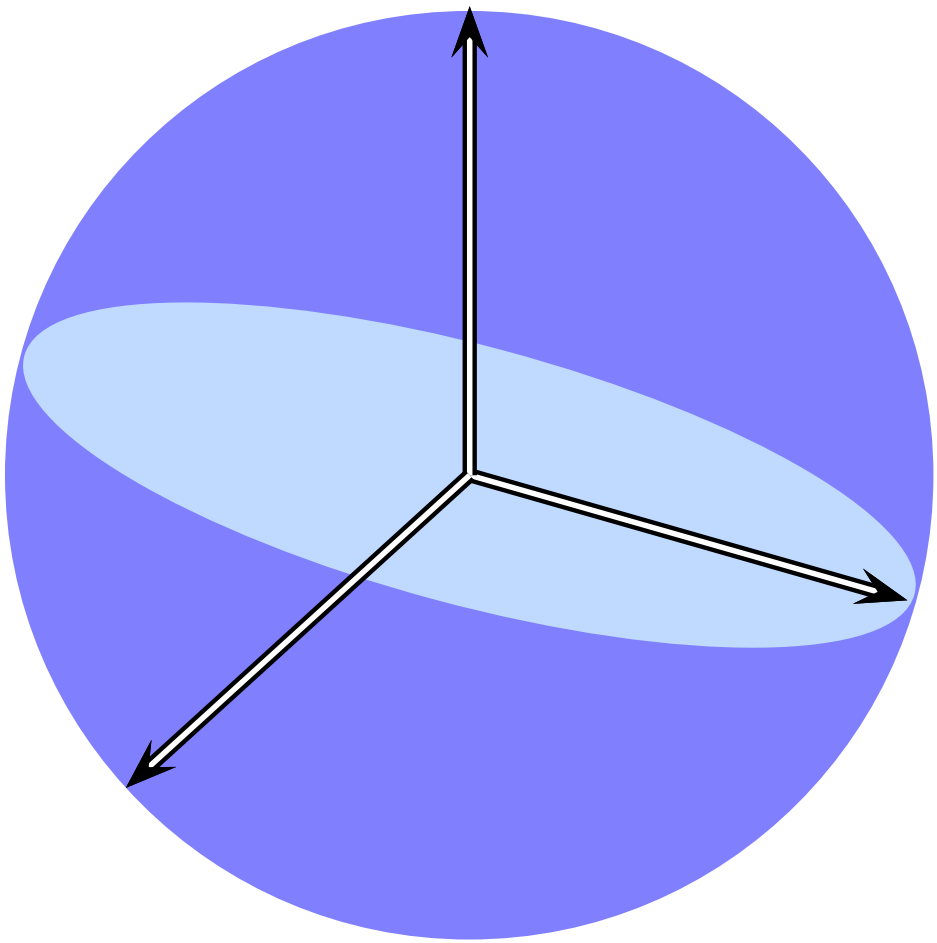
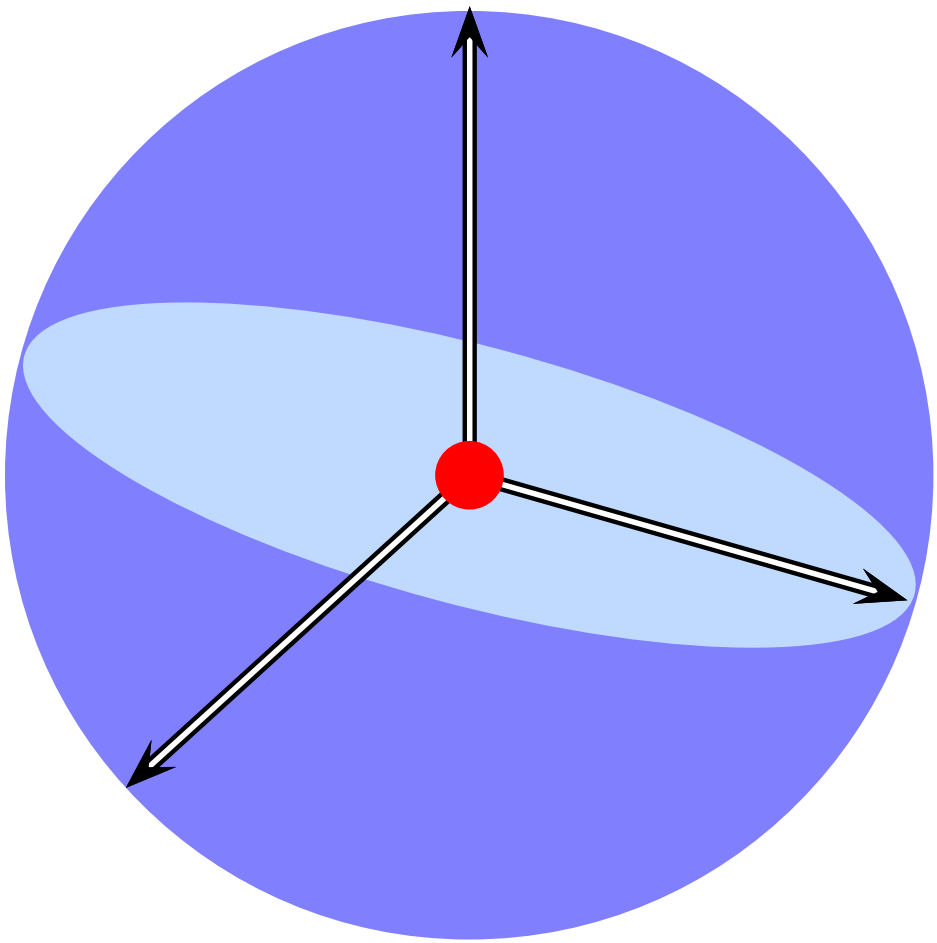
- Innovation
- Aesthetics
- Other important aspects :
  - Completeness
  - Rigour
  - Empirical demonstration
  - Effective communication

Innovation



- The sphere of knowledge

Innovation



- The sphere of knowledge
- Initial general learning

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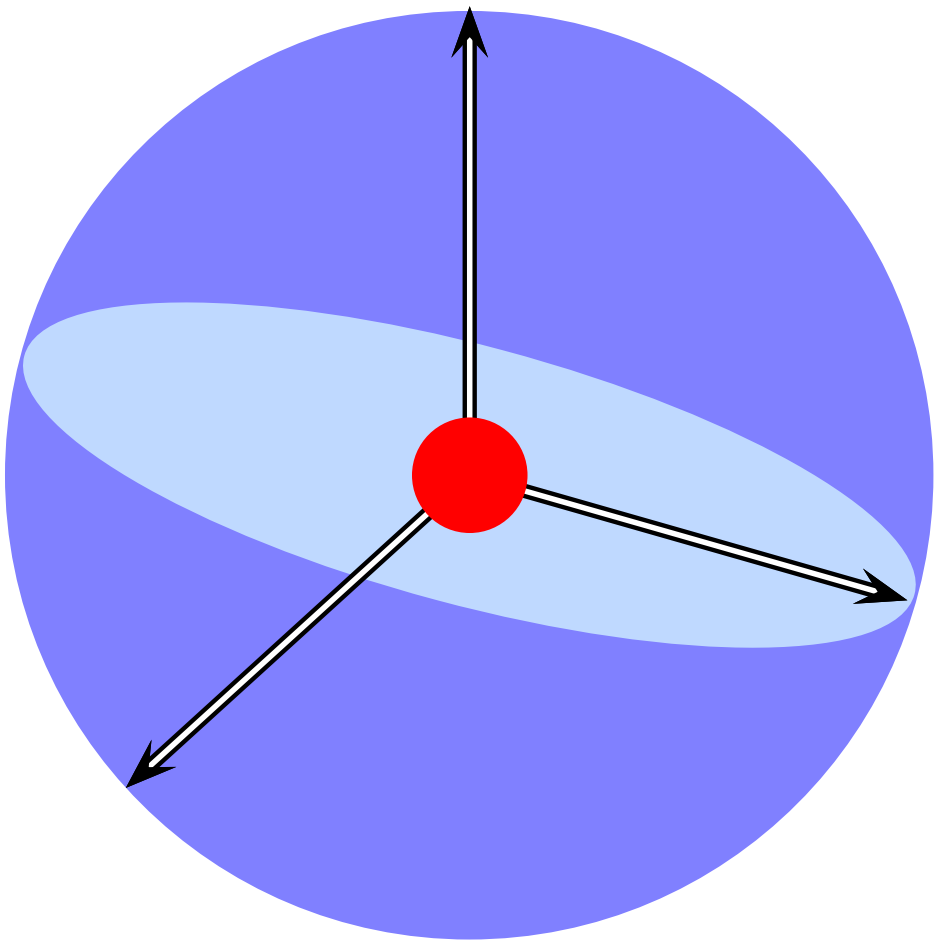

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- Initial general learning
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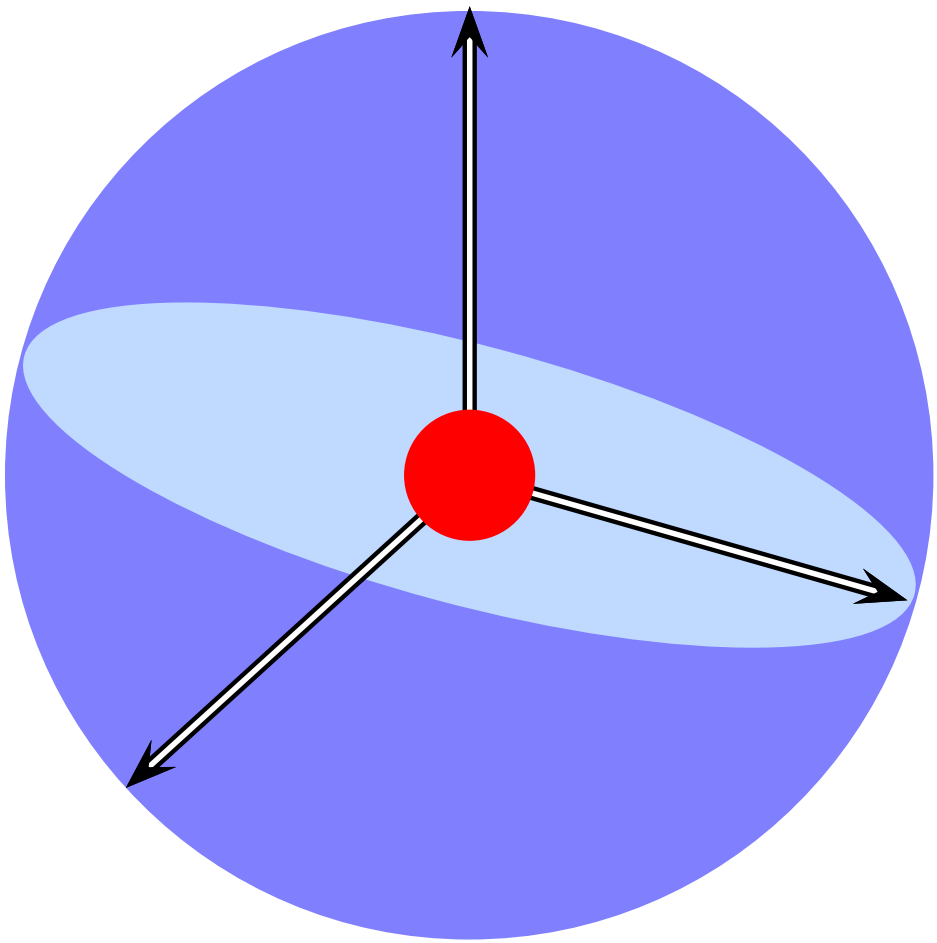

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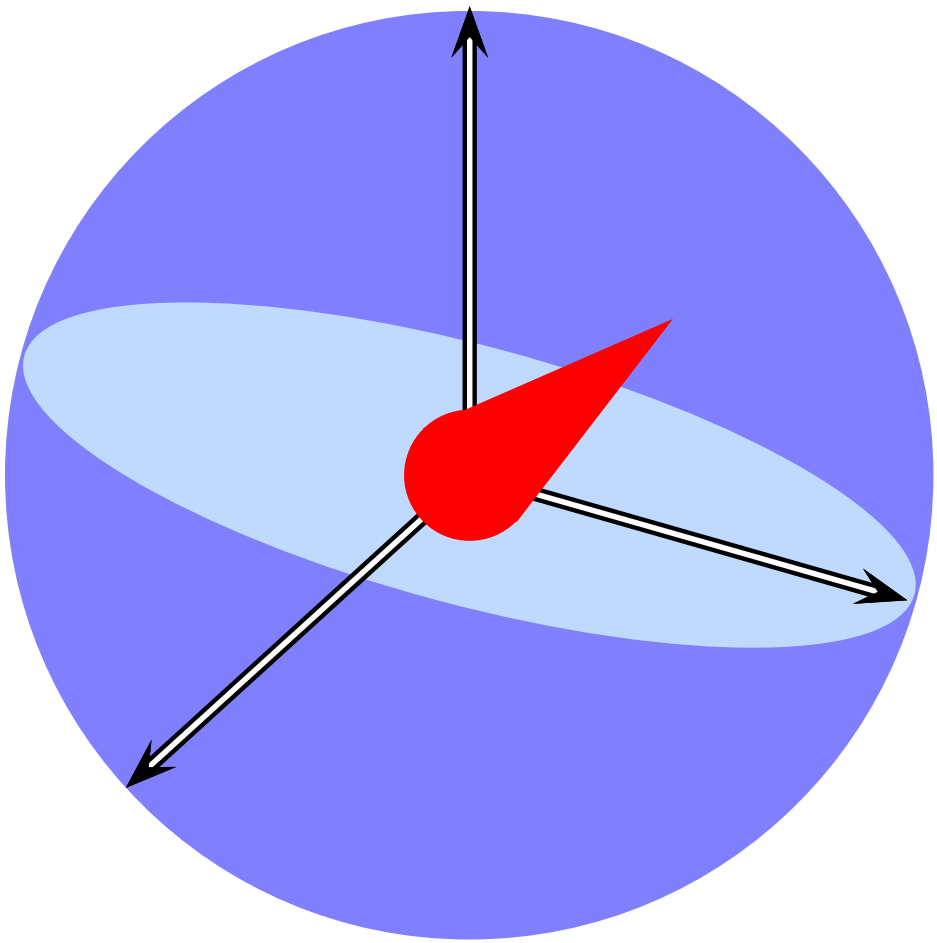

- The sphere of knowledge
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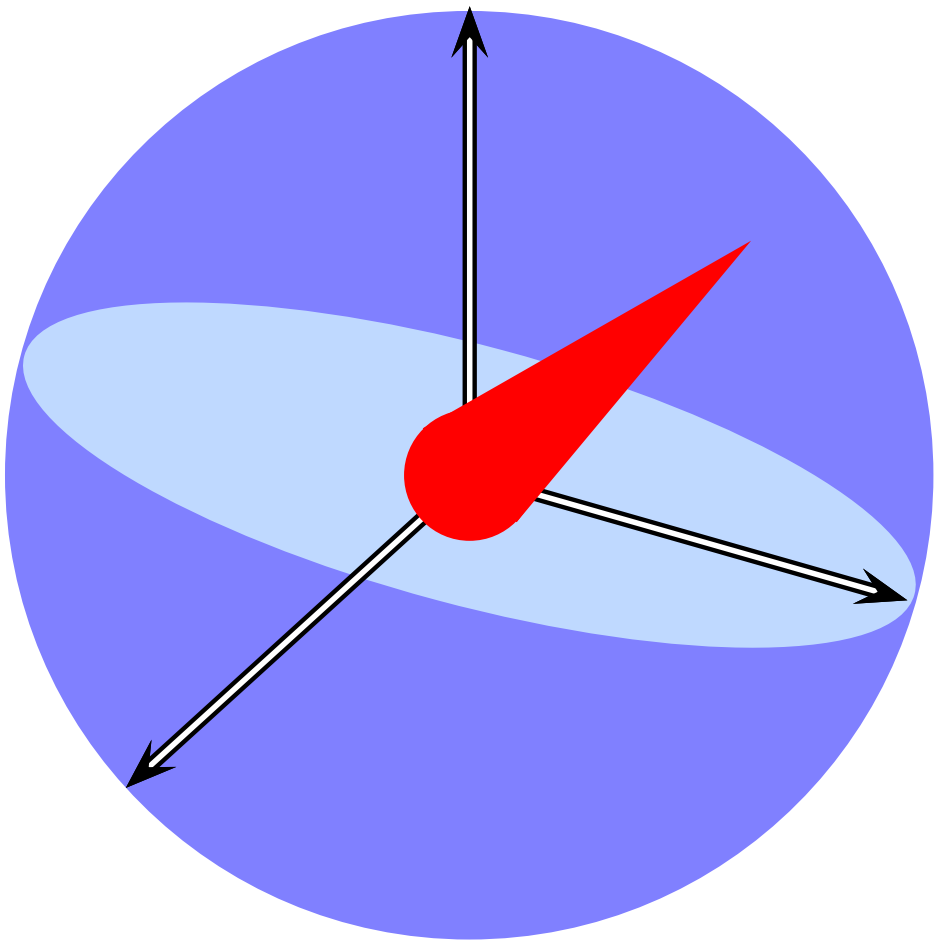
Innovation



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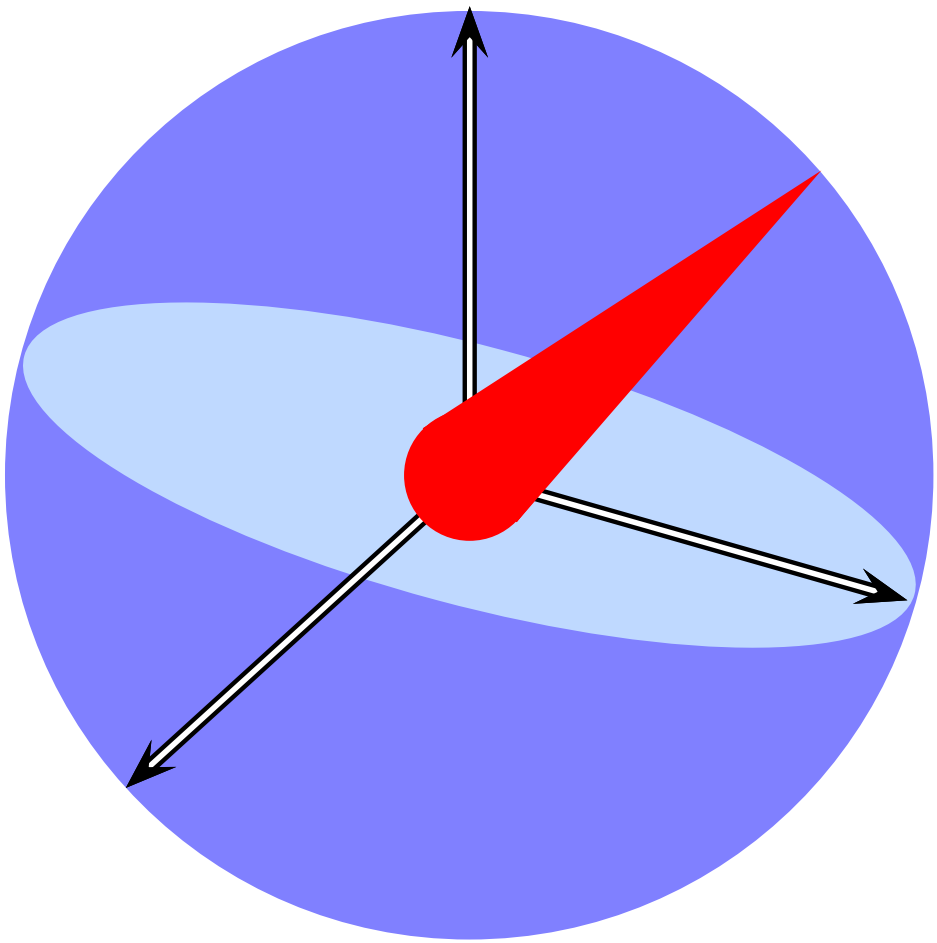
Innovation



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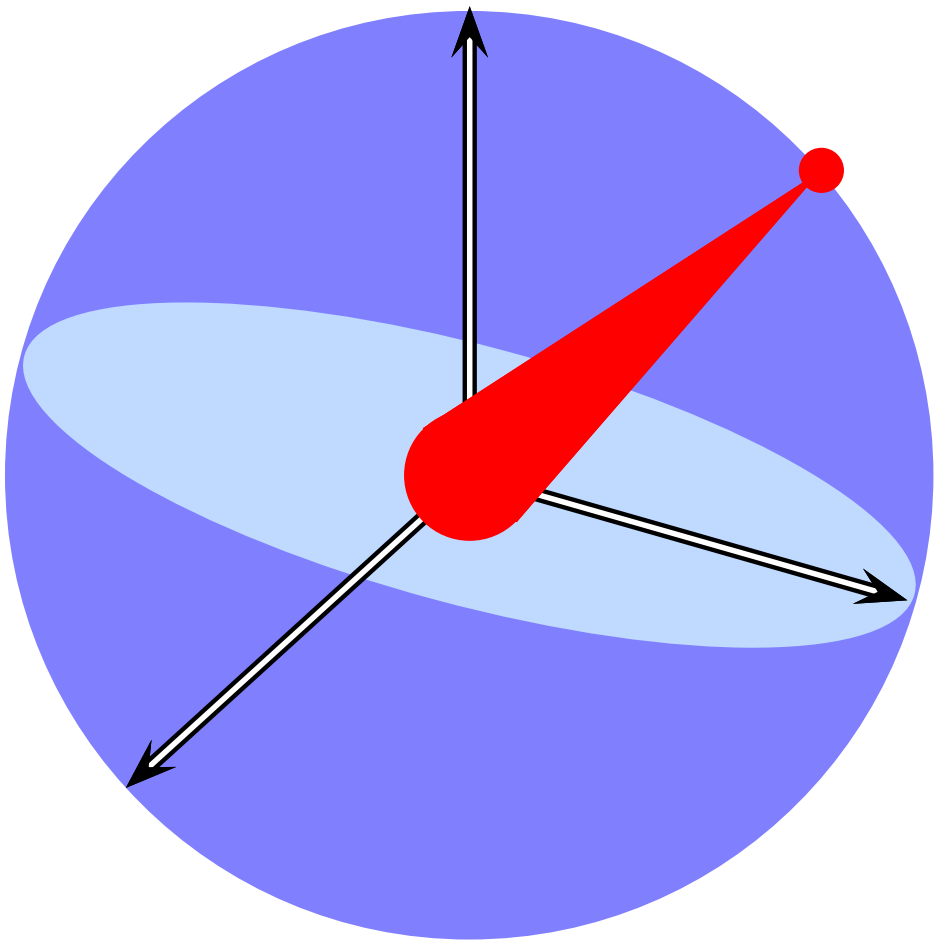

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- Learning increases with time
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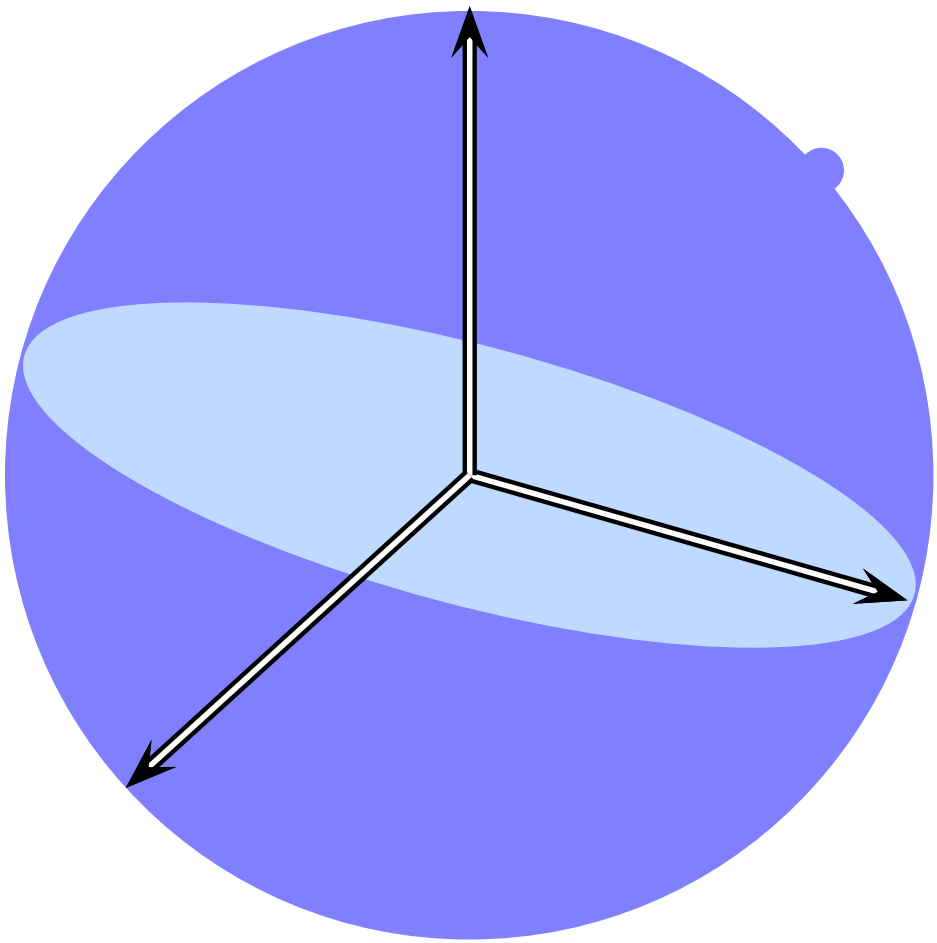
- Specialize more and more until you reach the unknown
- Try to push the boundary
- If you keep trying try hard enough, you may succeed

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/

What Qualifies as Innovation?

- Everything that is new need not be innovative
  - Example: Finding sum of two obscure 100 digit numbers
- Creation without creativity does not qualify as innovation
- The novelty quotient of an innovation depends on
  - how non-obvious the result seemed before you established it
  - how obvious the result appears in hindsight

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Innovation in research should enrich the set of "first principles"

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** . . ."

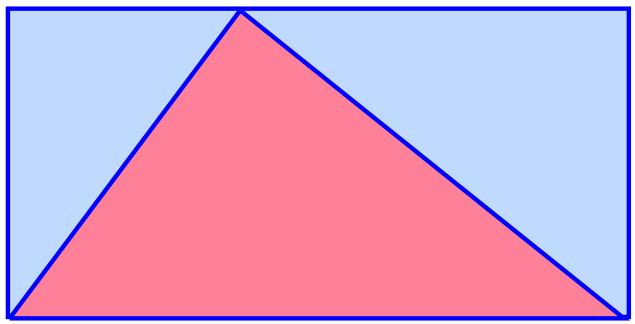
  – Henry Poincare

- Example : Painting

  Proportion of colours Vs. their arrangements

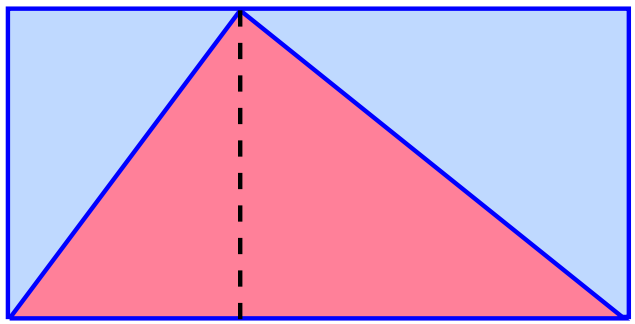
- Casserole design

Aesthetics and Beauty of an Idea



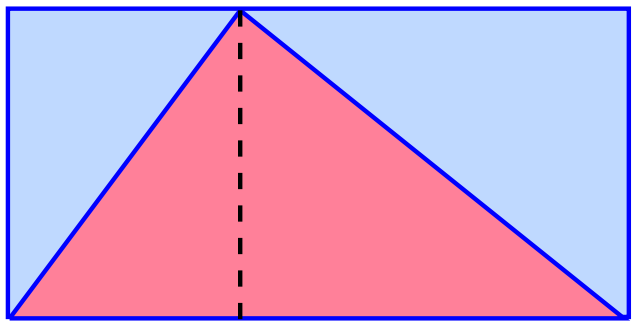
- What proportion of the box does the pink triangle occupy?
- Would the result hold for *any* triangle in a box?

Aesthetics and Beauty of an Idea



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

Aesthetics and Beauty of an Idea



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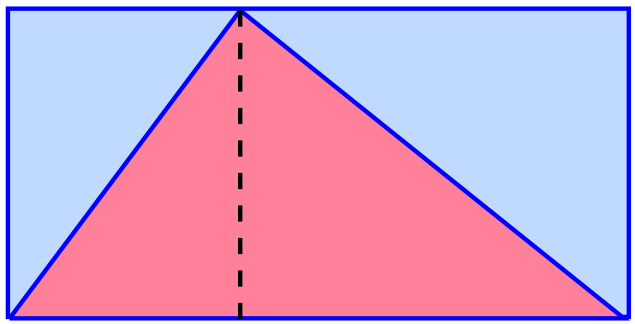

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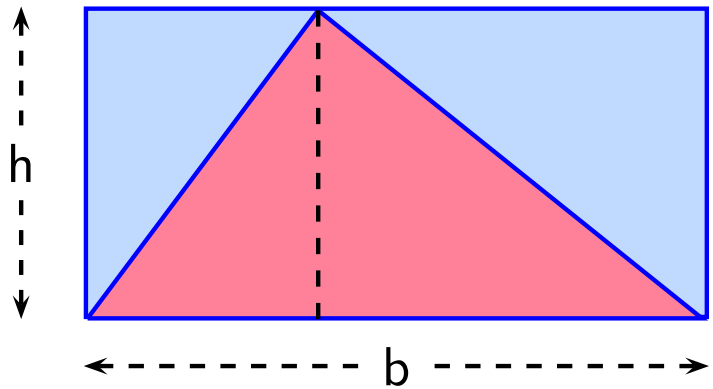

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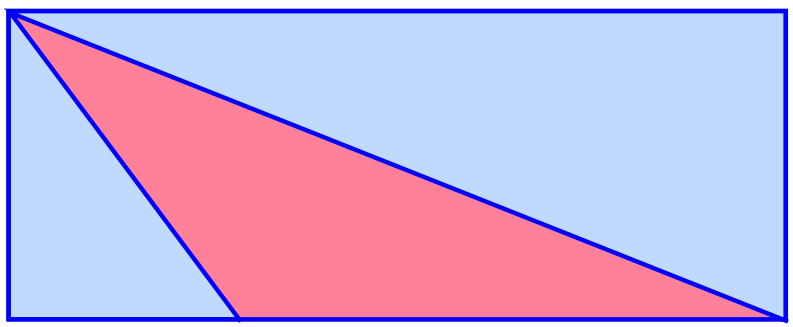
- Area of a triangle $= \frac{1}{2} \times b \times h$

Food for Thought

What about this pink triangle?



Beauty of an Idea

- Ideas talk back to us

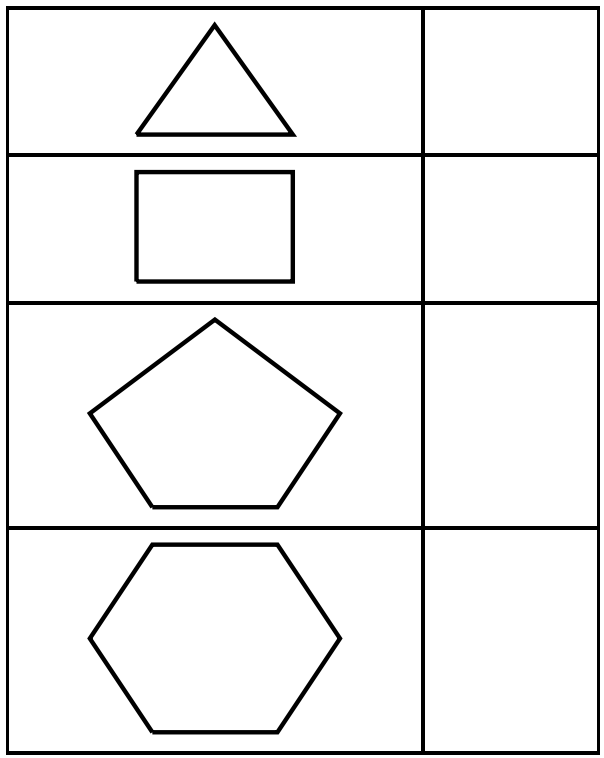
  When we fix one idea, it fixes some other ideas

- 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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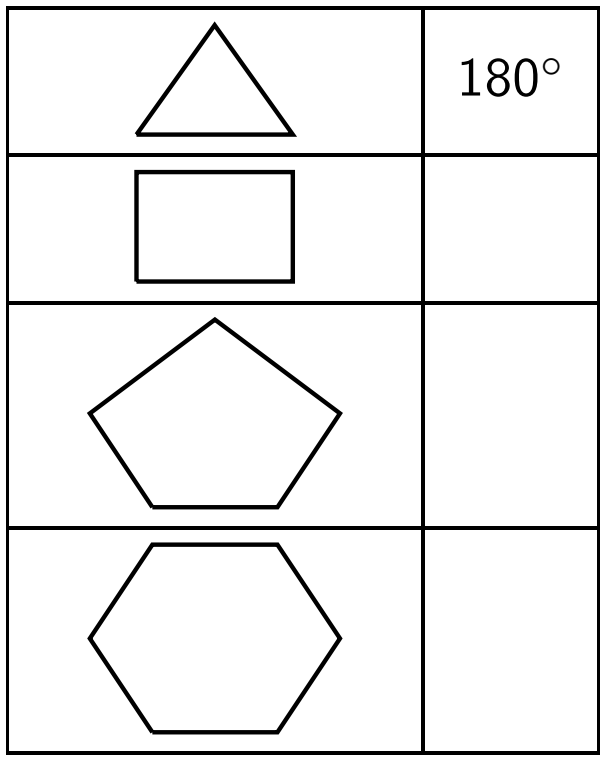

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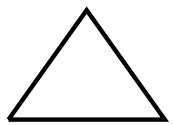	180°
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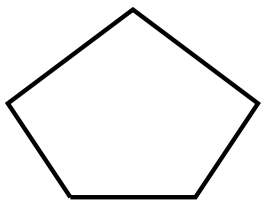	
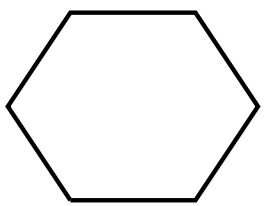	

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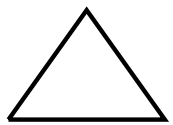	180°
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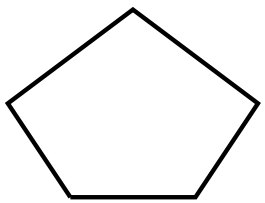
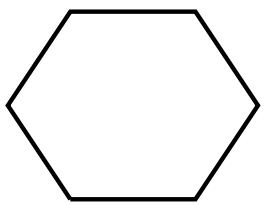
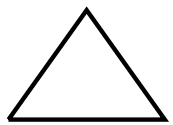
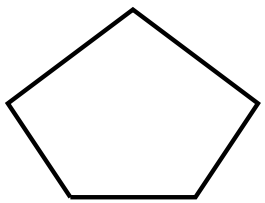
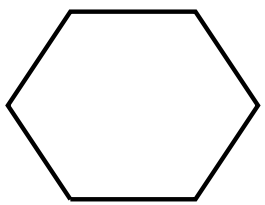
	540°
	

Another Example of Beauty of an Idea

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

	180°
	360°
	540°
	720°

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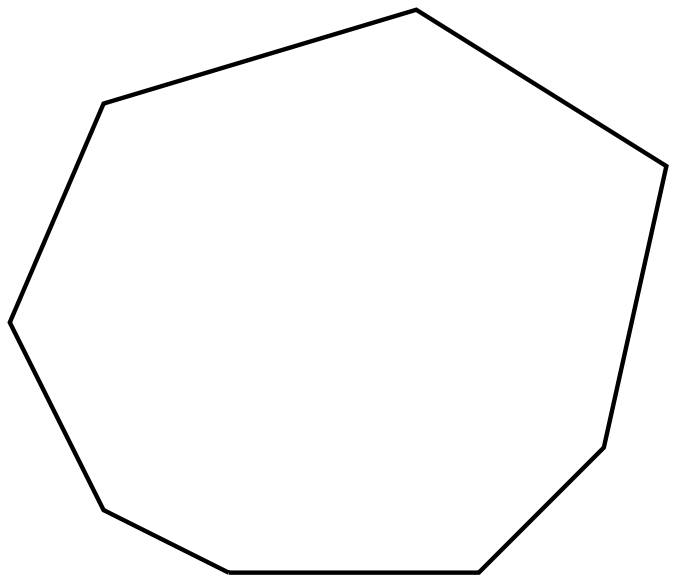
  - Consider an n sided polygon



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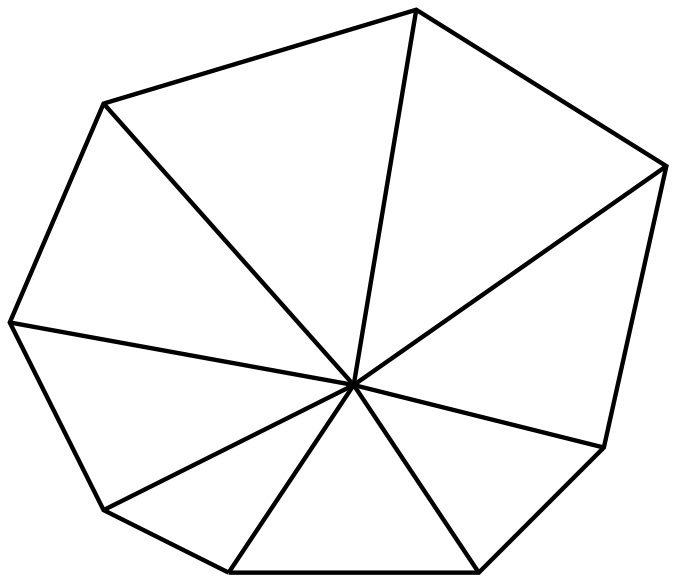

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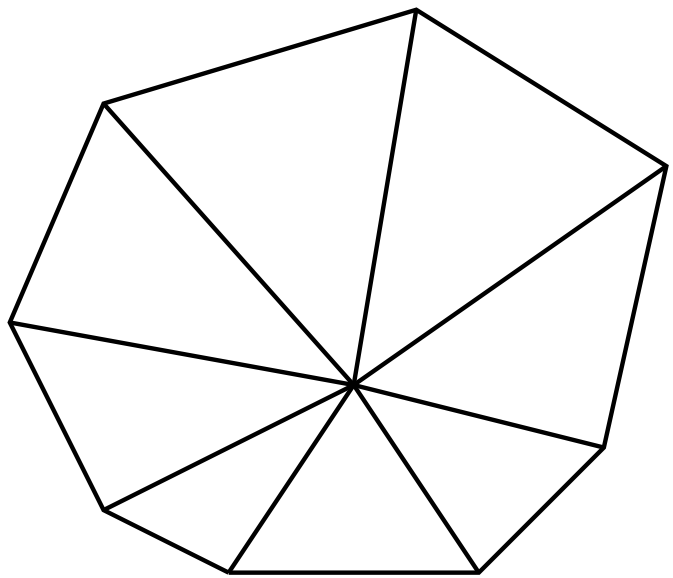

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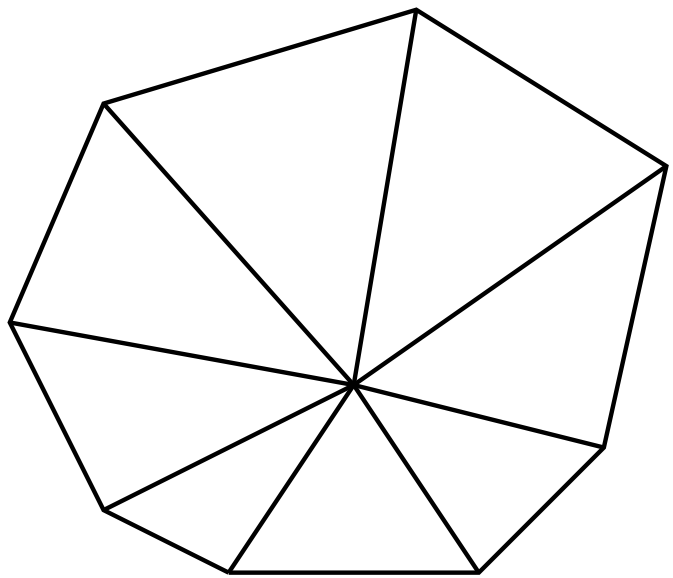

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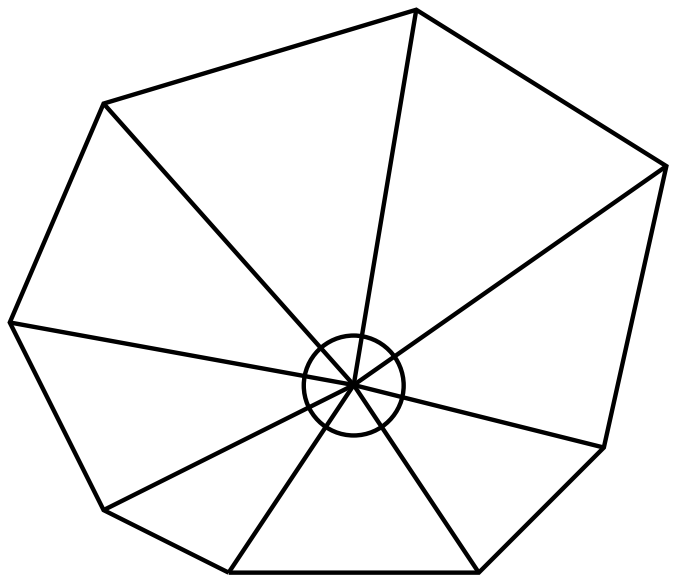

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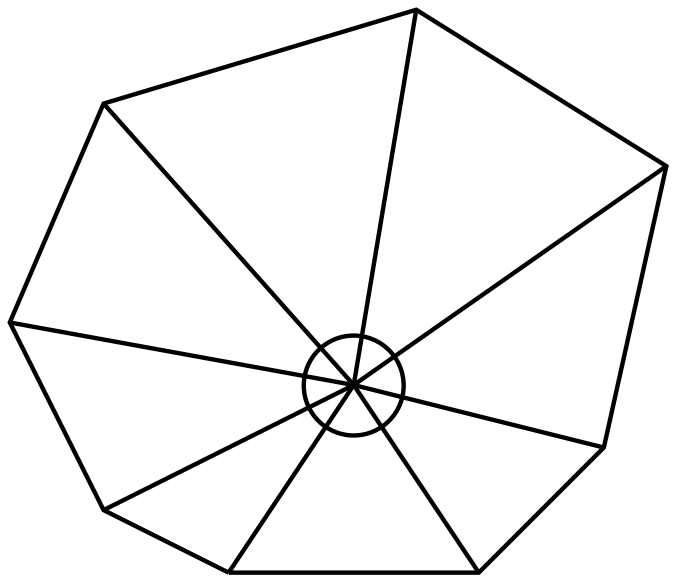

- Answer: $(n \cdot 180 - 360)^\circ$

On the Role of Rigour in an Idea

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

Part 4

Where Do Good Ideas Come From?

Based on
Where Good Ideas Come From. Steven Johnson. Penguin Books, 2010

What Makes Good Ideas Possible?

We structure our answer along the following aspects:

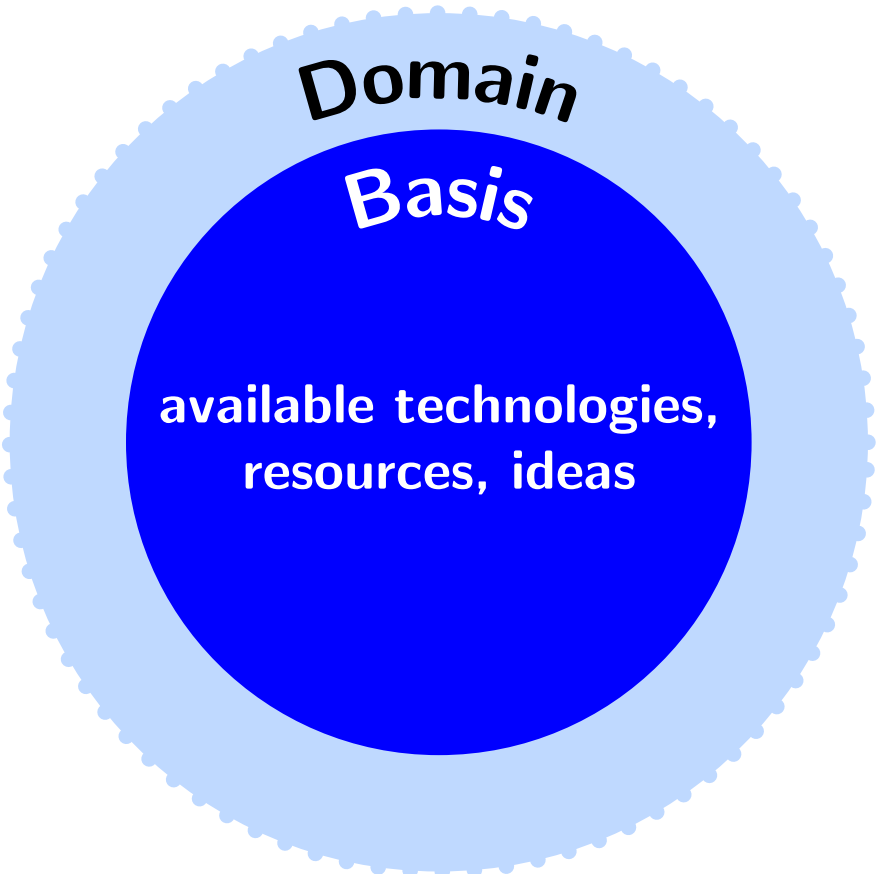
- The *basis* of good ideas.
- The *domain* of good ideas.
- The *heuristics* of exploring the domain of good ideas.
- The *facilitators* of good ideas.

The Basis and the Domain of Good Ideas

- Basis:

- Domain:

The Basis and the Domain of Good Ideas



- Basis: Available resources
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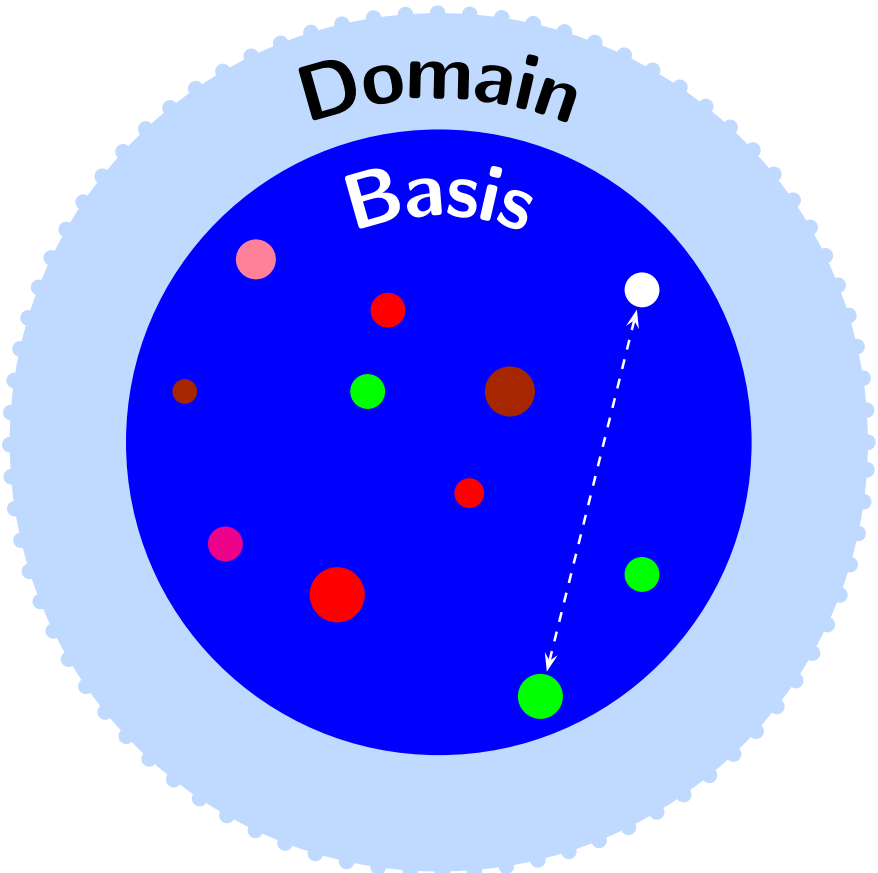
The Basis and the Domain of Good Ideas



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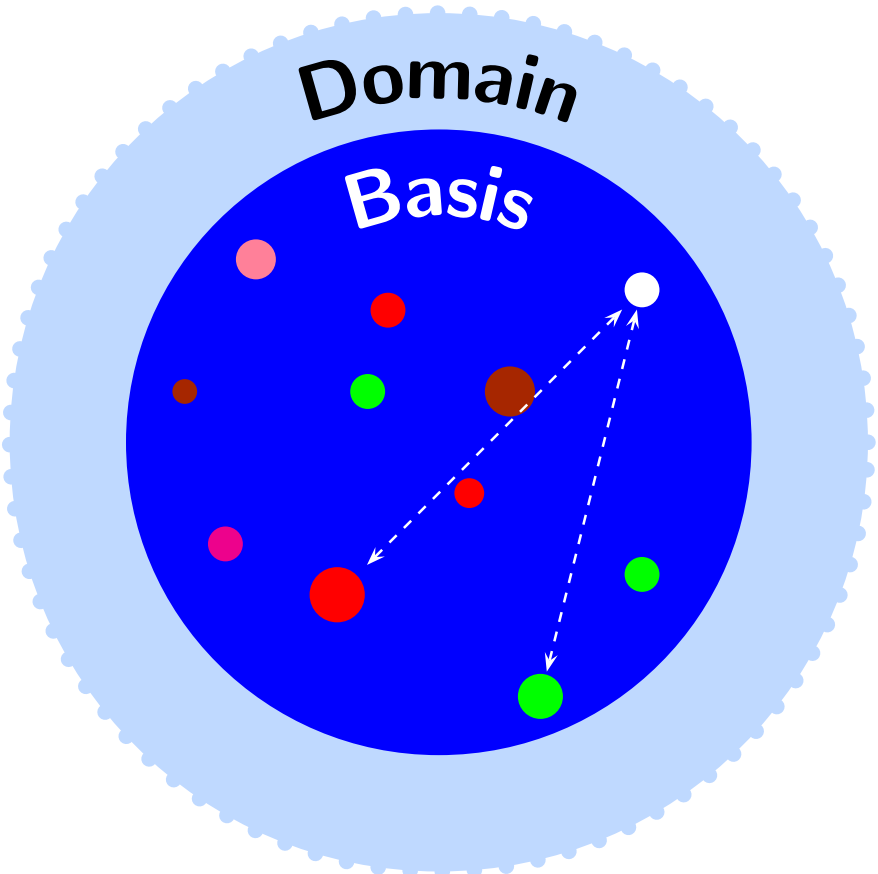

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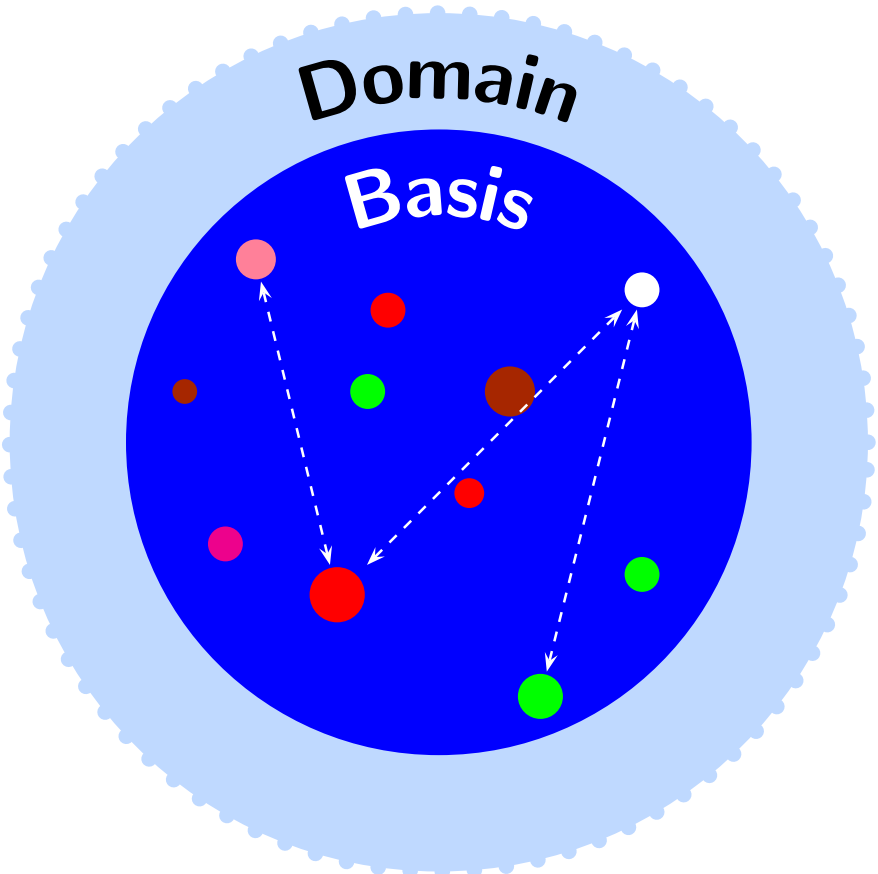

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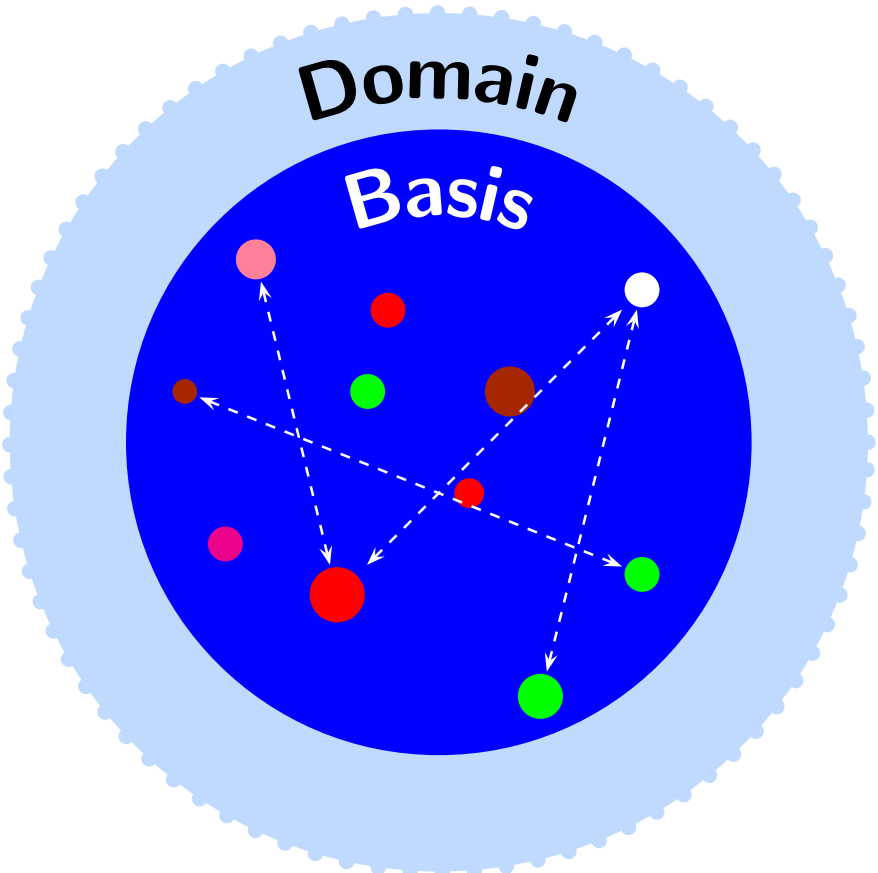

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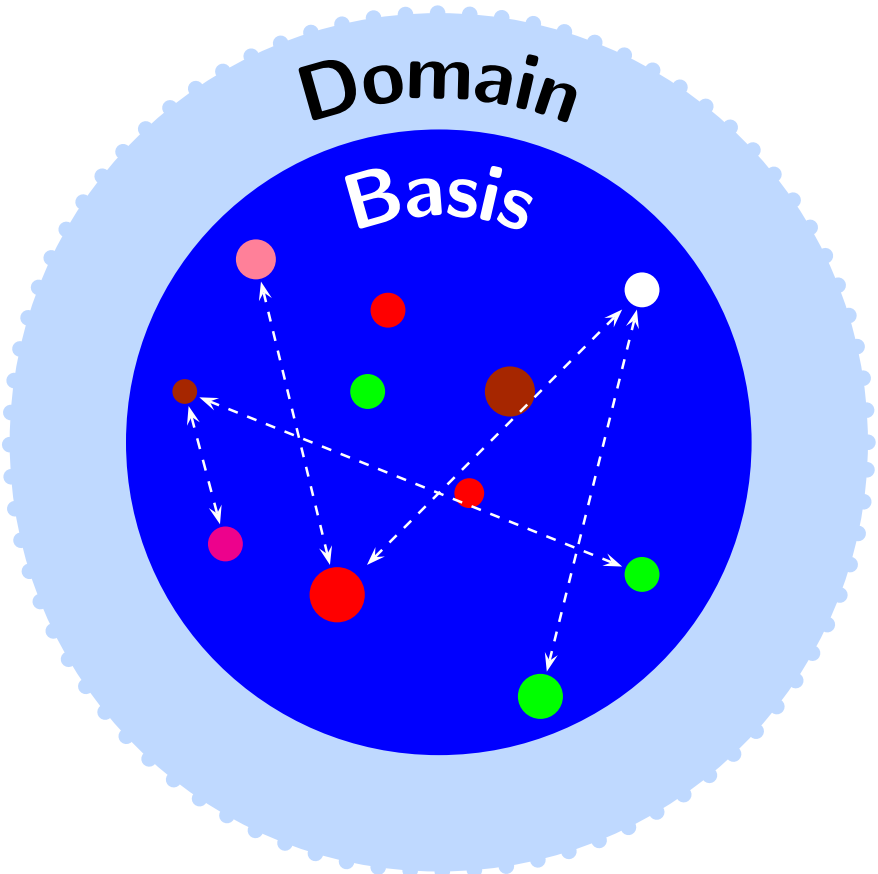

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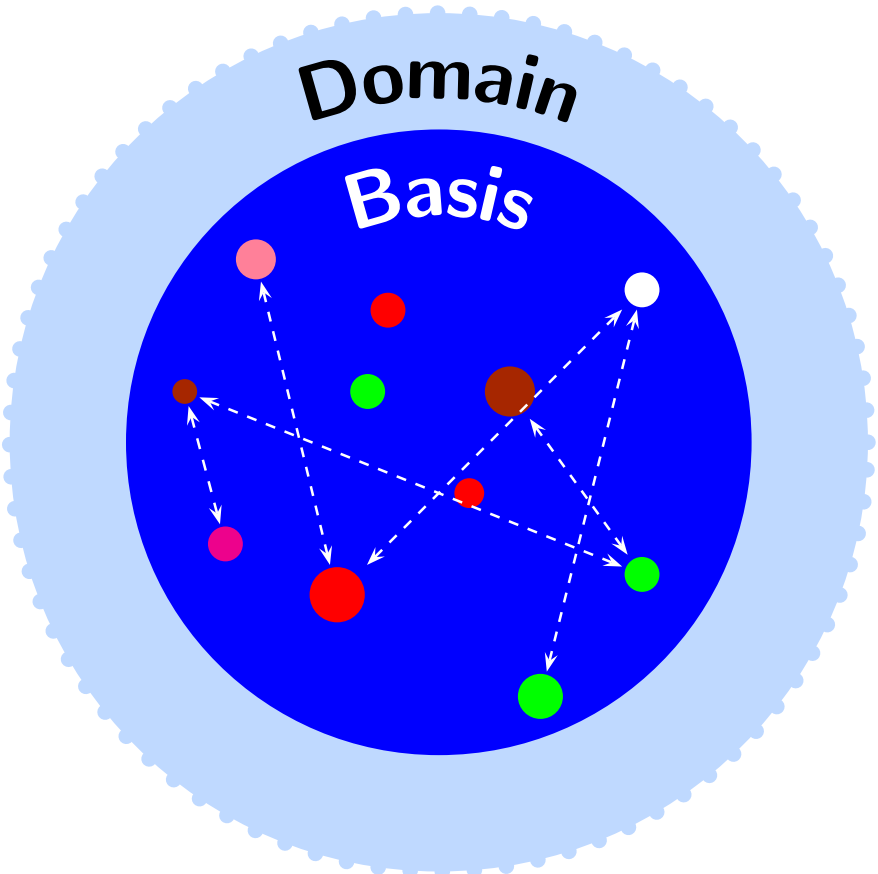

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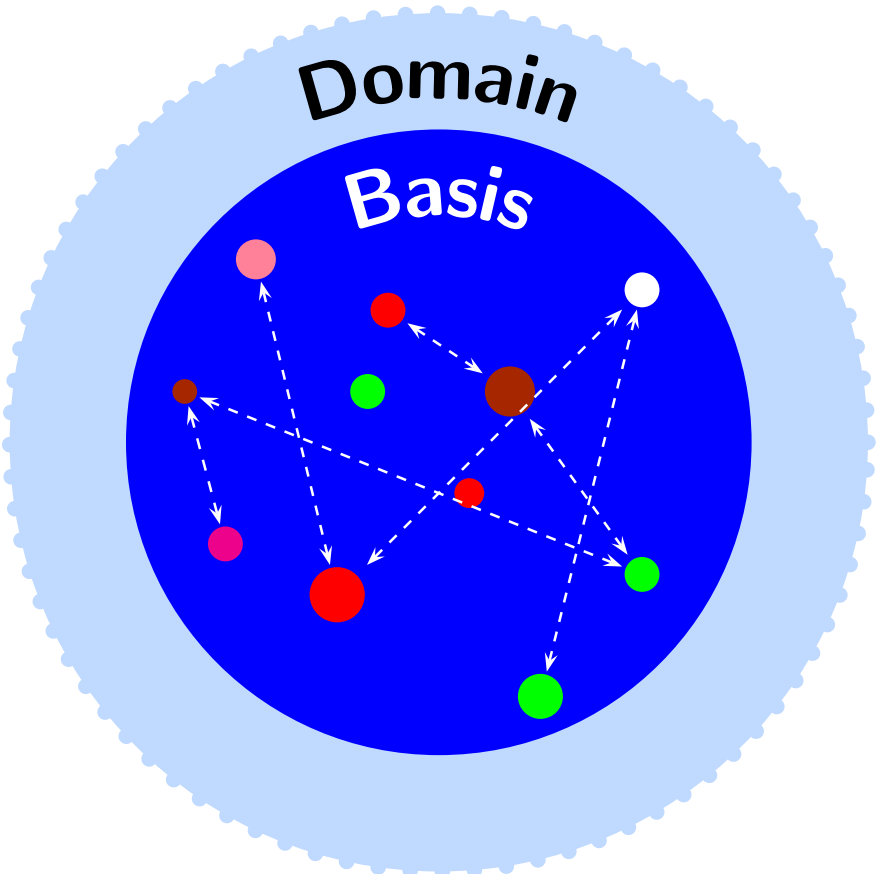

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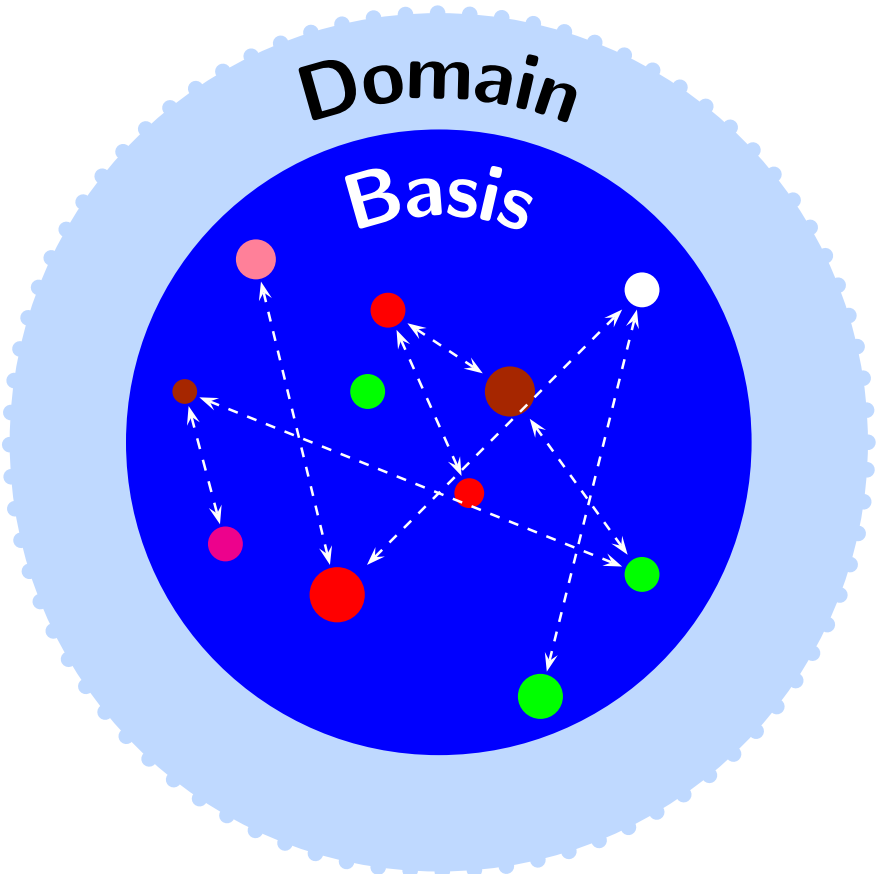

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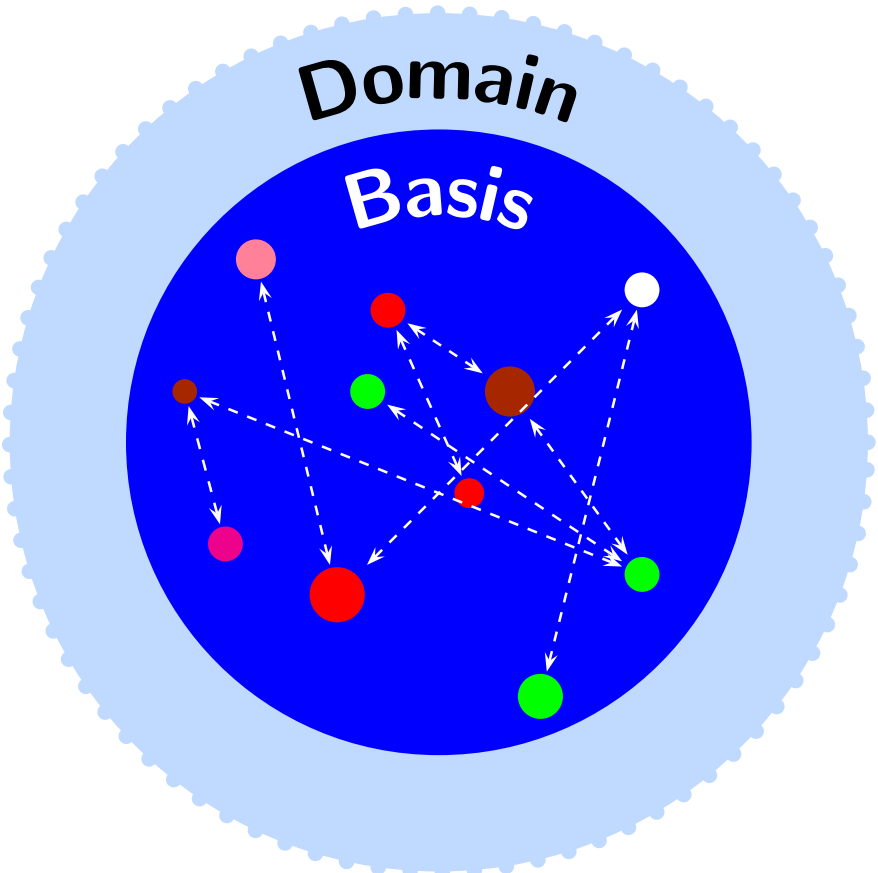

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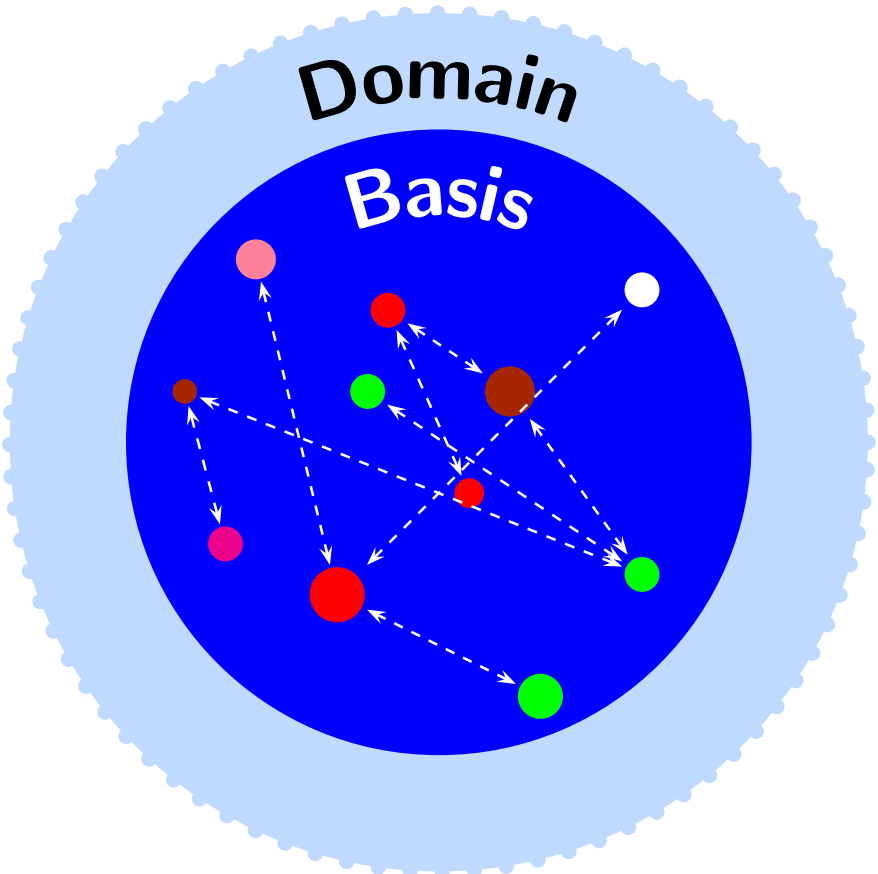

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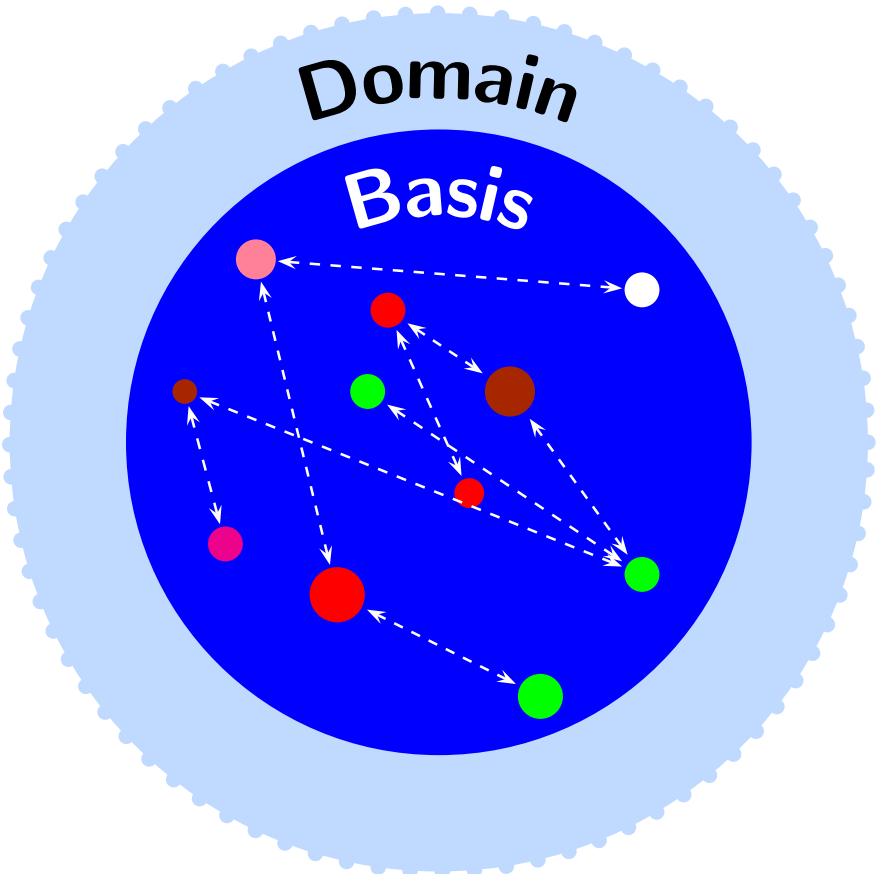

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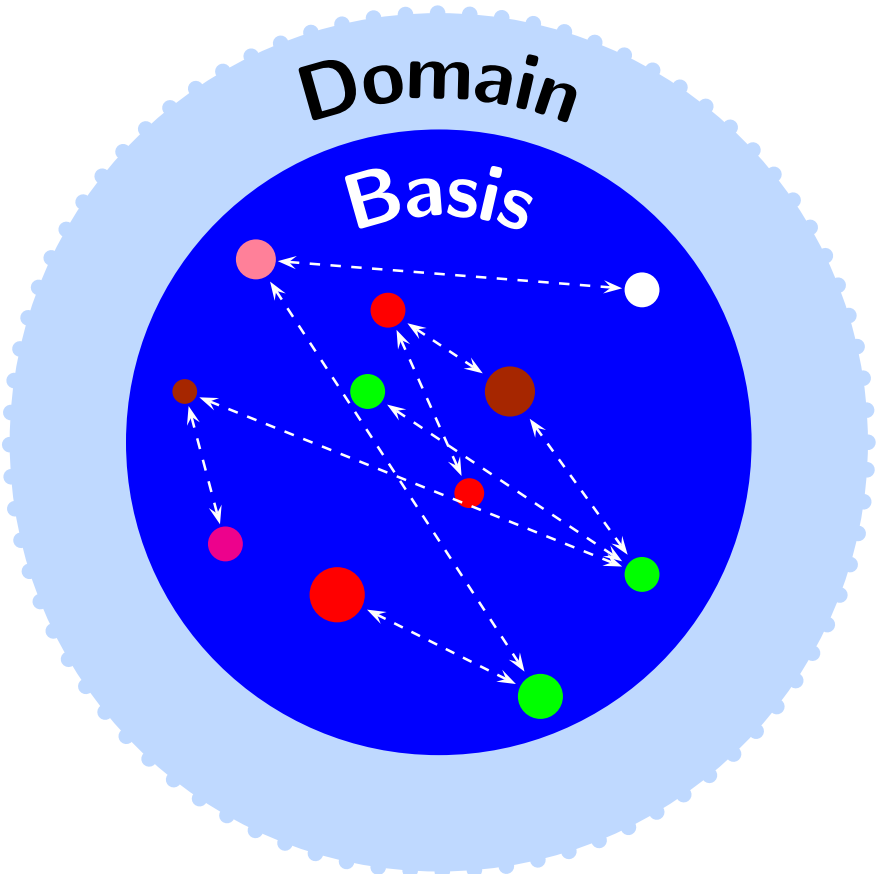

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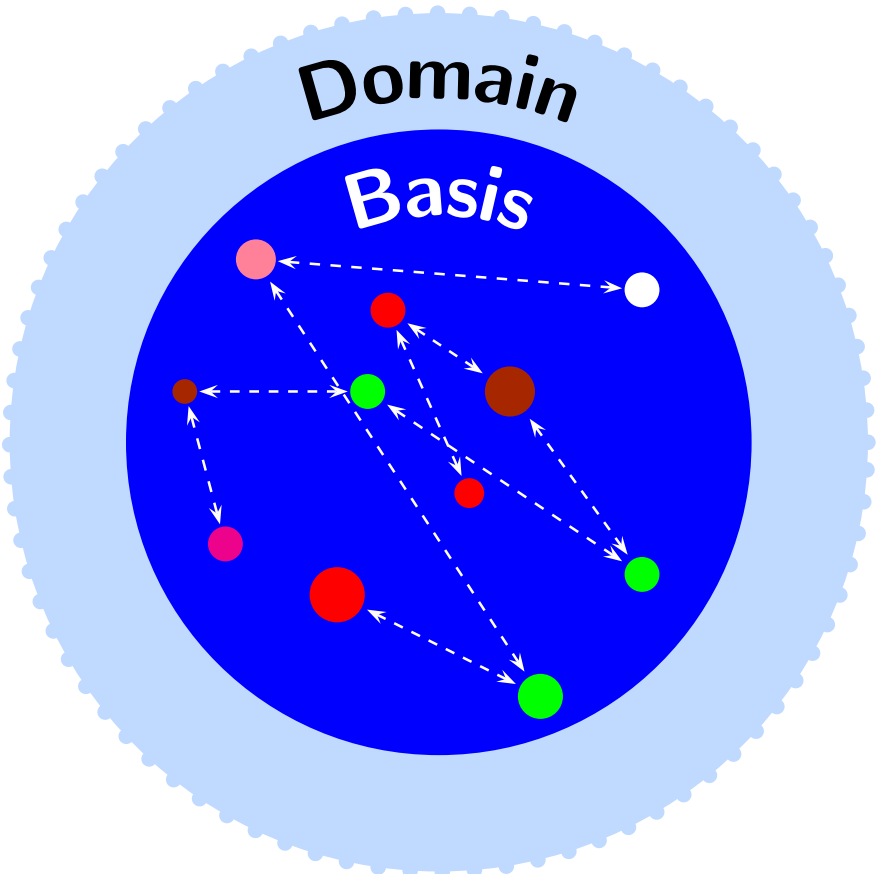

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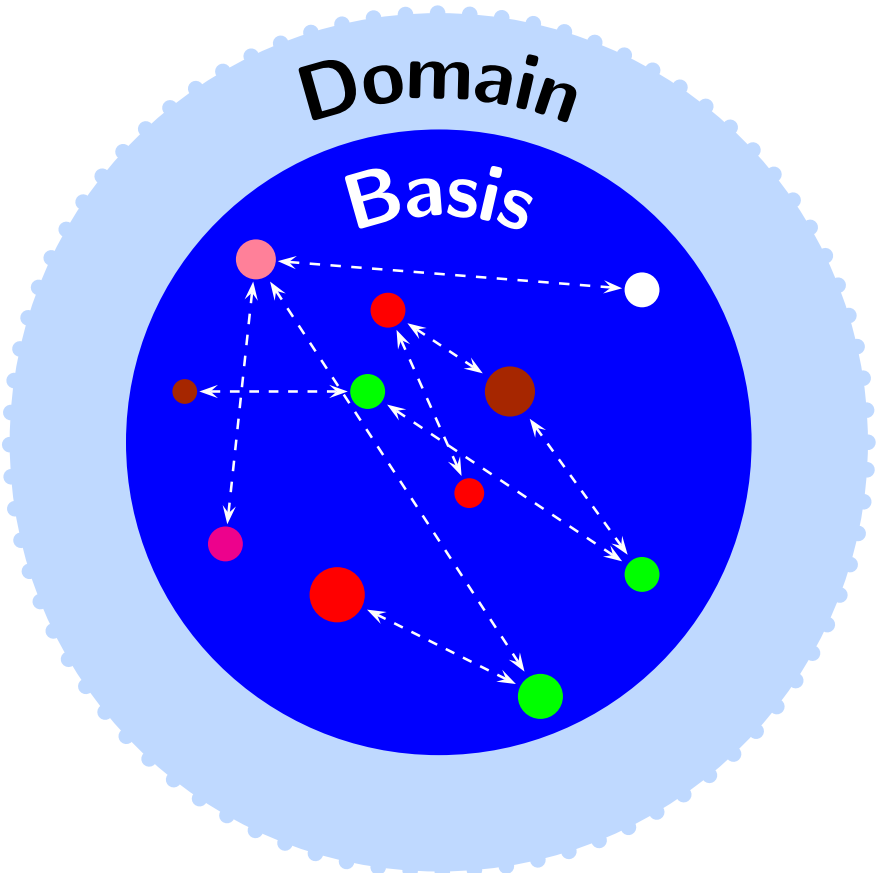

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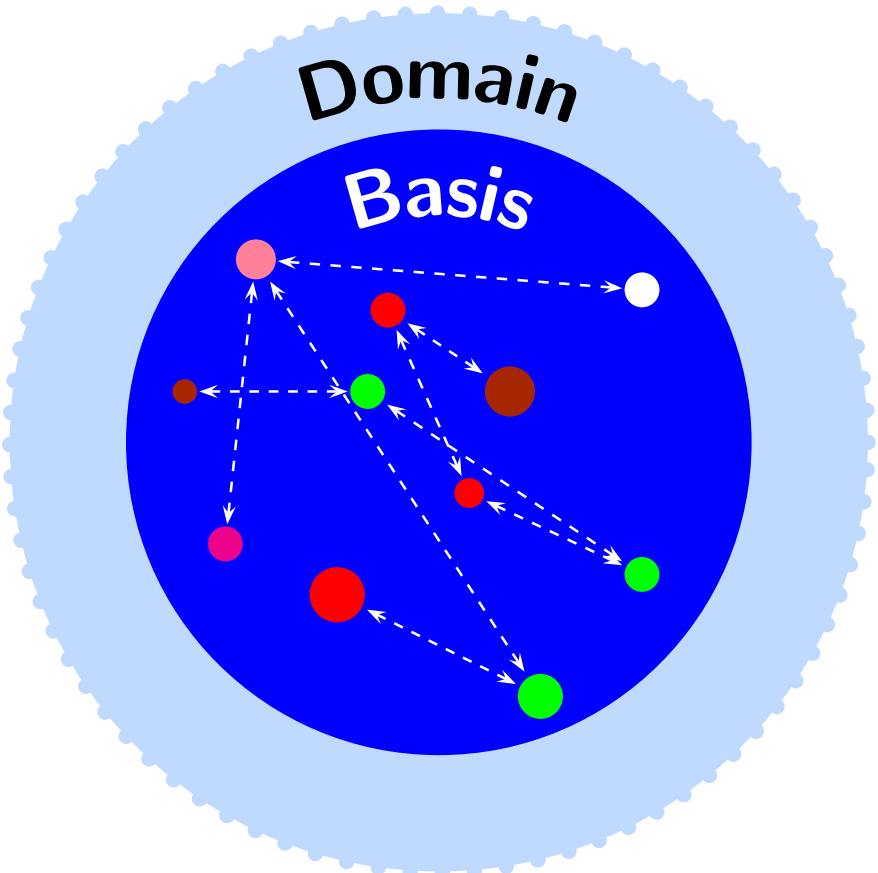

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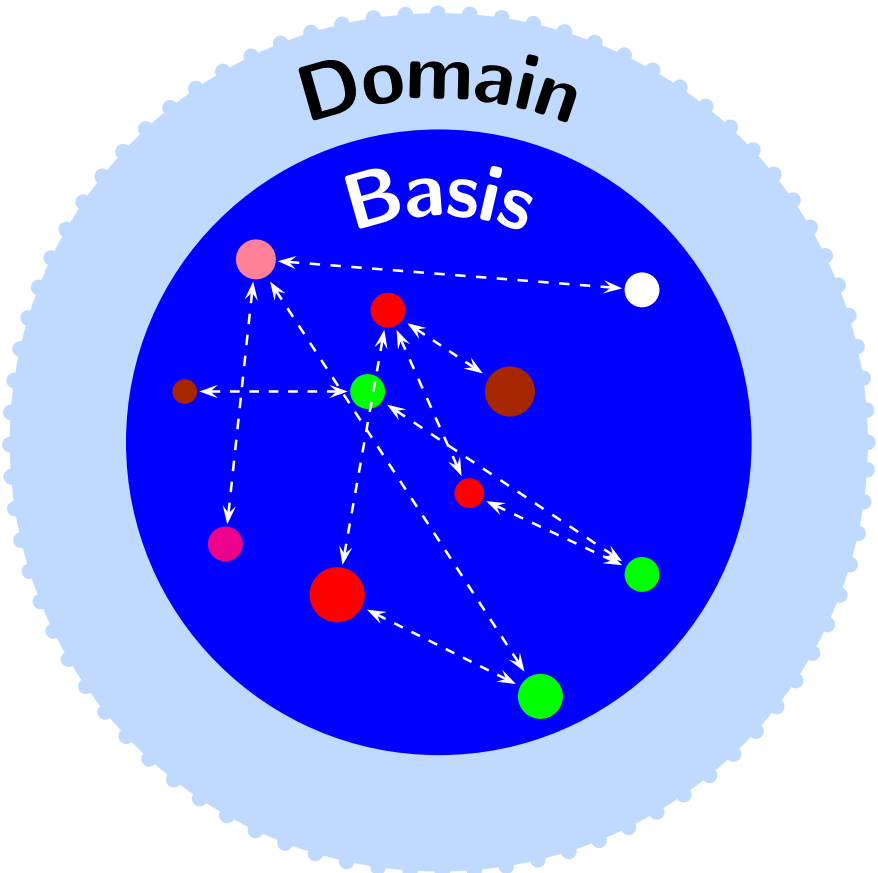

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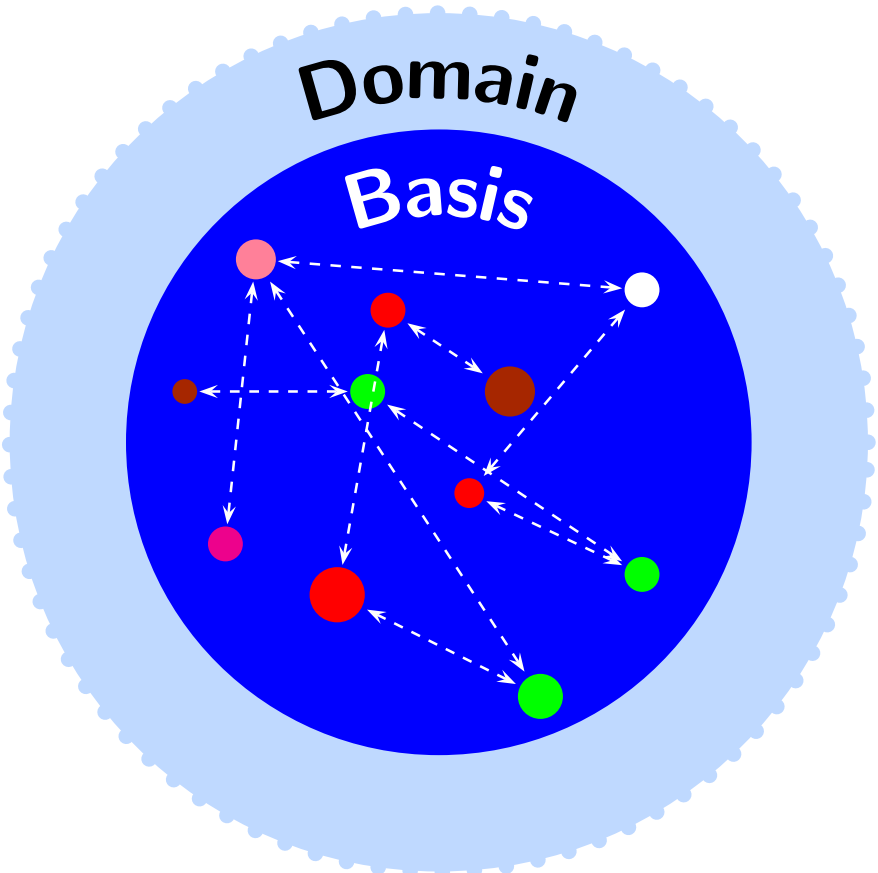

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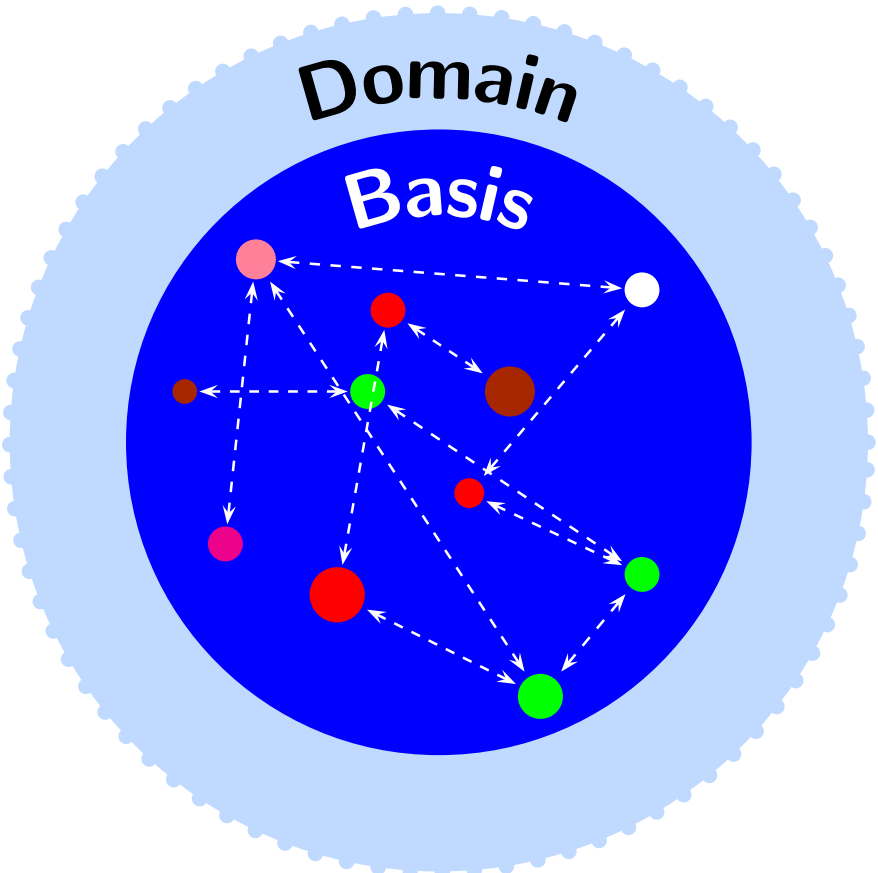

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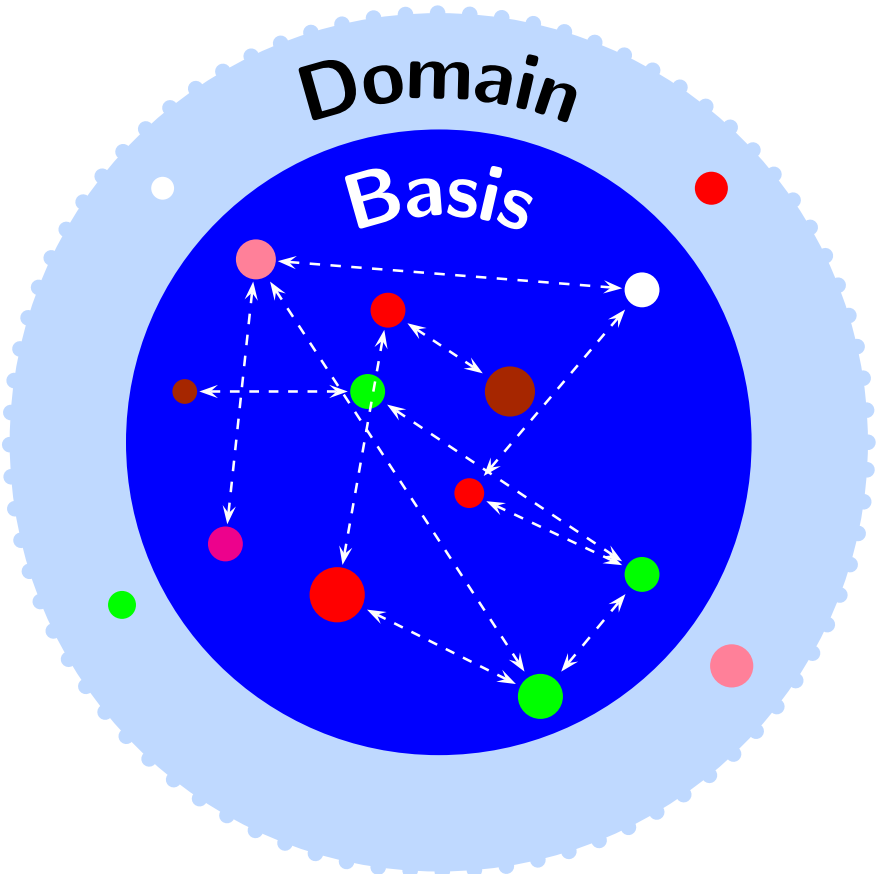

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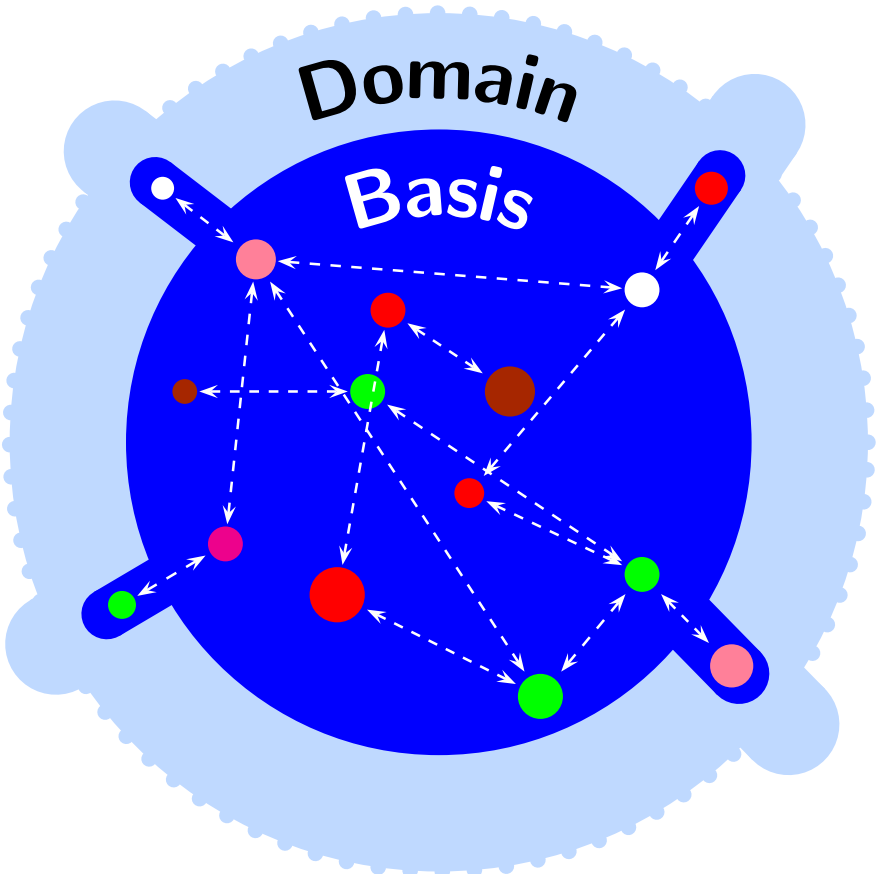

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Adjacent Possible

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Car headlights provide only a short lookahead in the night

Yet we can cover long distances over time . . .

Some Heuristics for Exploring the Adjacent Possible

- Seeking duality: Observing similarity in apparently unrelated things
- Seeking symmetry: Observing balance or patterned self-similarity
- Generalization: Removing specificities to cover more situations
- Refinement: Distilling to essesnce by removing irrelevant parts
- Extensions: Trying to stretch an idea in all possible directions
- Adaptation: Using an idea in an unrelated context

Adjacent Vs. Non-Adjacent

Charles Babbage's two revolutionary designs

- The Analytical Engine was far ahead of its time
  - All basic ideas were in place in 1837
  - The design was far too complex for the available technology (mechanical gears and switches)

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Charles Babbage's two revolutionary designs

- The Analytical Engine was far ahead of its time
  - All basic ideas were in place in 1837
  - The design was far too complex for the available technology (mechanical gears and switches)
- The Difference Engine was well within the bounds of adjacent possible
  - 15 ton contraption with 25000 mechanical parts
  - Calculating polynomial functions for creating trigonometric tables for navigation

  After many improvements, the idea actually transcended the adjacent possible when William Burroughs started mass production in 1844

Creation of FORTRAN as an Example of Adjacent Possible

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- Creation of FORTRAN is a triumph of the genius of AND over the tyranny of OR

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  Screw press for wine making used by Gutenberg for printing press

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  French weaver Jacquard's punch card system adopted by Charles Babbage for representing programs

More Adaptation Examples

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  Guier and Weiffenbach's Sputnik orbit tracing system developed at Applied Physics Laboratory of Johns Hopkins University (Oct 1957)

  - The inverse idea used for deciding the trajectory of missile fired from a submarine (discovering the exact location of a submarine using a satellite with known orbit)
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- Adaptation Example 4:

  Shannon's Master's thesis: *A Symbolic Analysis of Relay and Switching Circuits*, MIT, 1937

  - Digital circuit design was an engineering art with no clear science or mathematics behind them
  - Shannon noted that the switches were either open or closed. This coincided nicely with the algebra created by George Boole in 1847

The Facilitators of Discovery of Good Ideas

- The obvious facilitators
  - Curiosity
  - Experimentation
  - Observation
  - Discussion
- Some non-obvious facilitators
  - Slow Hunch
  - Serendipity
  - Error

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- Example: Darwin's theory of natural selection (Oct 1838)

  "favourable variations would be preserved and unfavourable would be destroyed"'

  - His autobiography suggests he realized this on 28 Sept 1838 while reading an essay on population by Robert Malthus,
  - Historical evidence shows that it evolved over 15 months with early traces of the idea found in his notings in 1937

Serendipity

Word coined by English novelist Horace Walpole (1754), inspired by Persian fairy tale "*Three Princes of Serendip*"

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  Dmitri Mendeleev's idea of periodic table ordered by atomic weight

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- Error Example 2: De Forest's electrodes in a gas filled glass tubes
  - Original experiment involved spark gap transmitter for telegraphy
  - A twisted wire middle electrode resulted in a good amplifier
  - Eventually, it led to a vacuum tube based triode

Part 5

The Process of Research

The Spirit of Inquiry (1)

Very few of us know,
how much we have to know,
in order to know,
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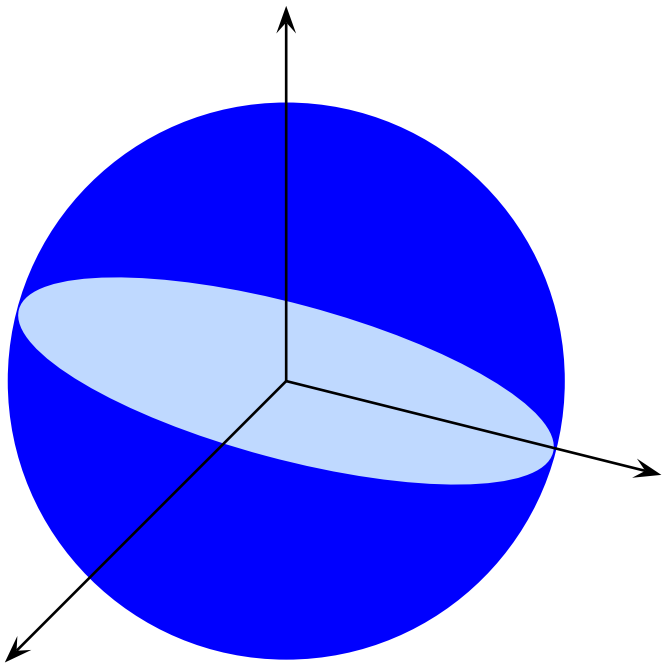

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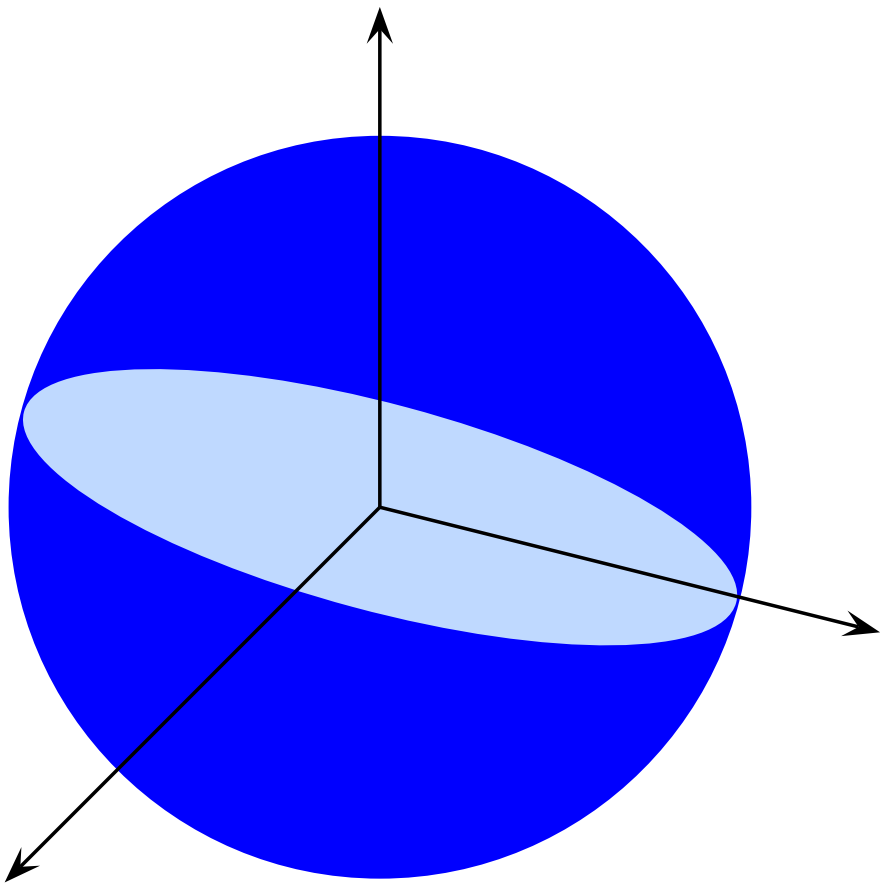

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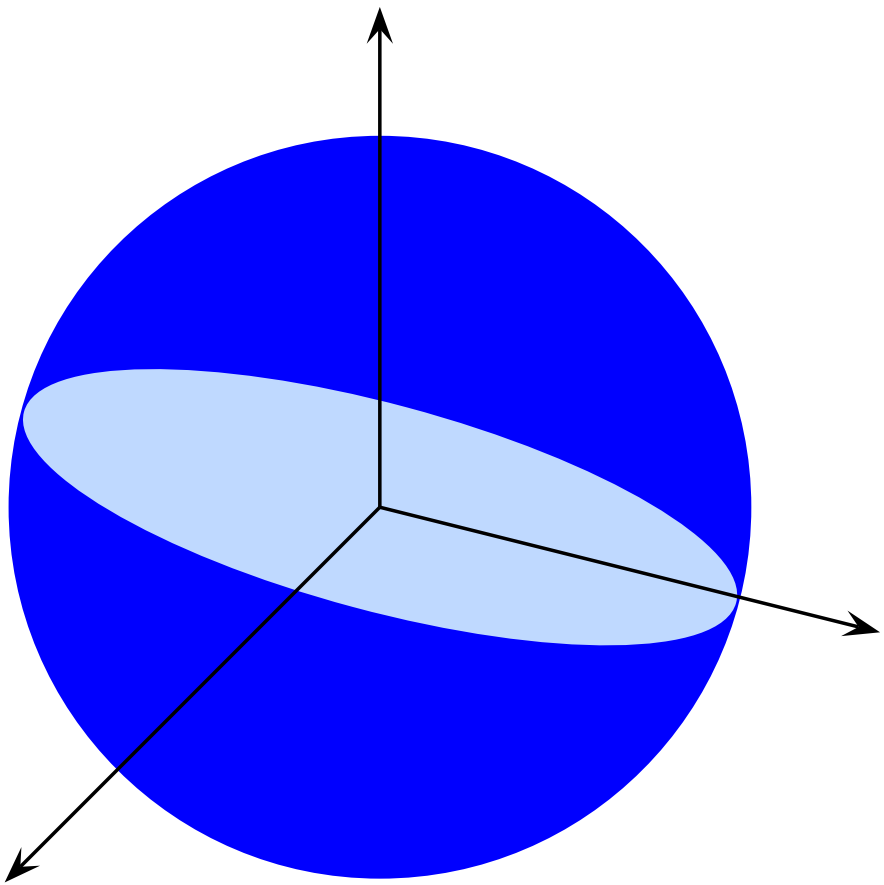

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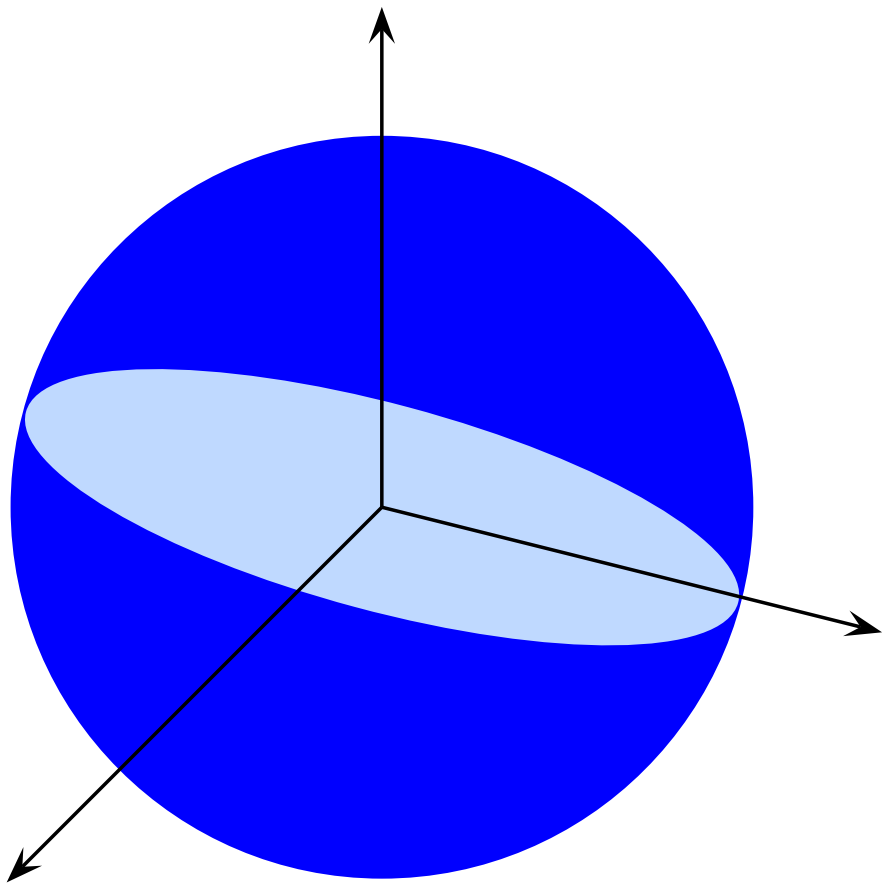

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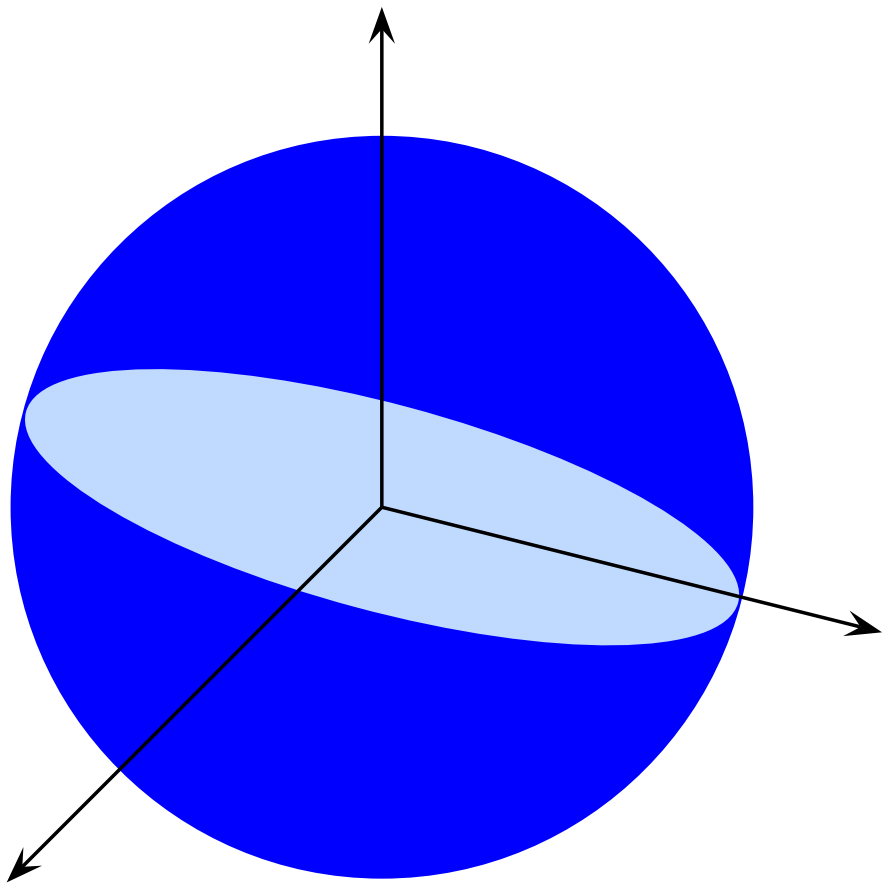

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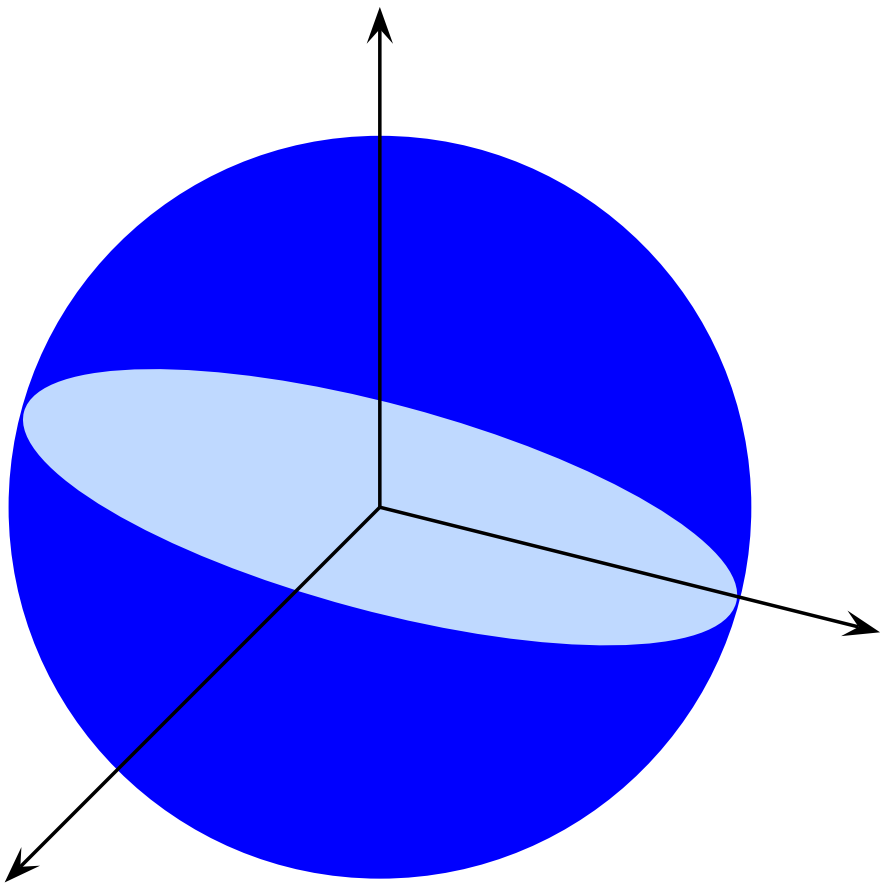

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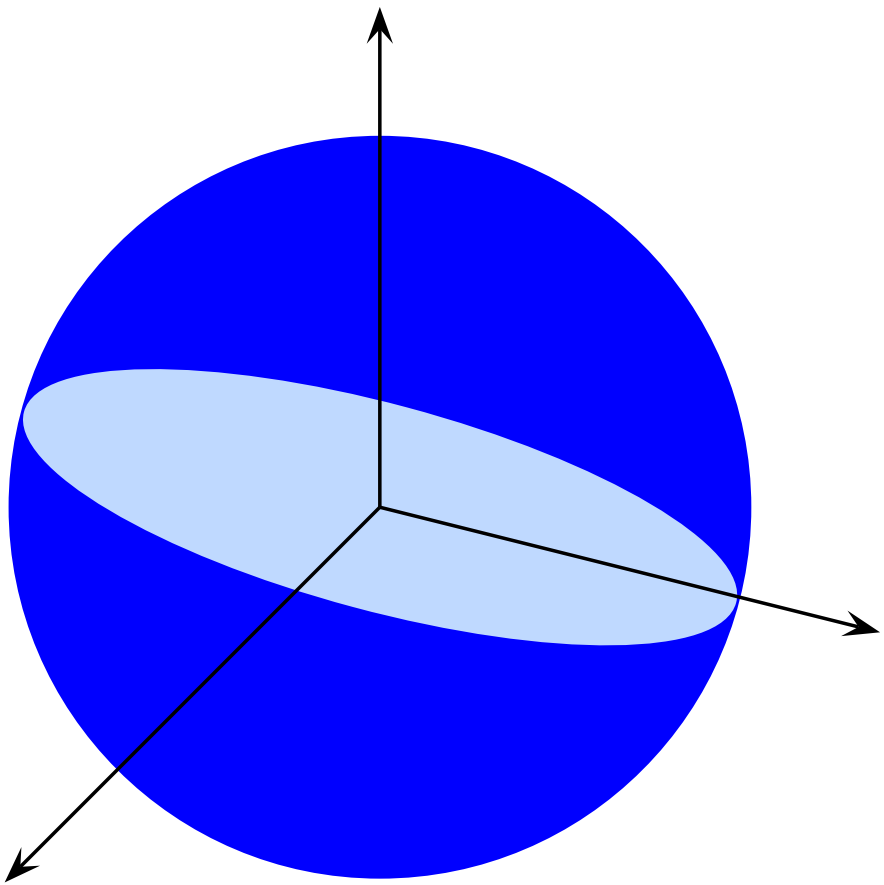

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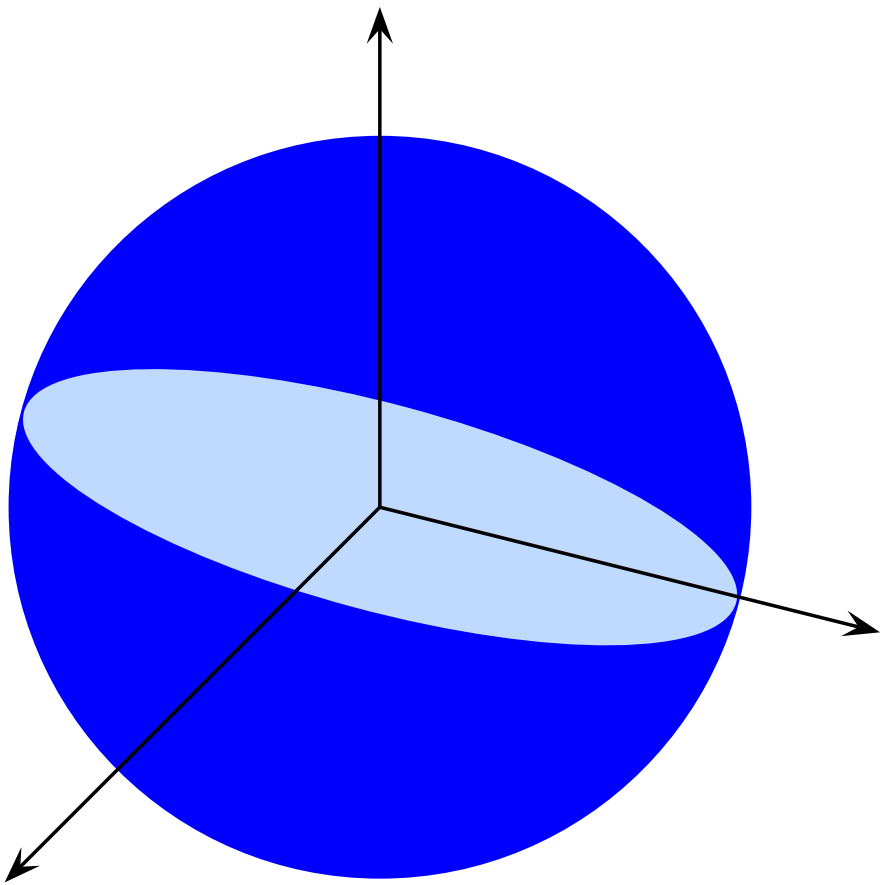

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It's important to know what we know and what we don't and be comfortable with it

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- Is independent thinking disrepectful?
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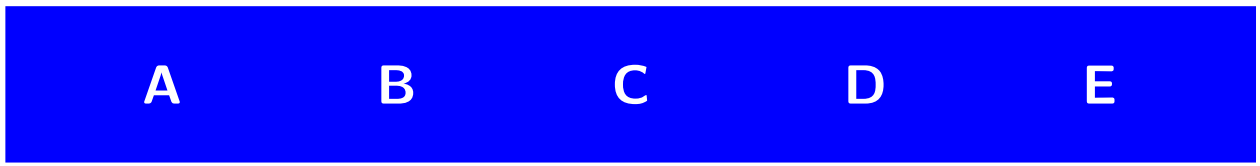

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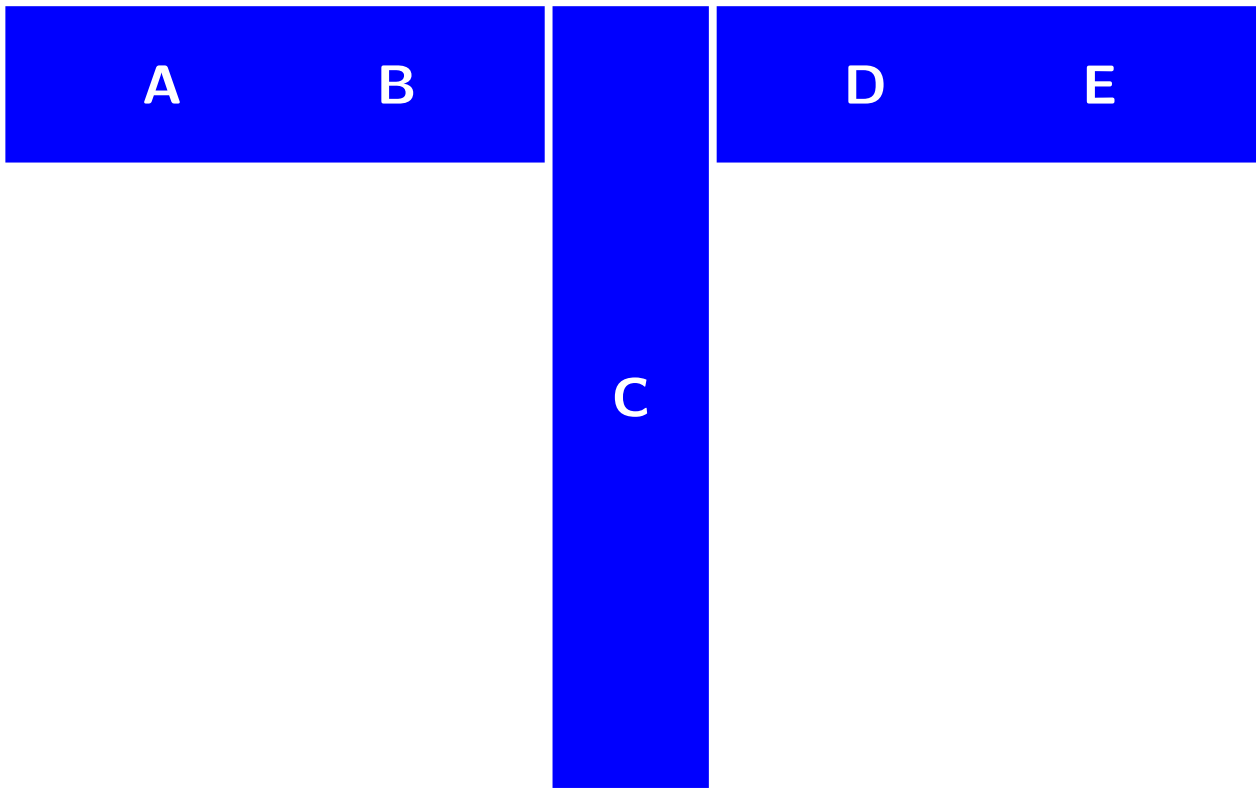

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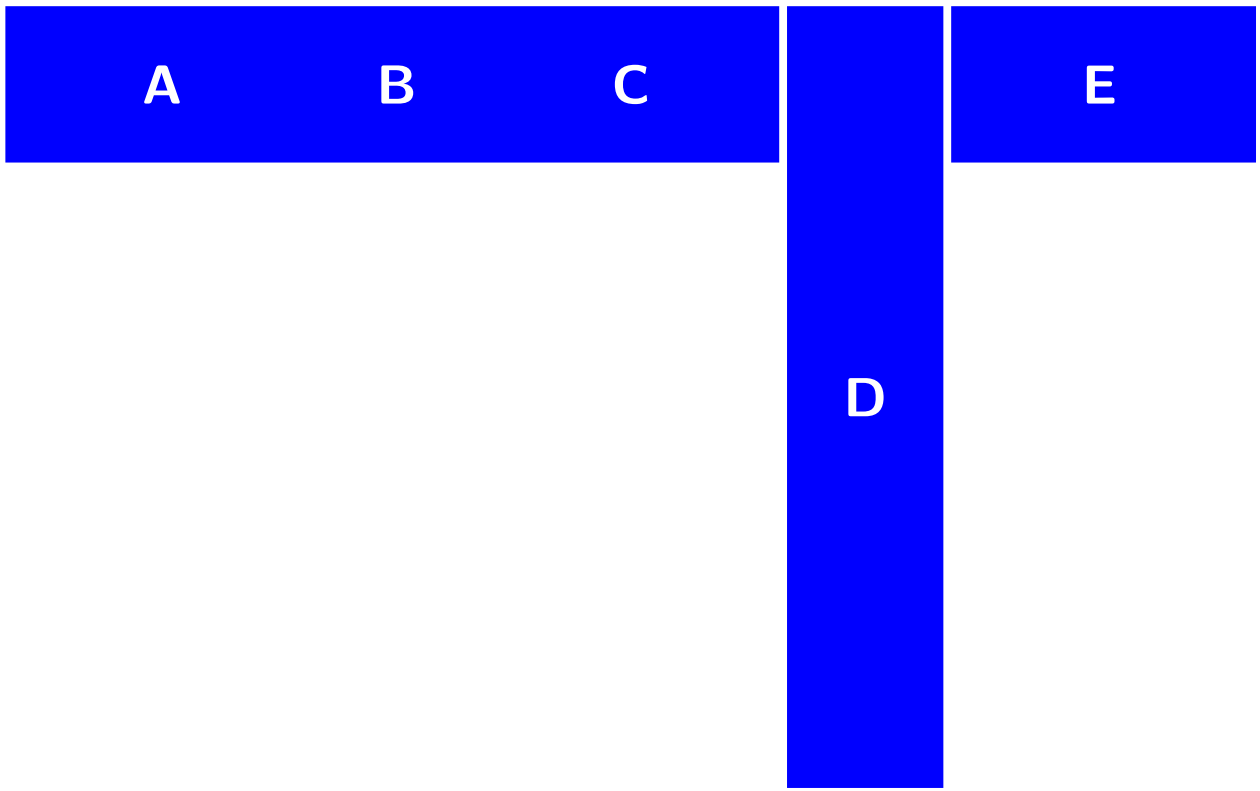

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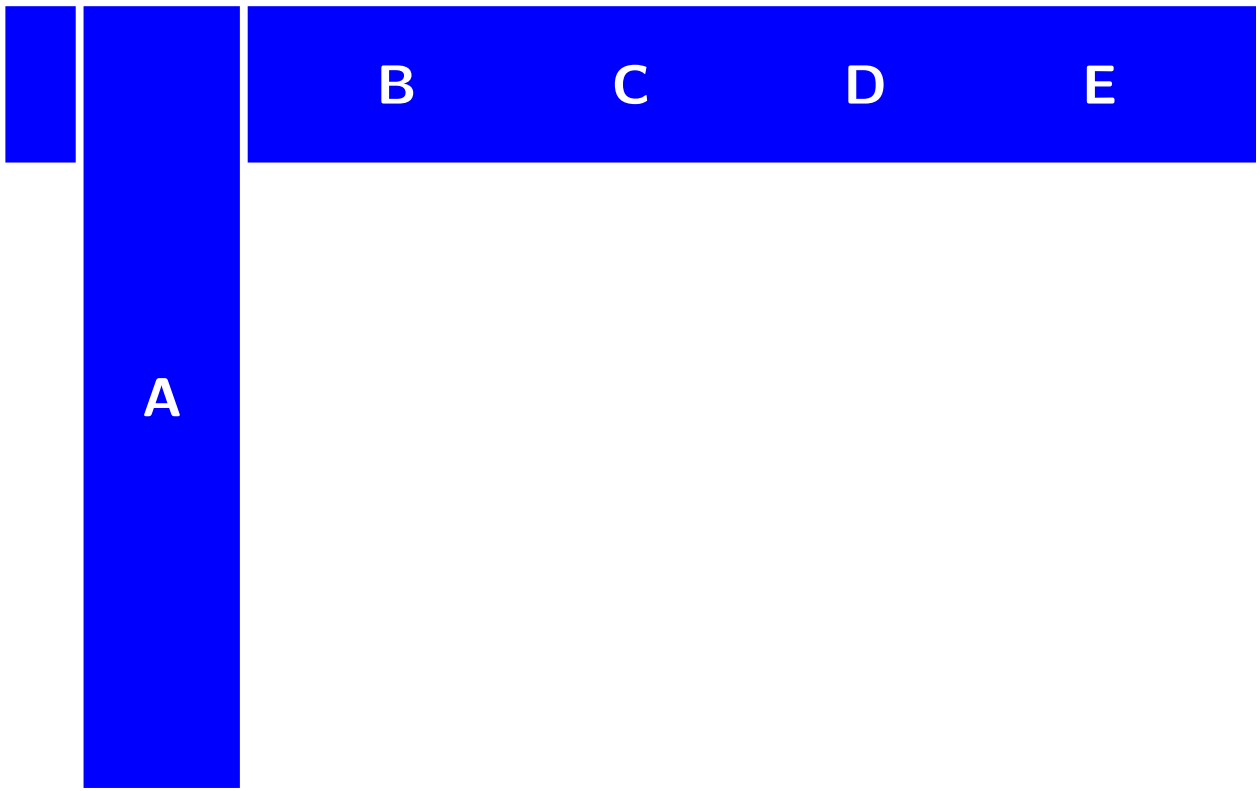

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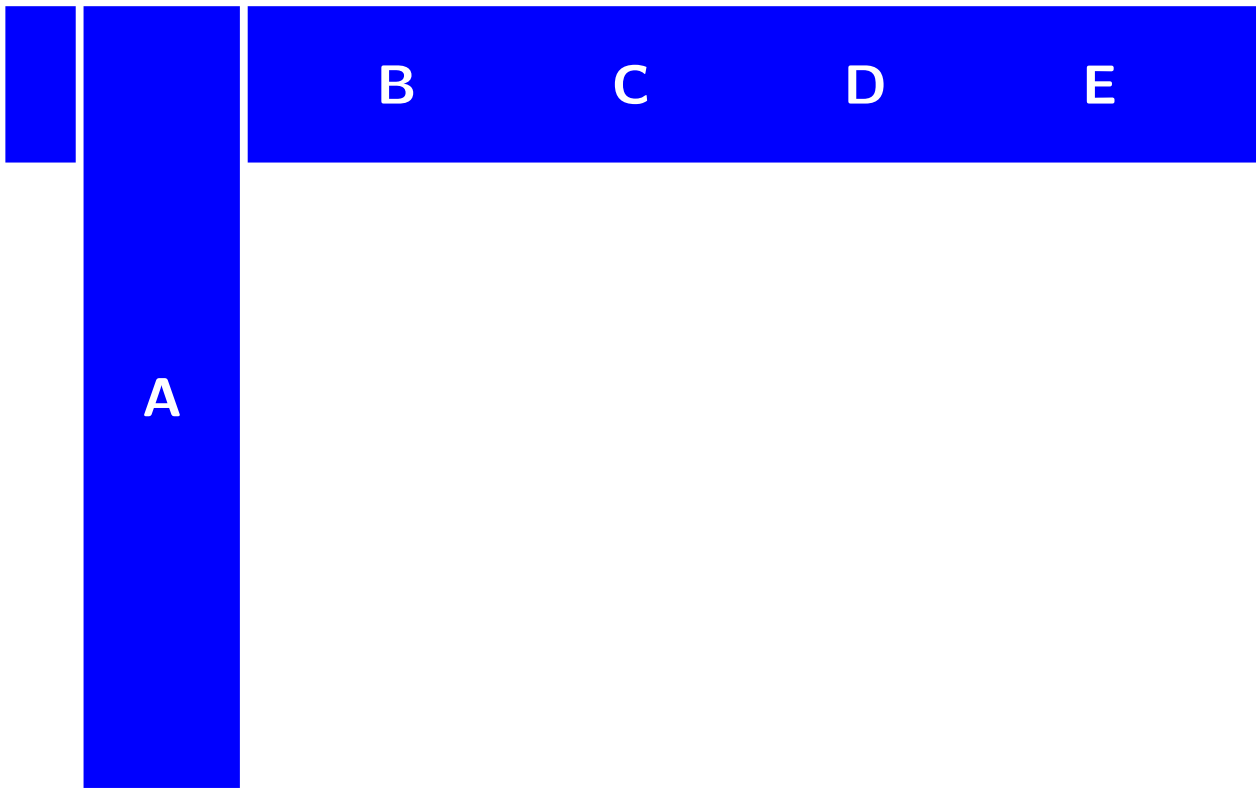

Breadth or Depth?

Breadth Vs. Depth

Achieve depth in one area and overall breadth

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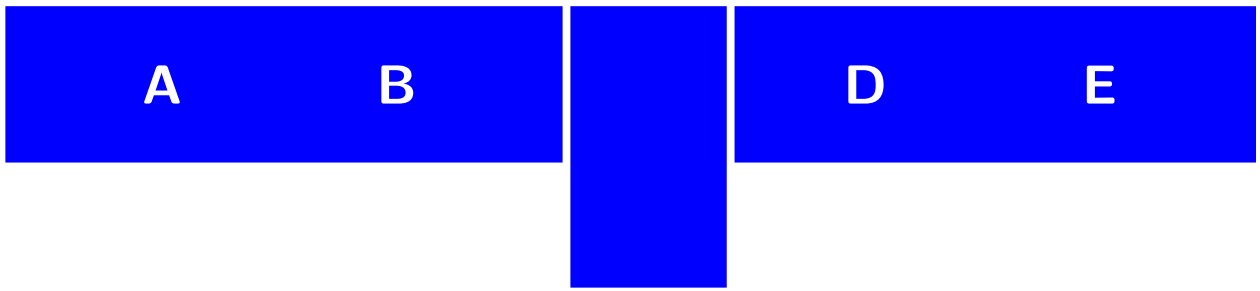

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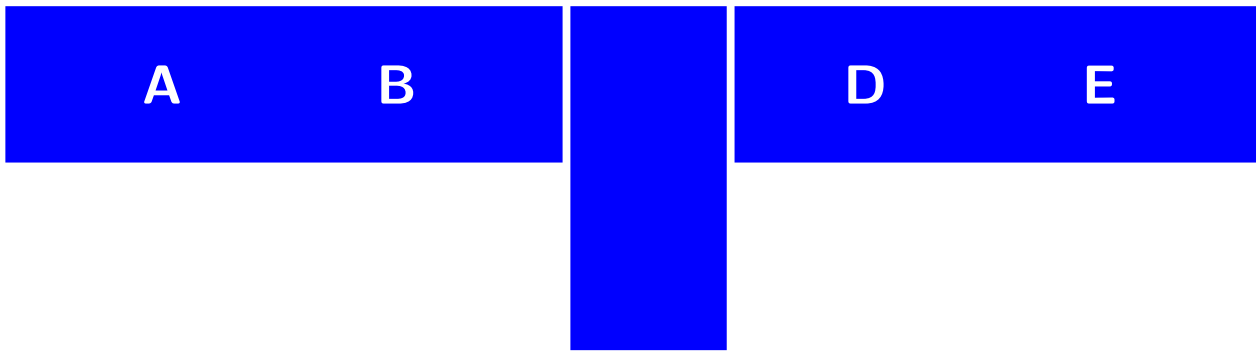

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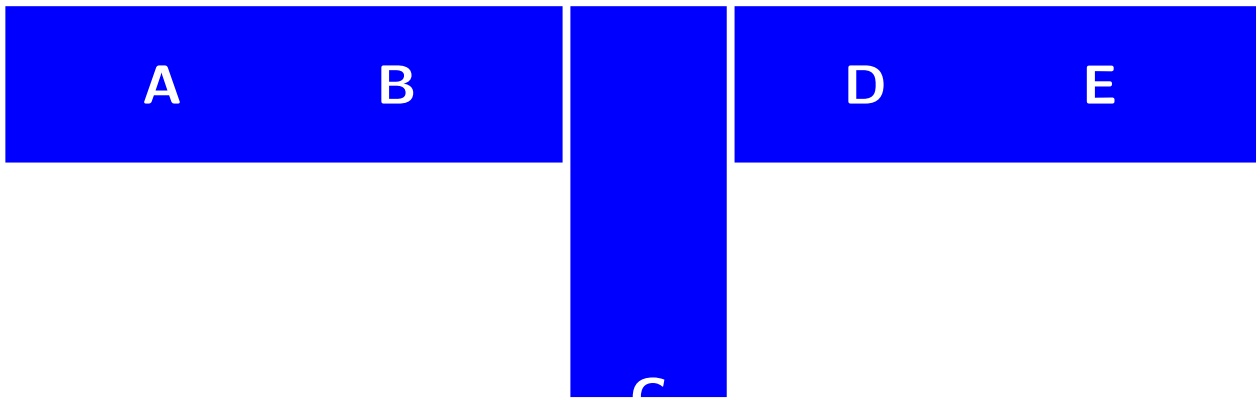

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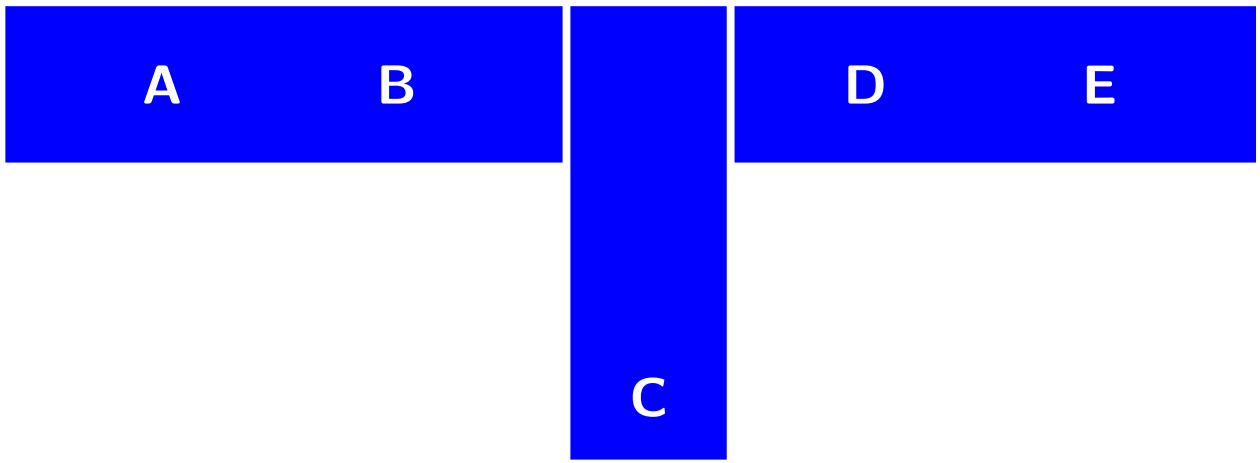

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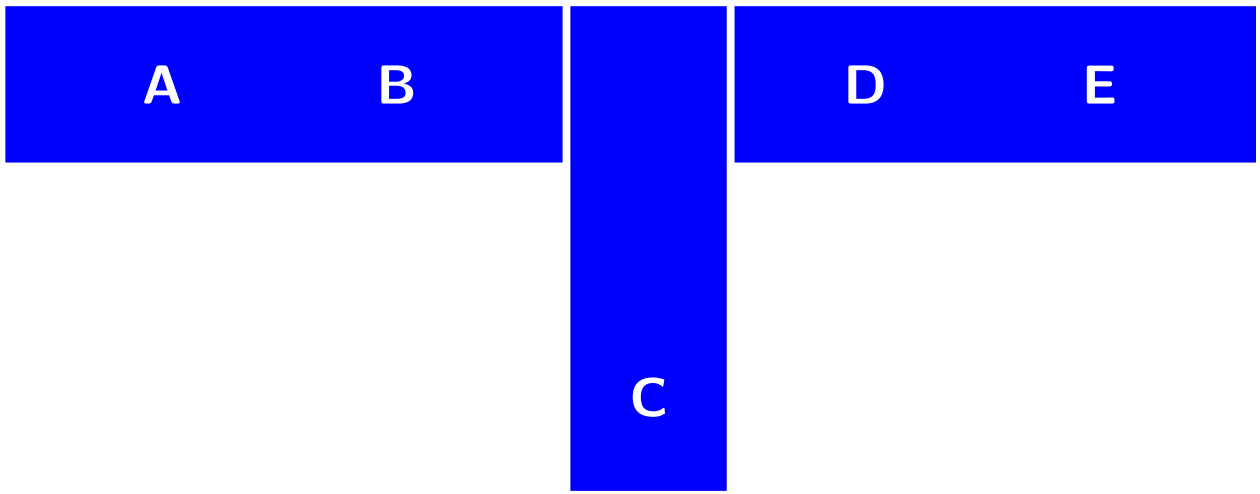

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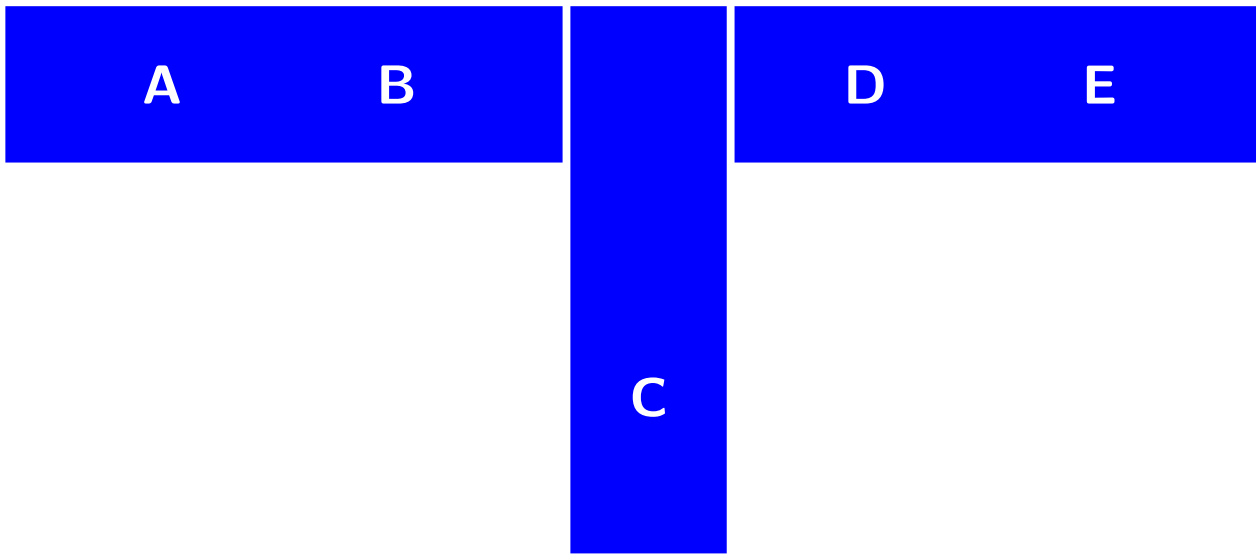

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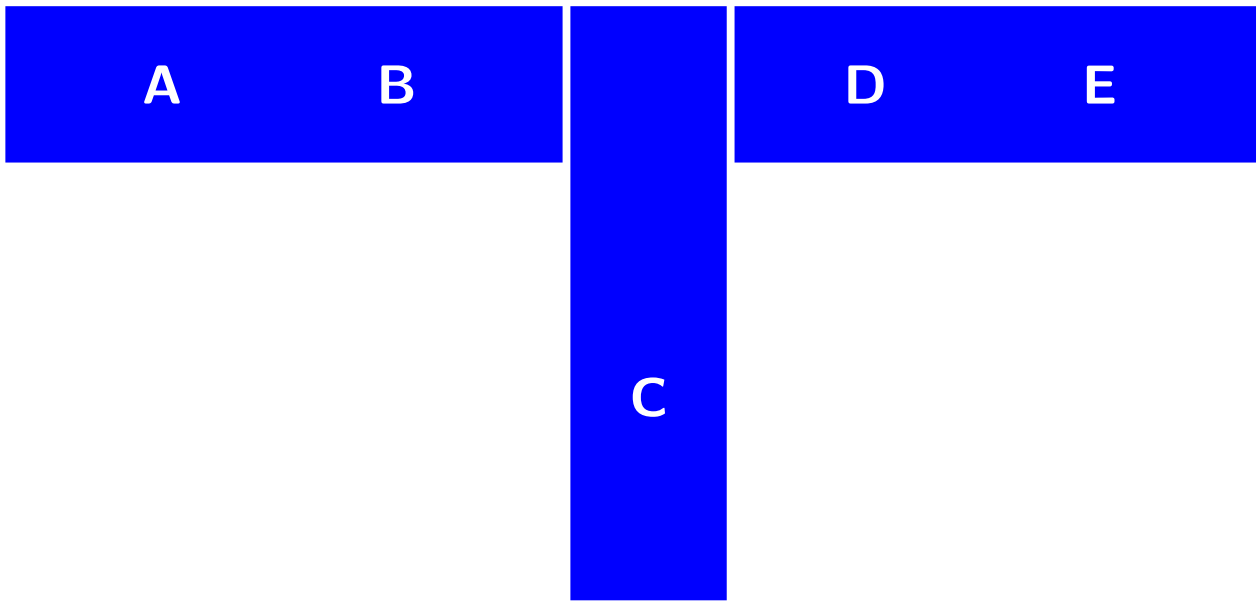

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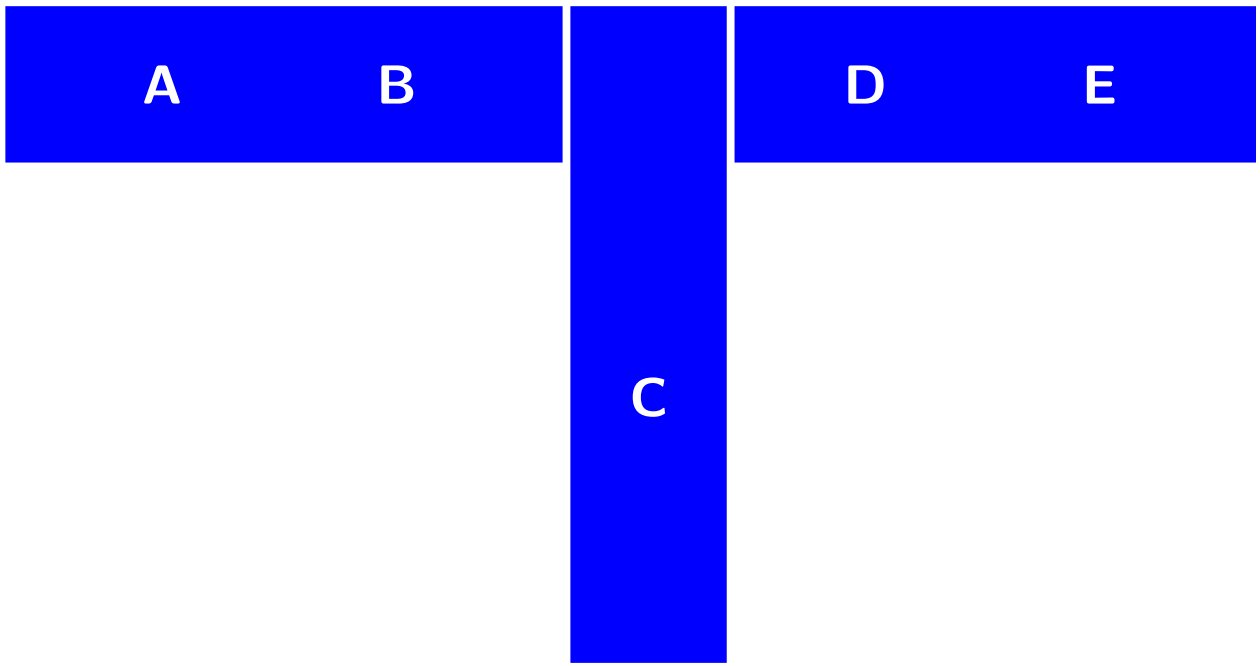

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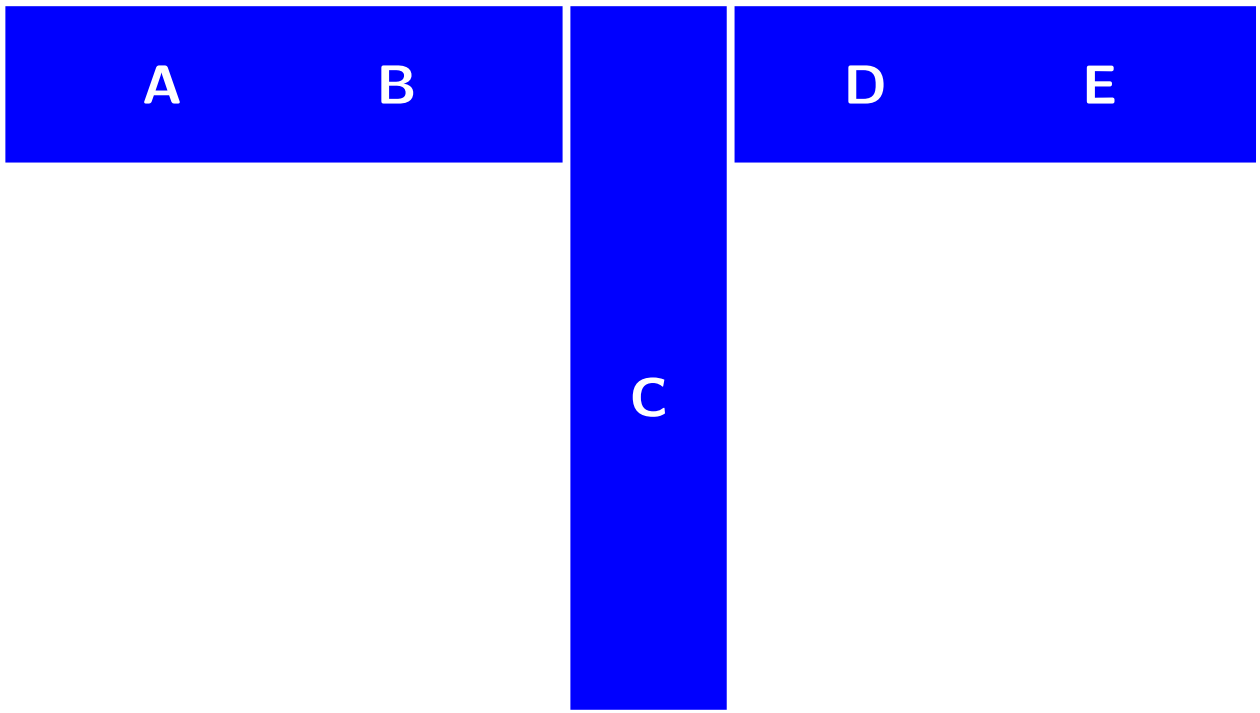

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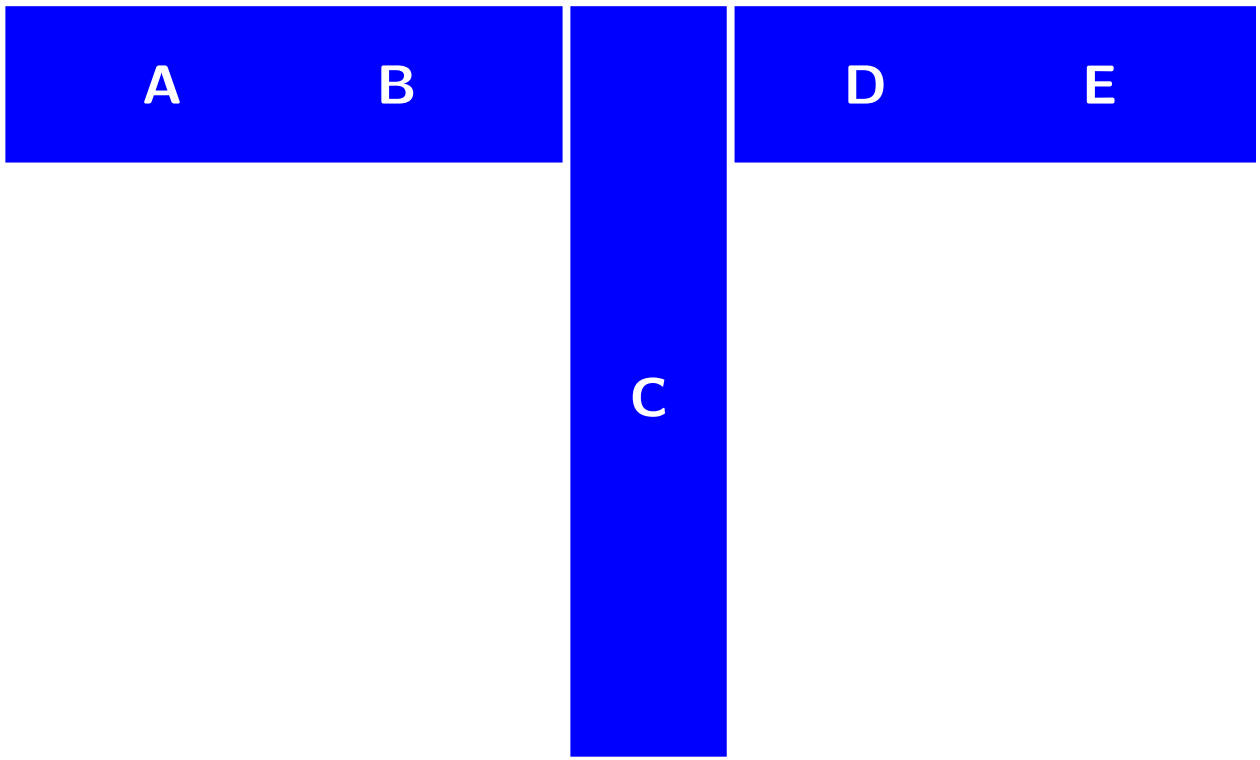

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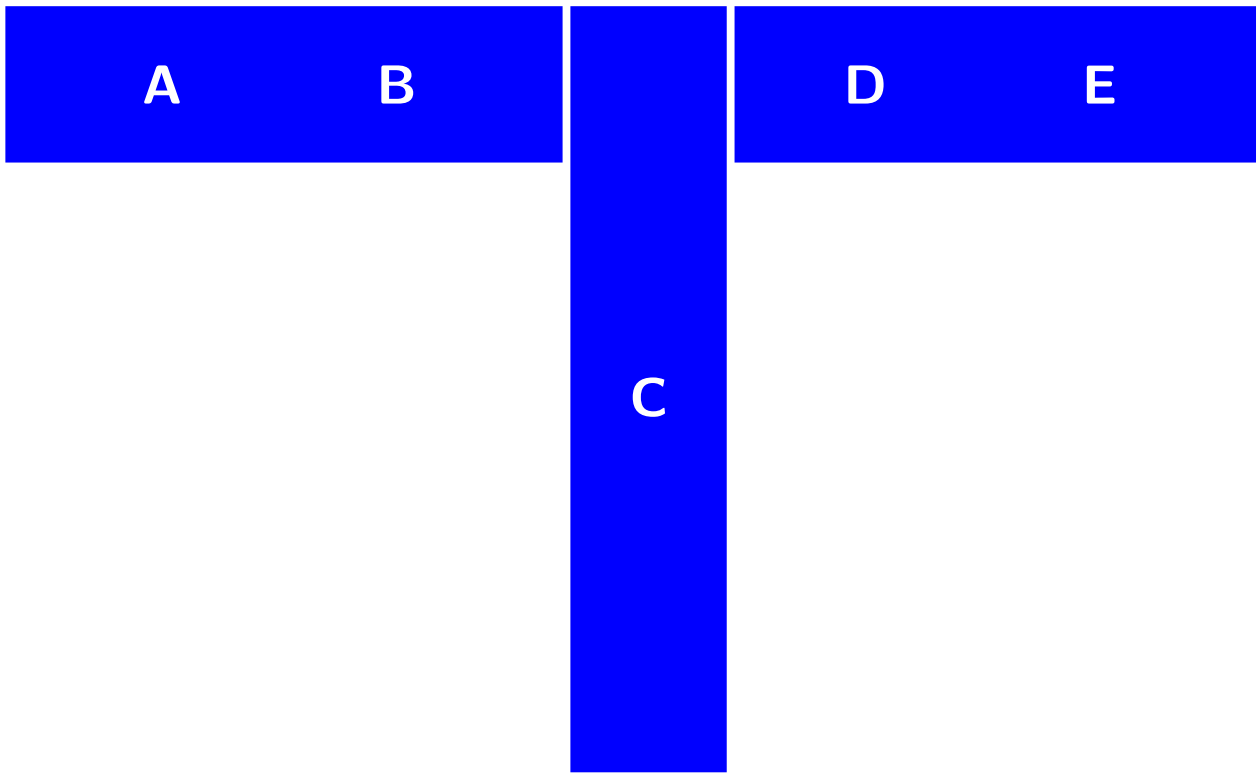

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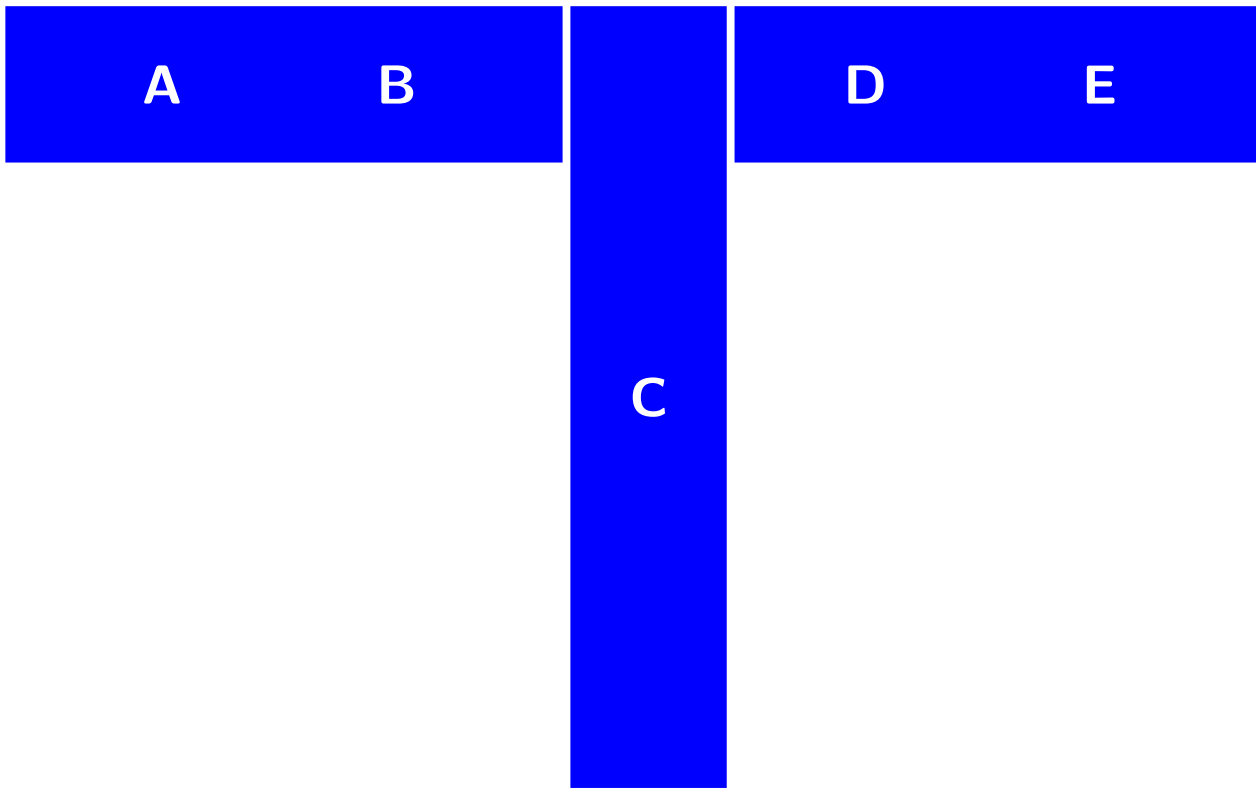

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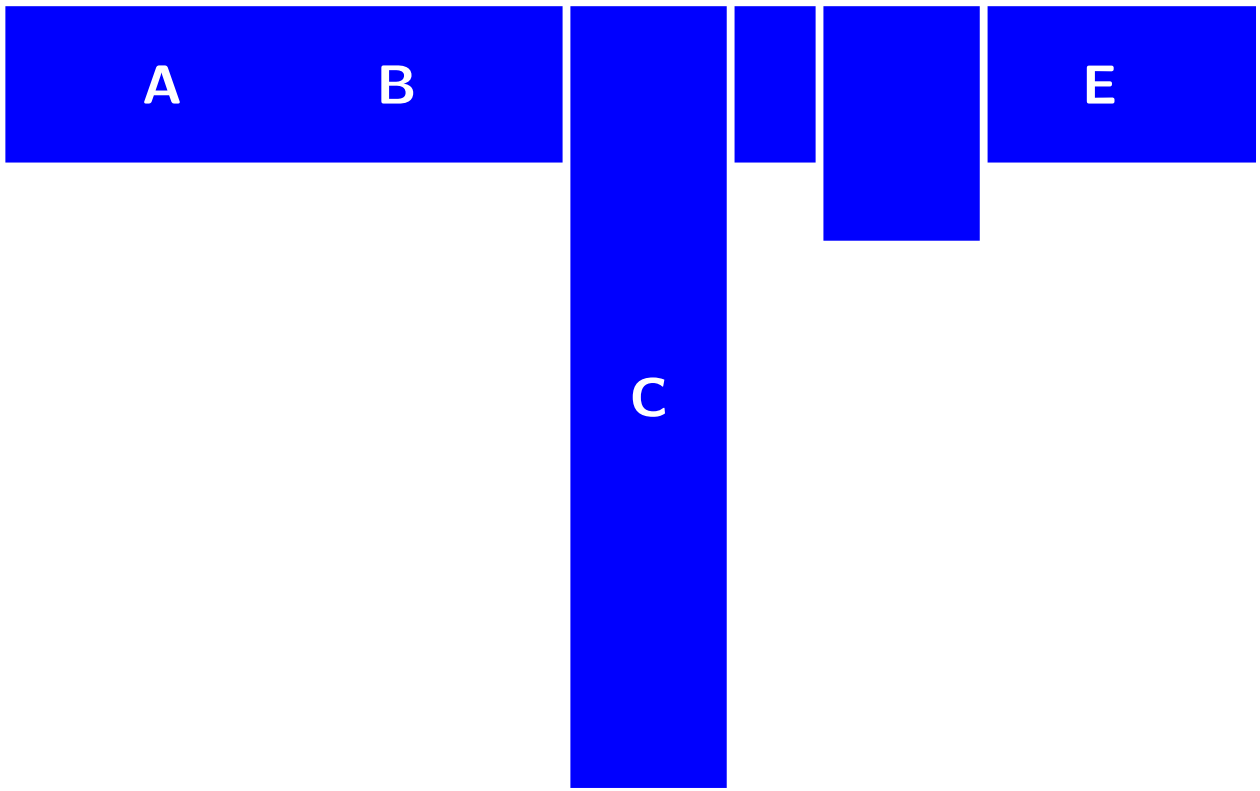

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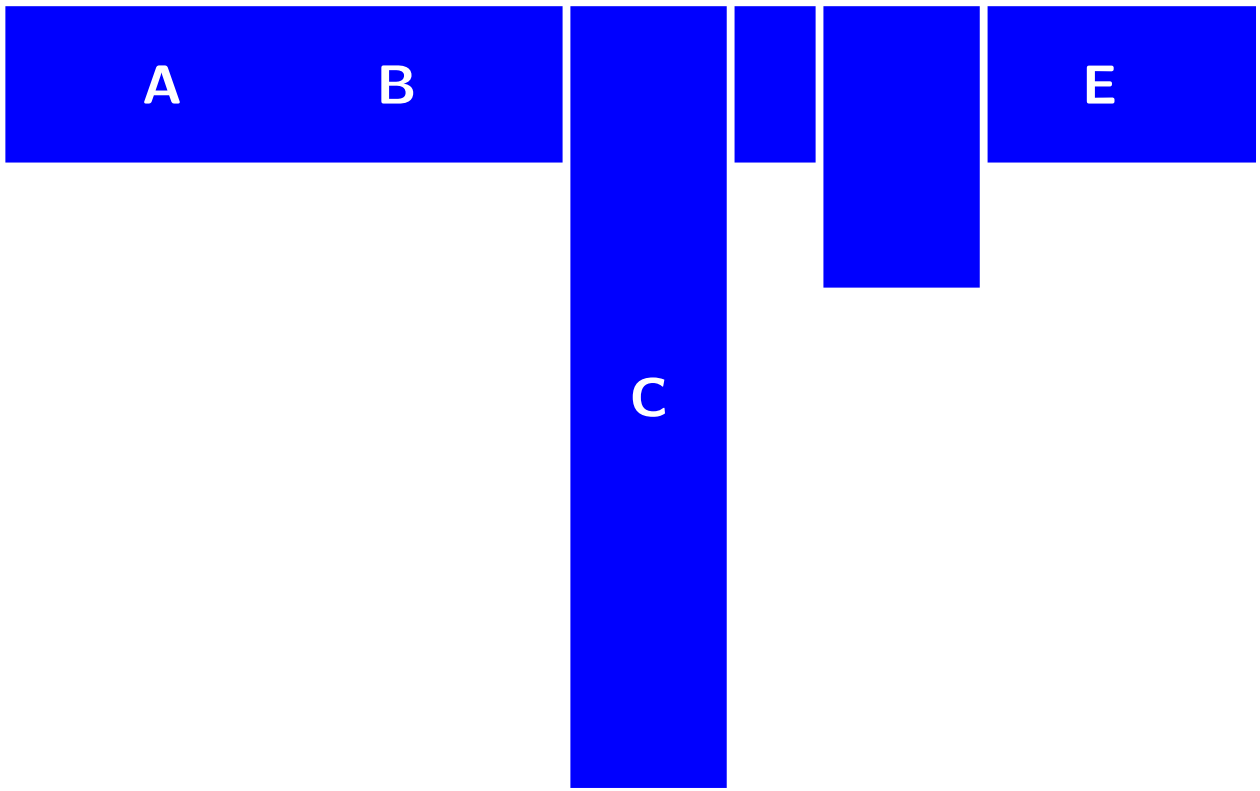

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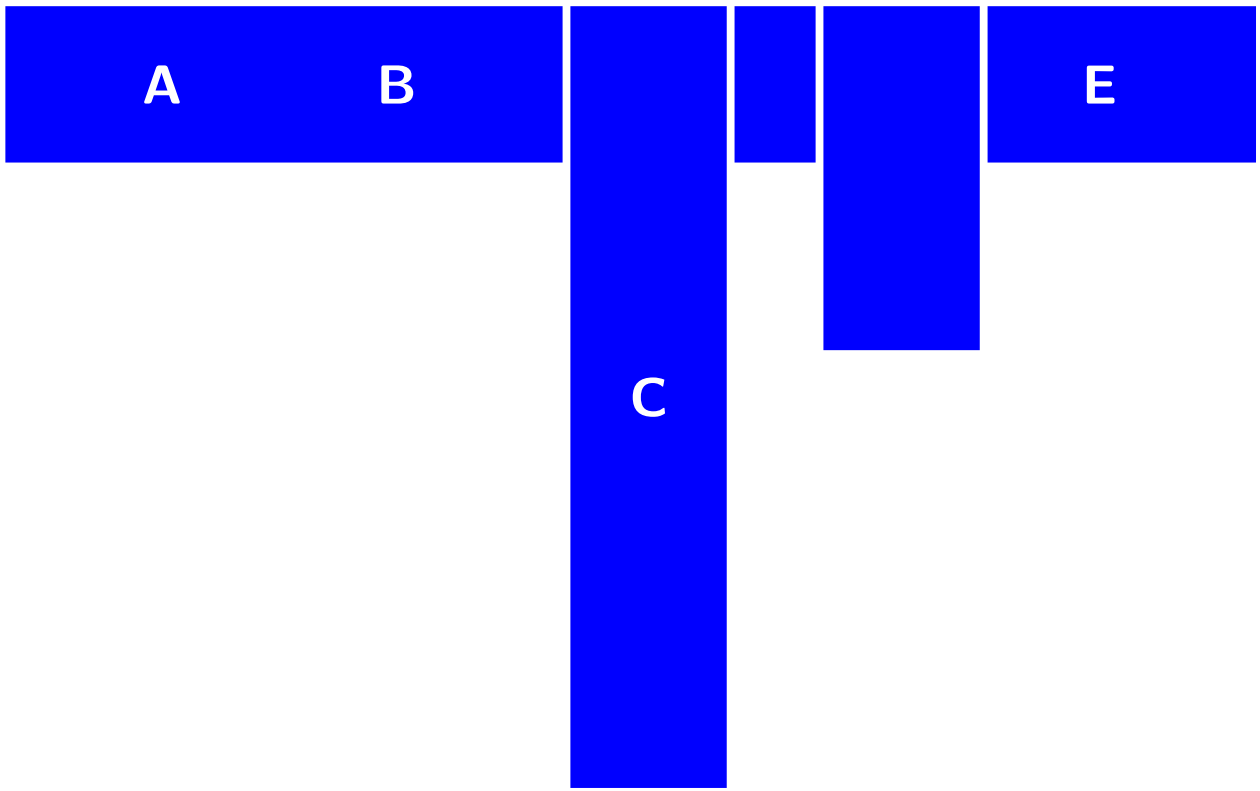

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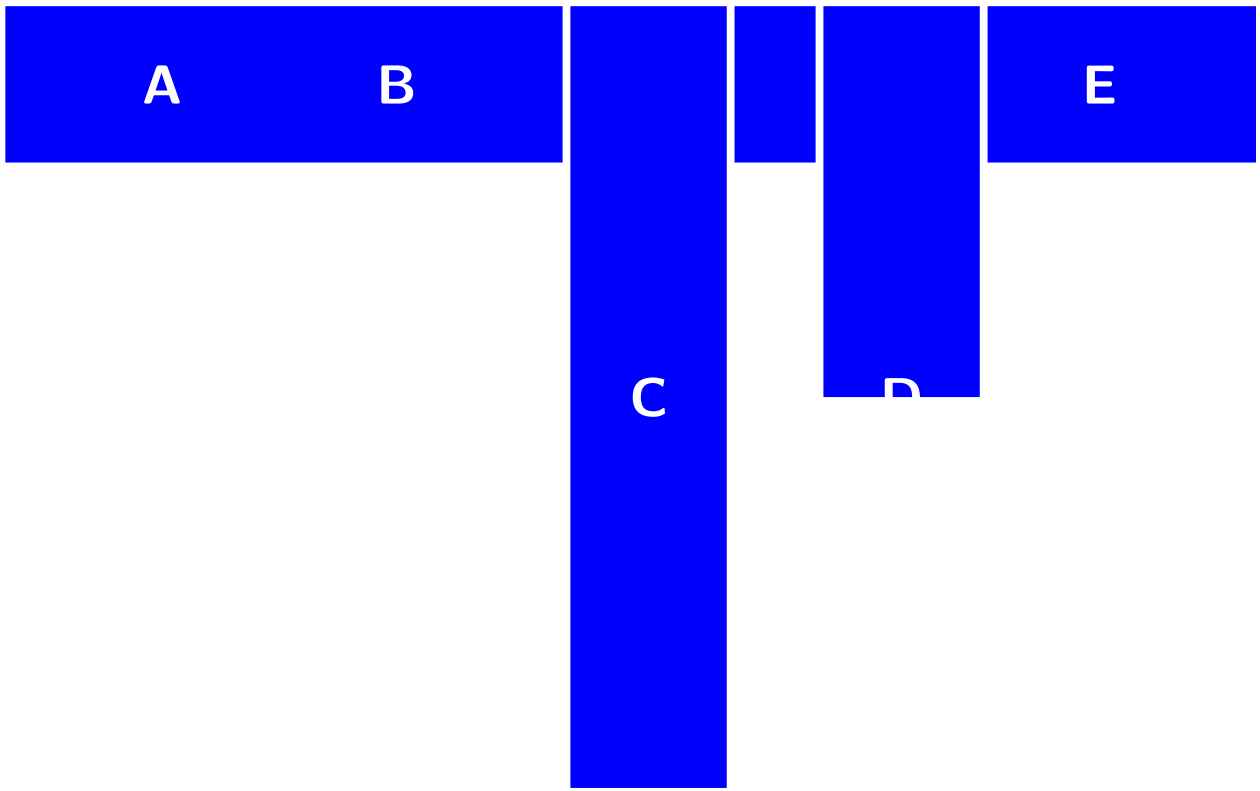

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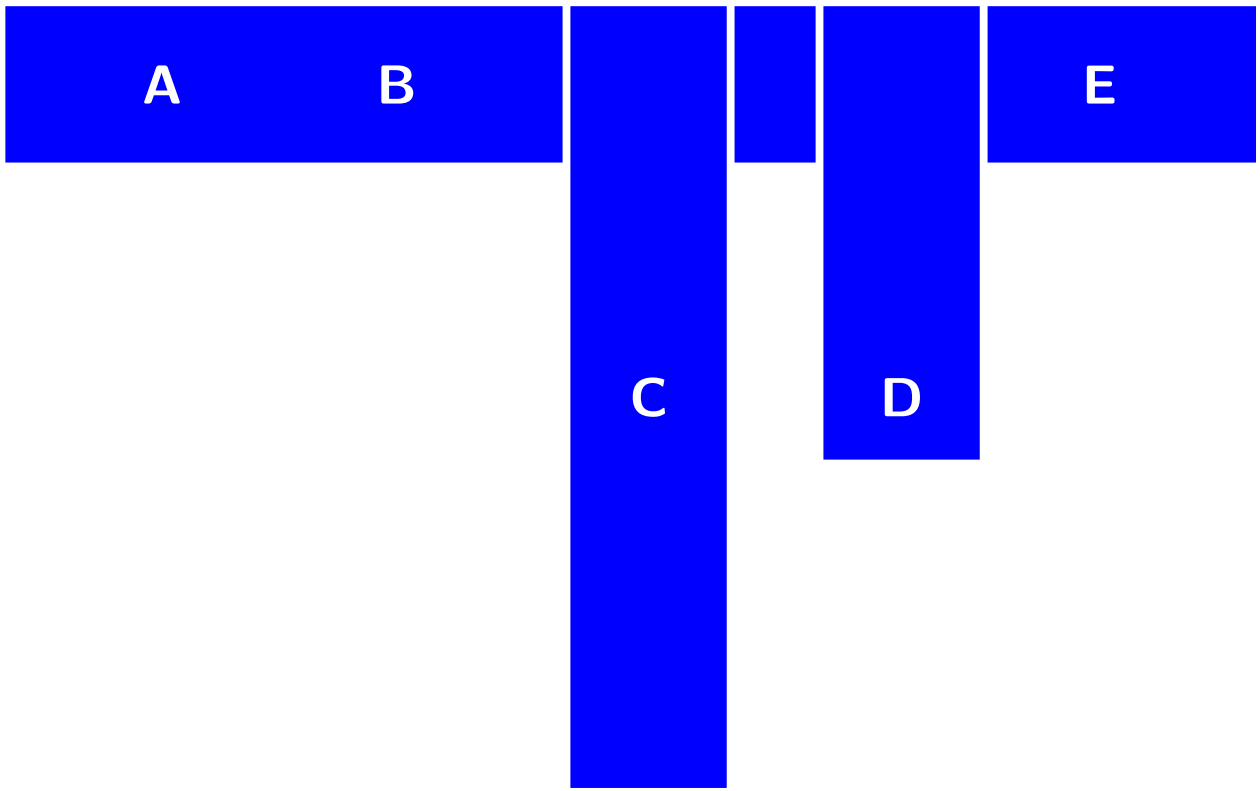

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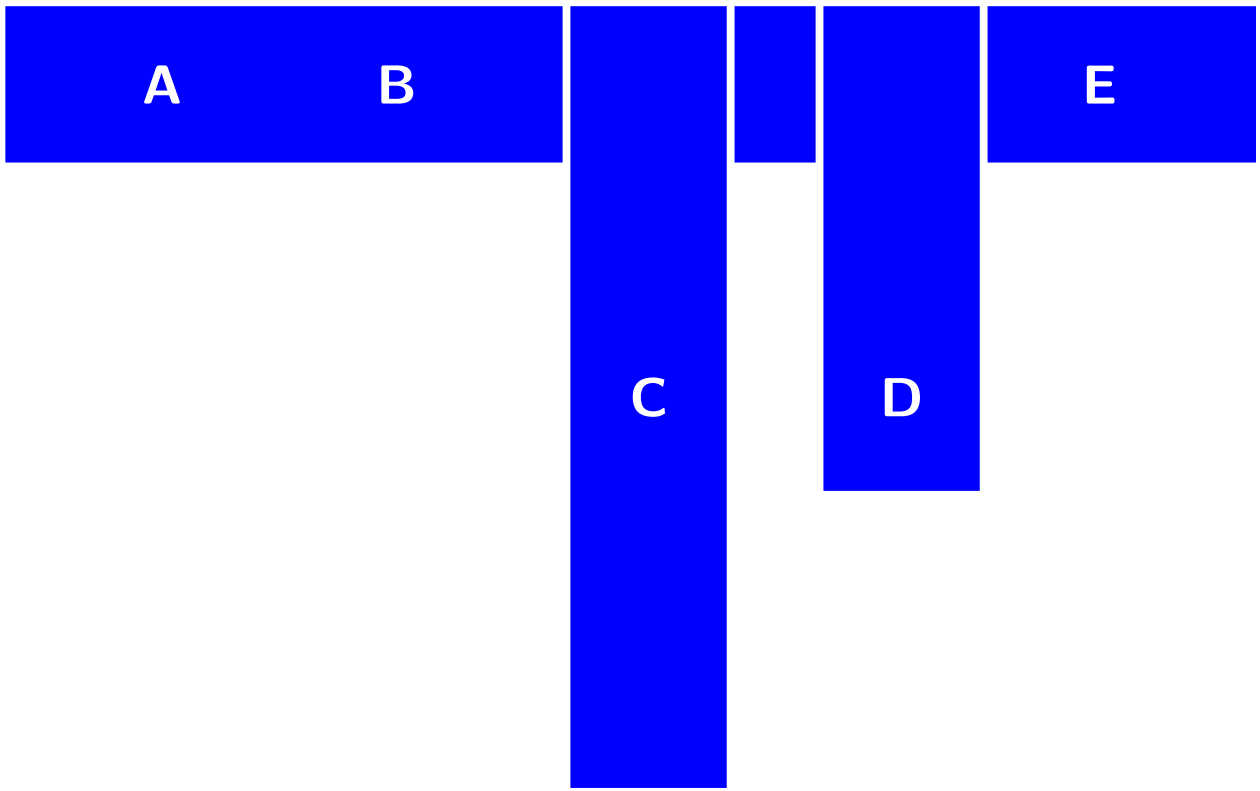

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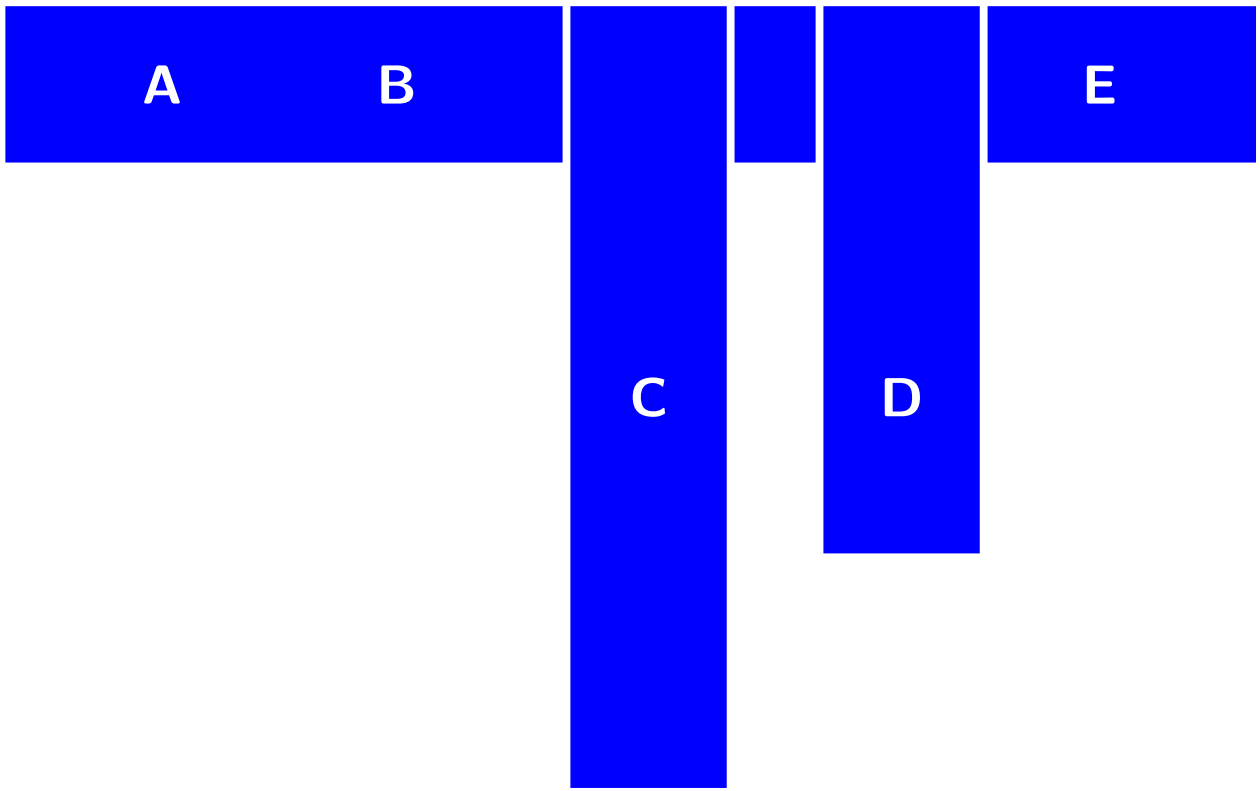

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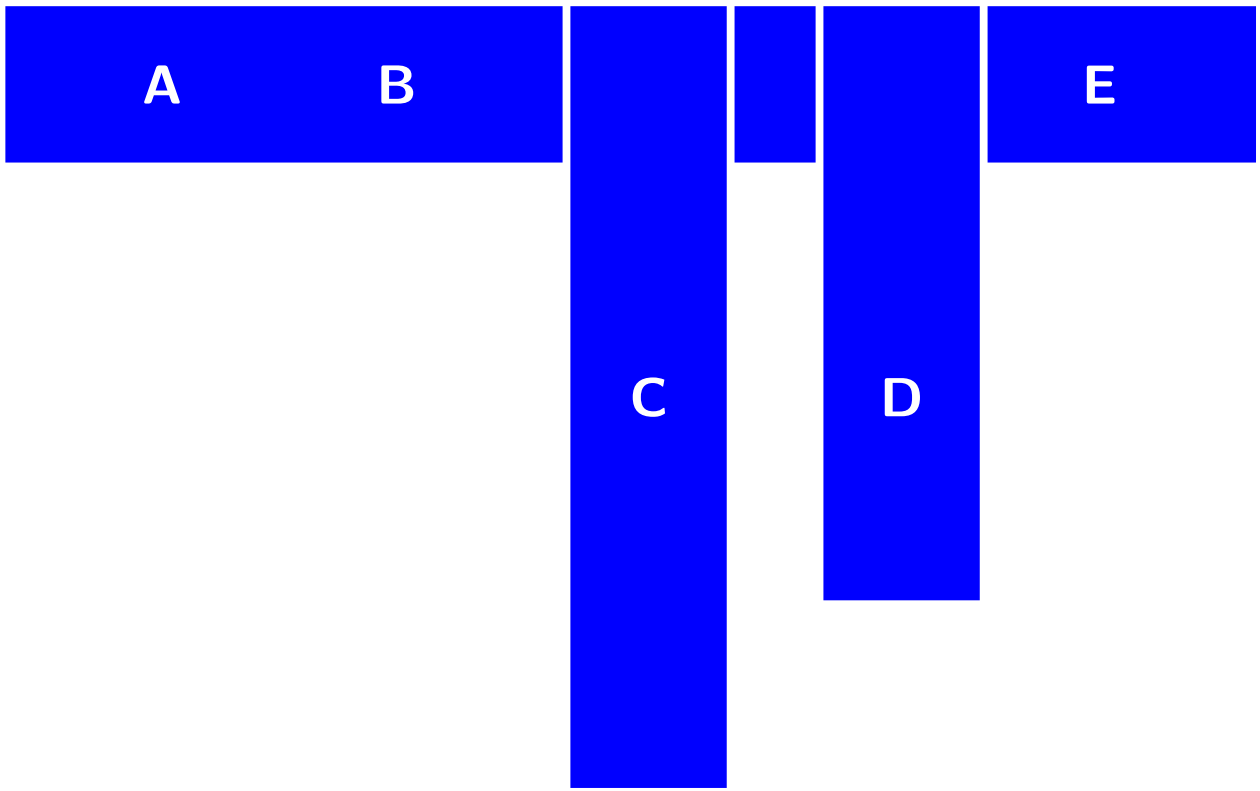

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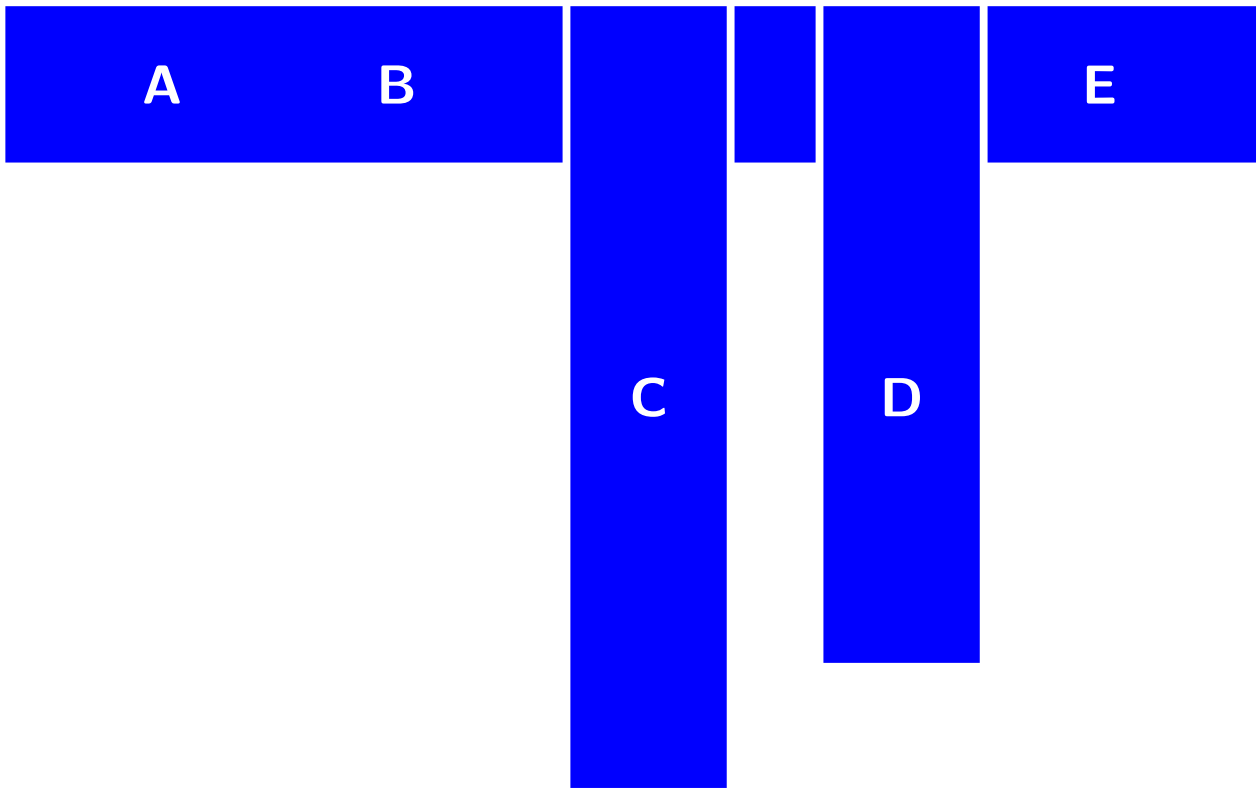

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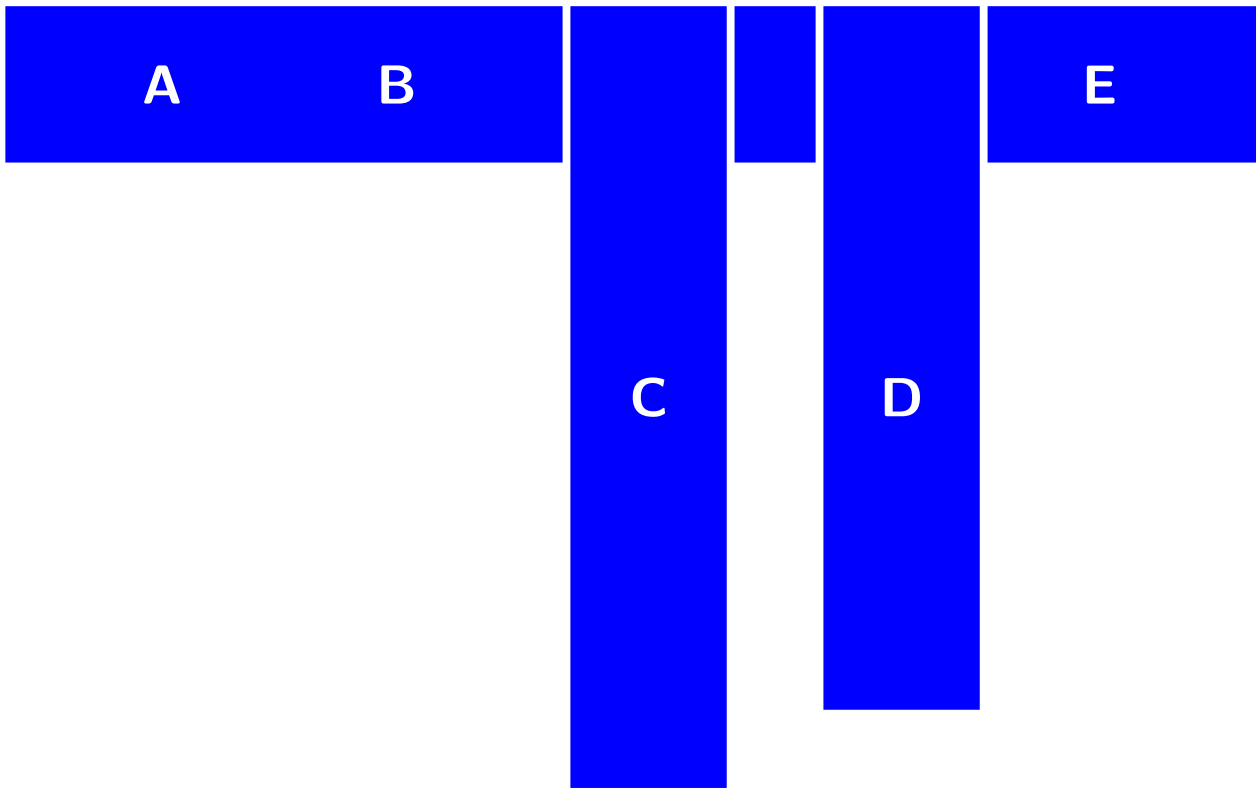

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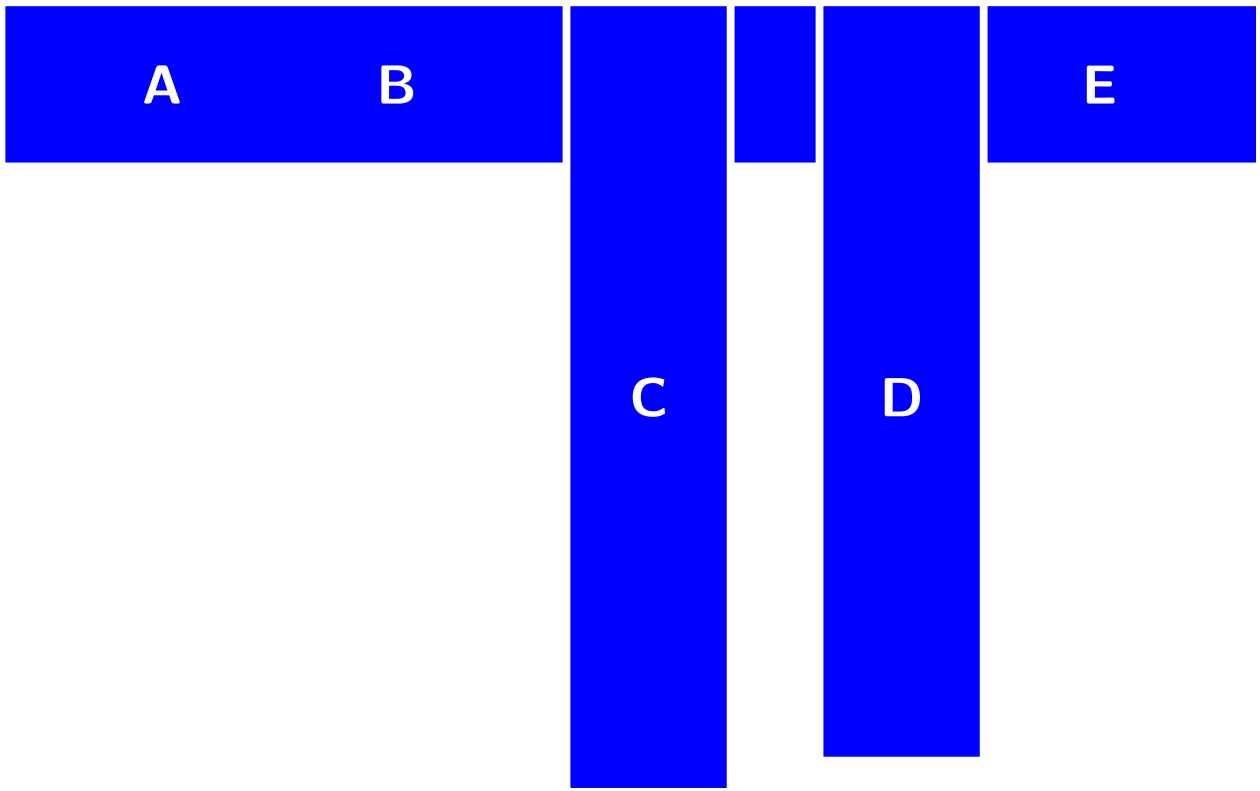

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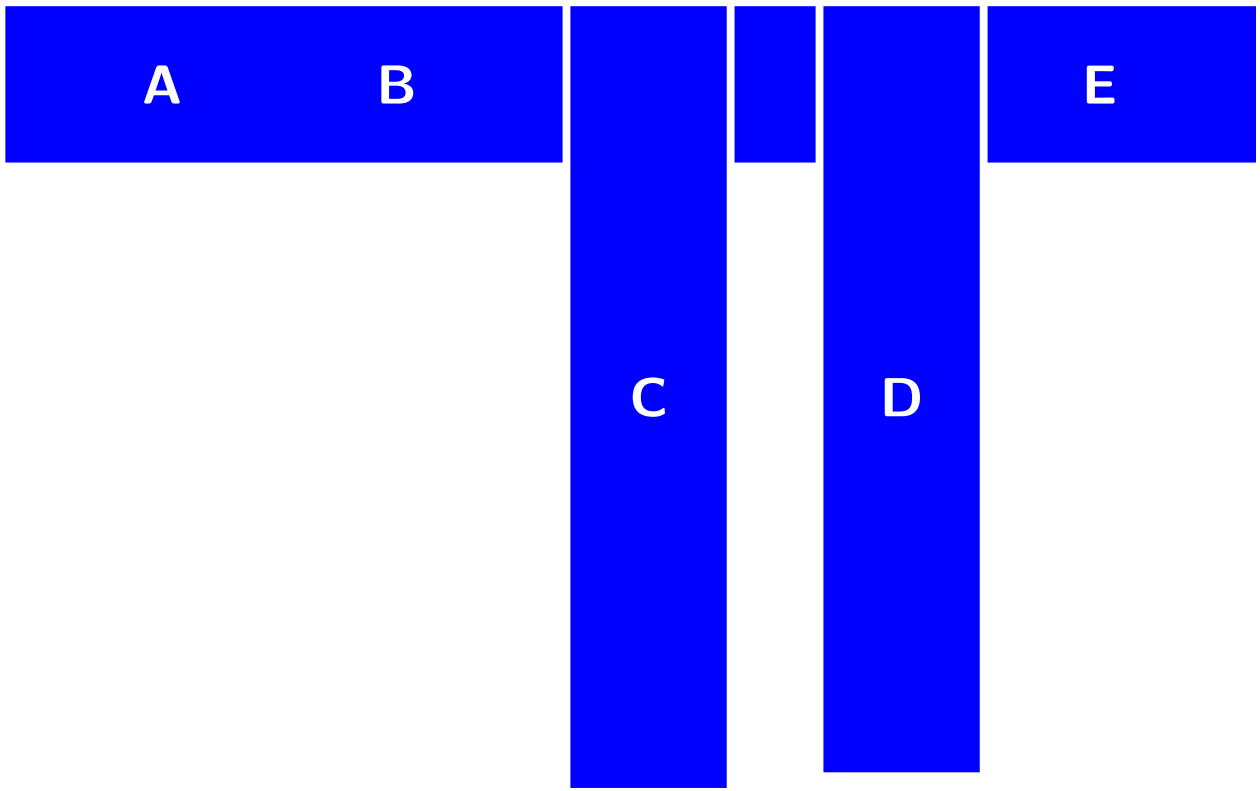

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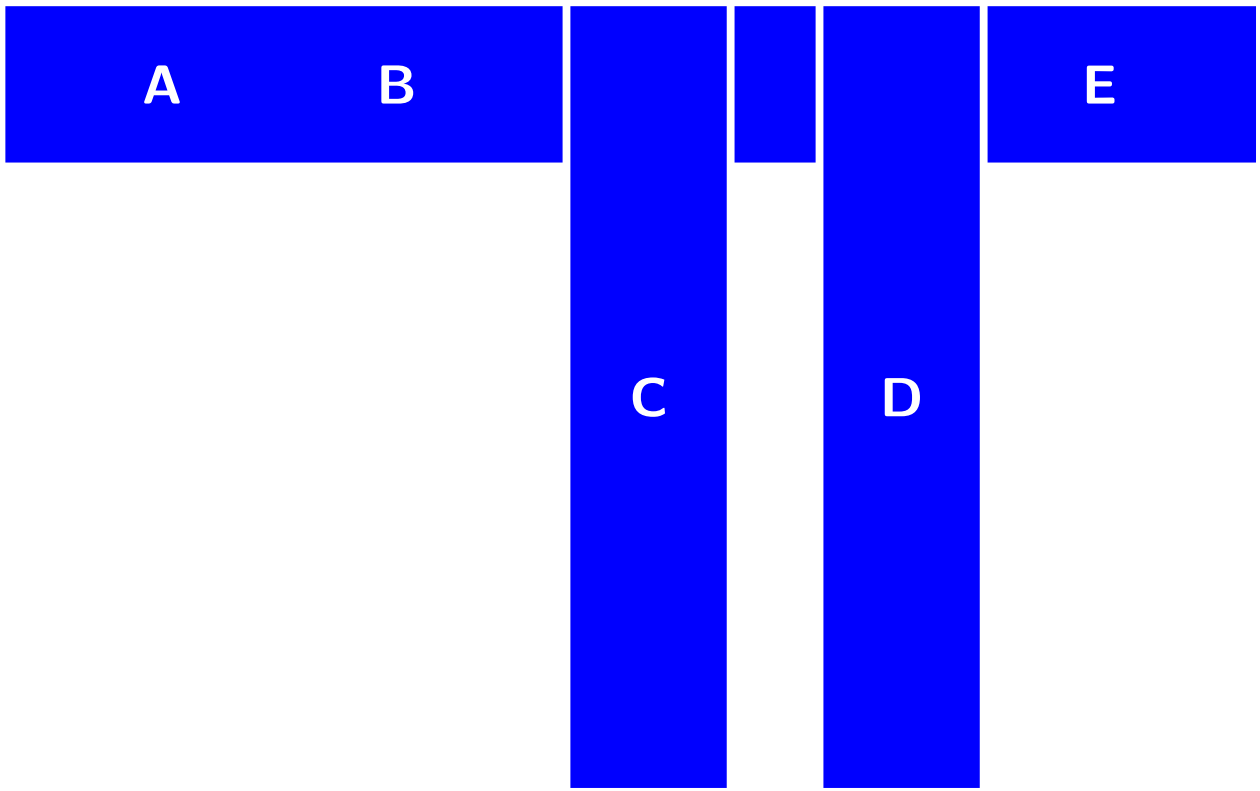

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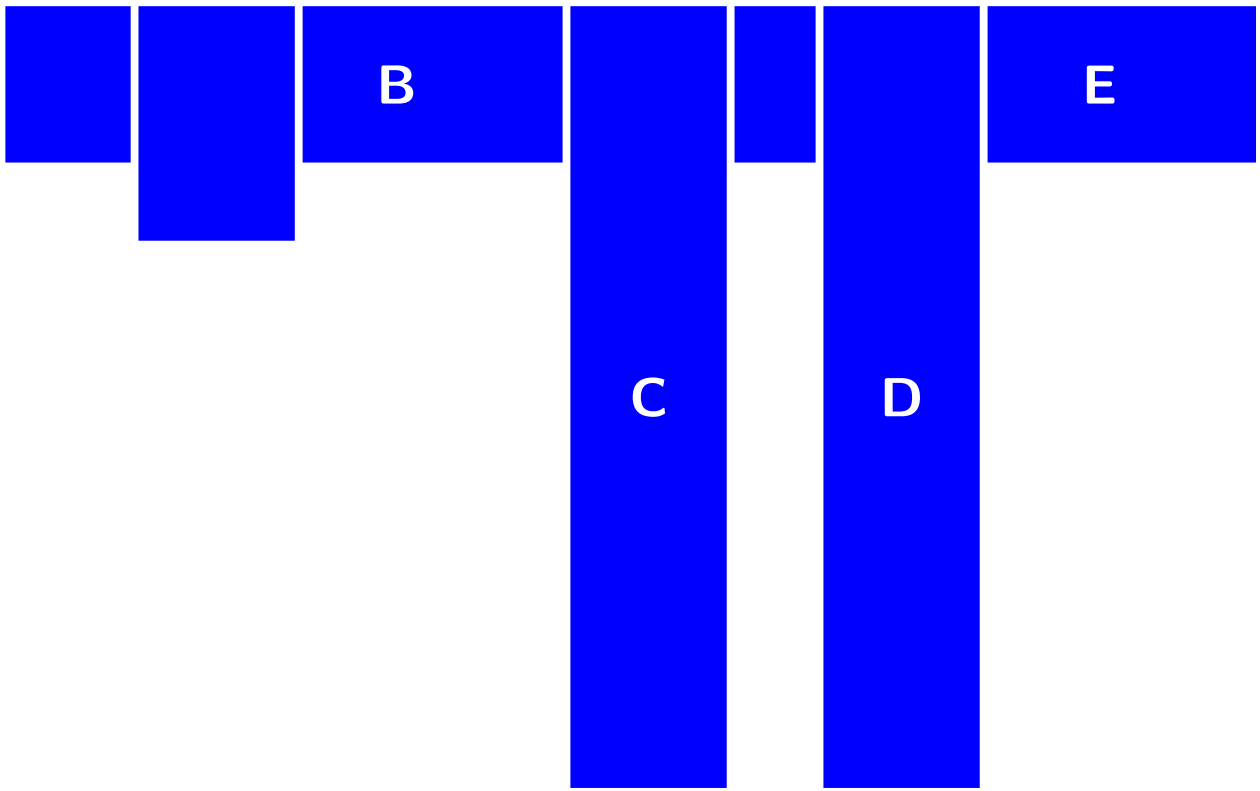

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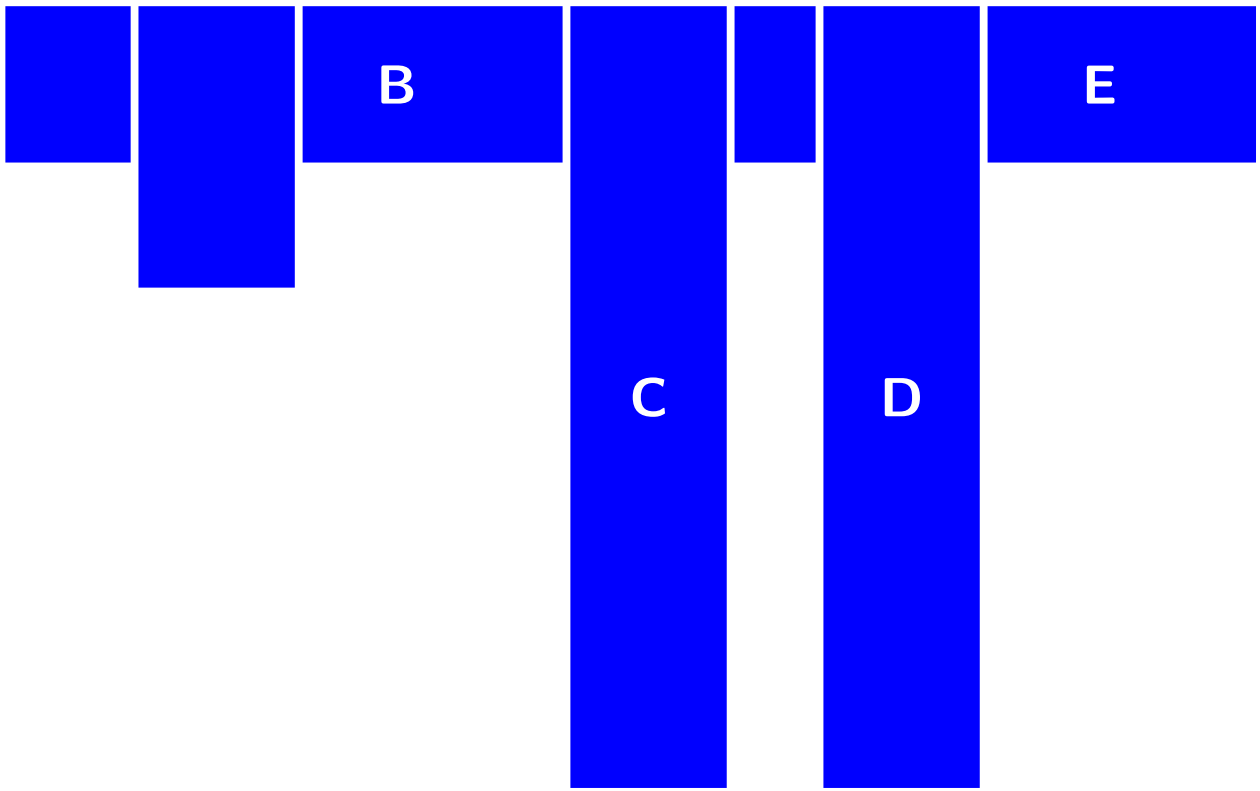

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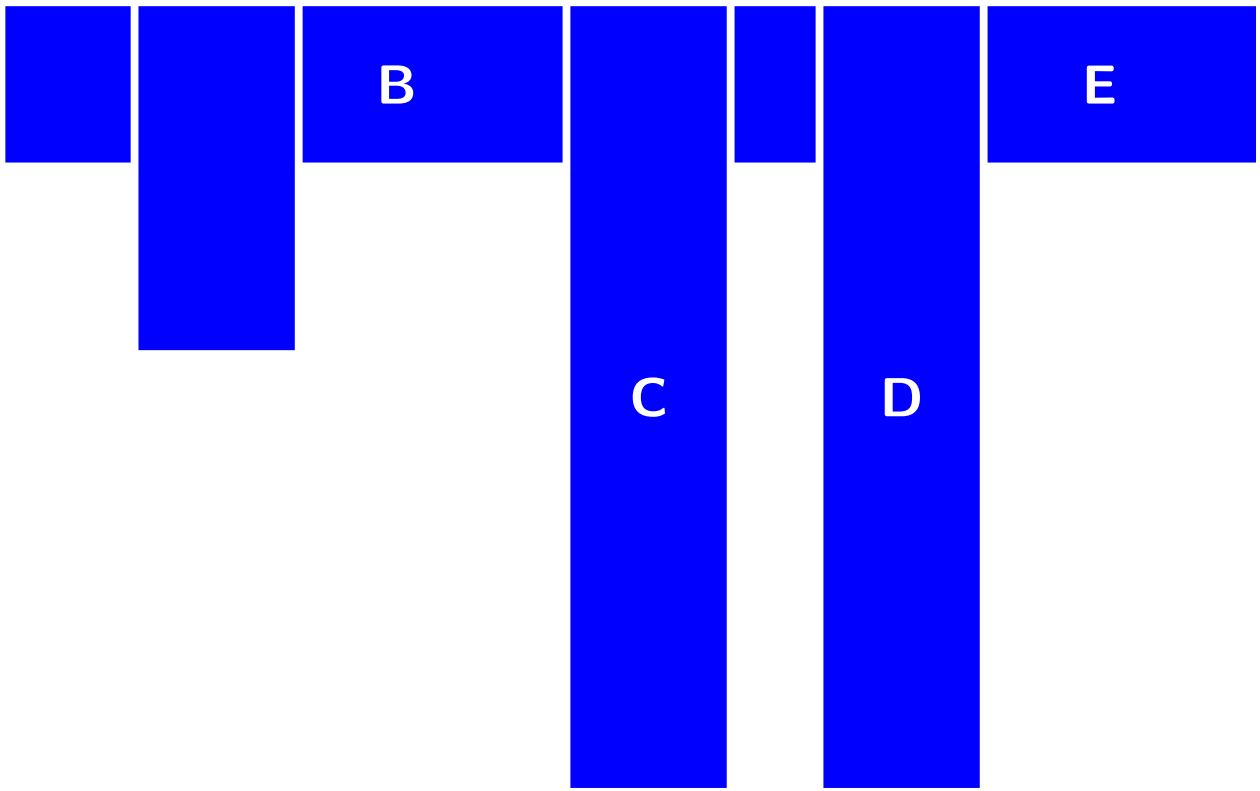

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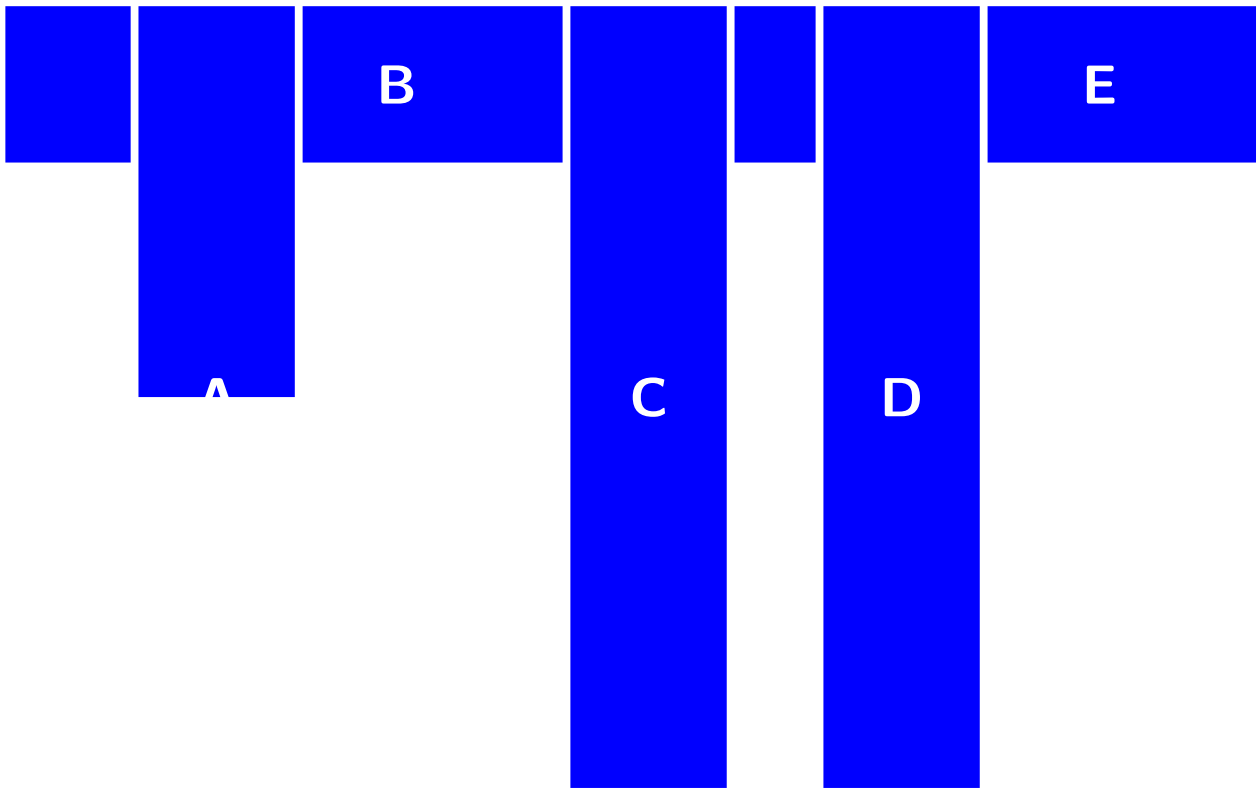

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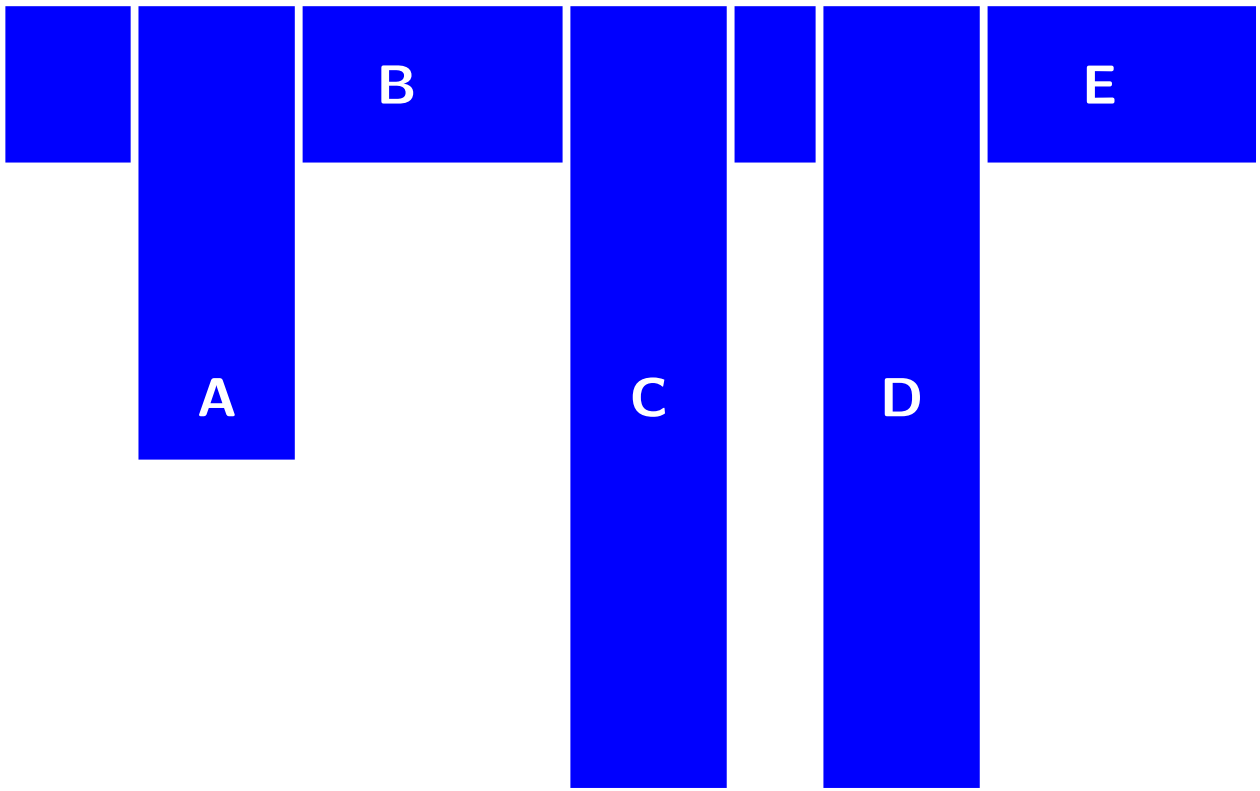

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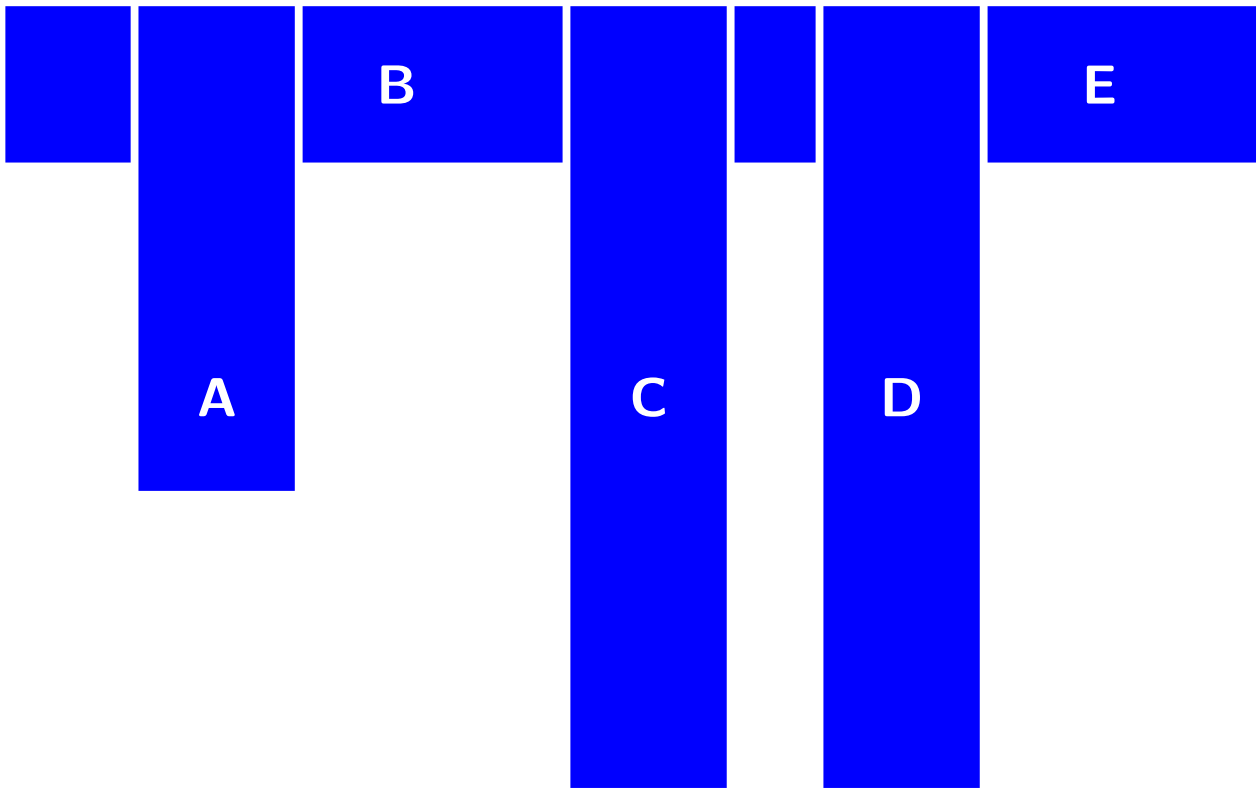

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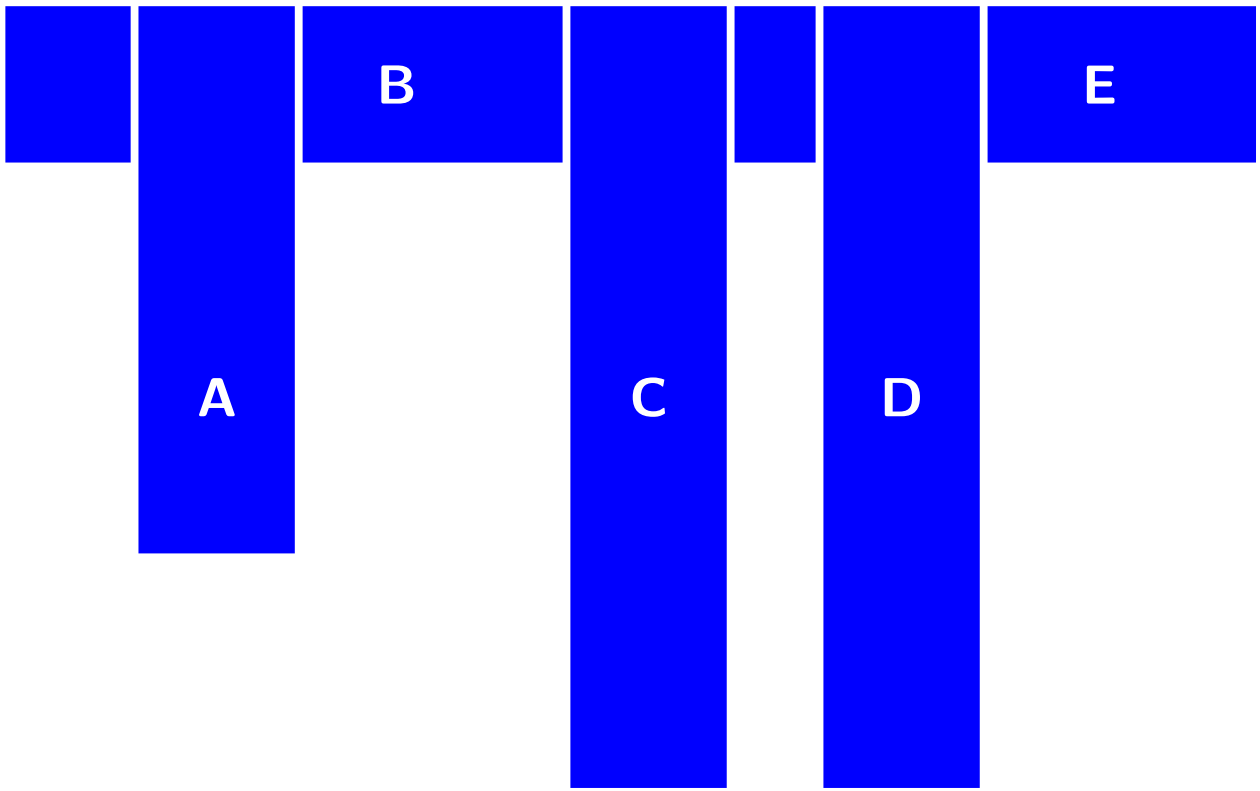

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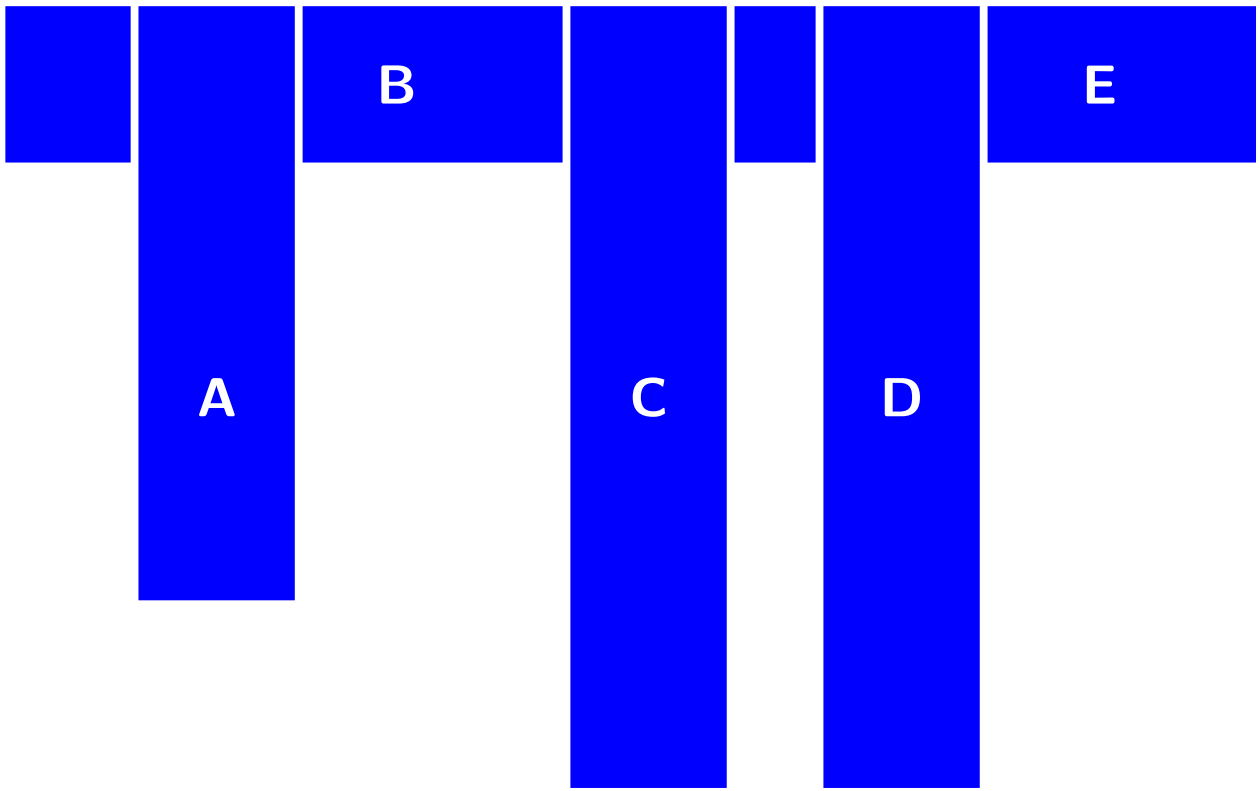

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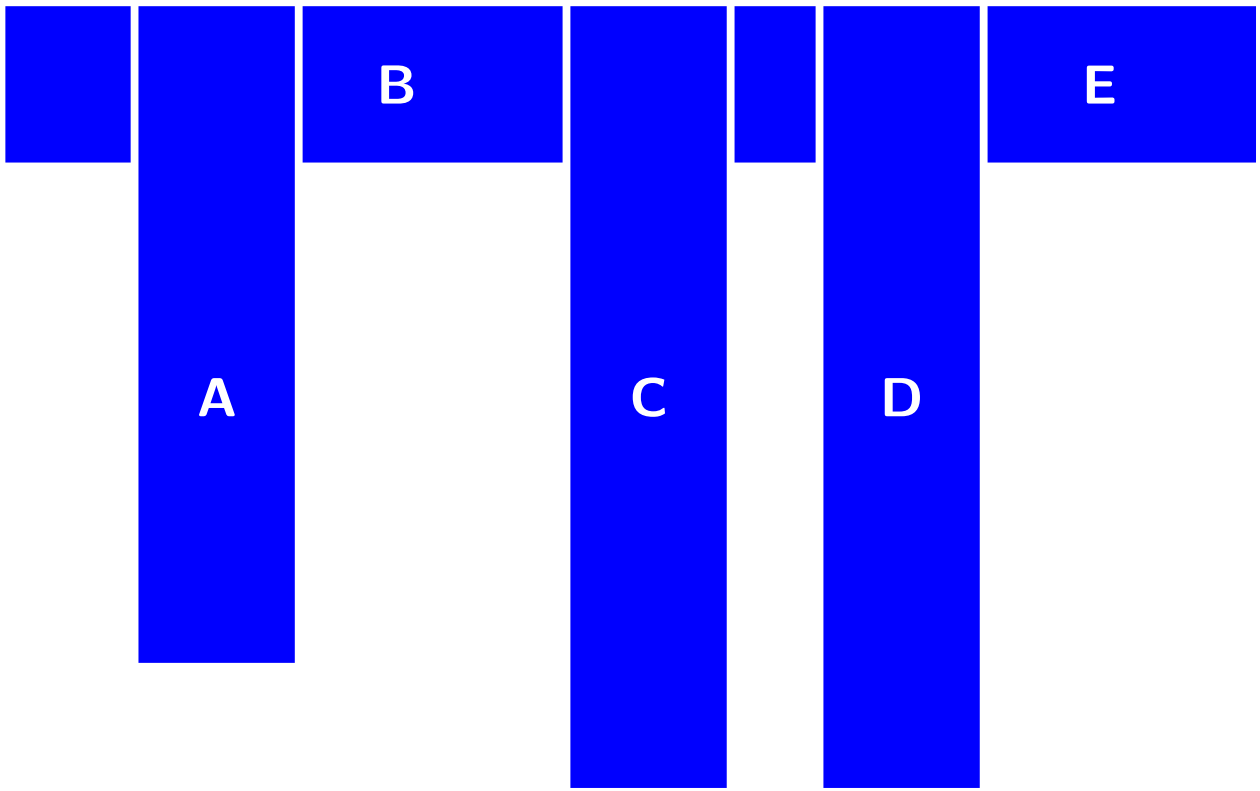

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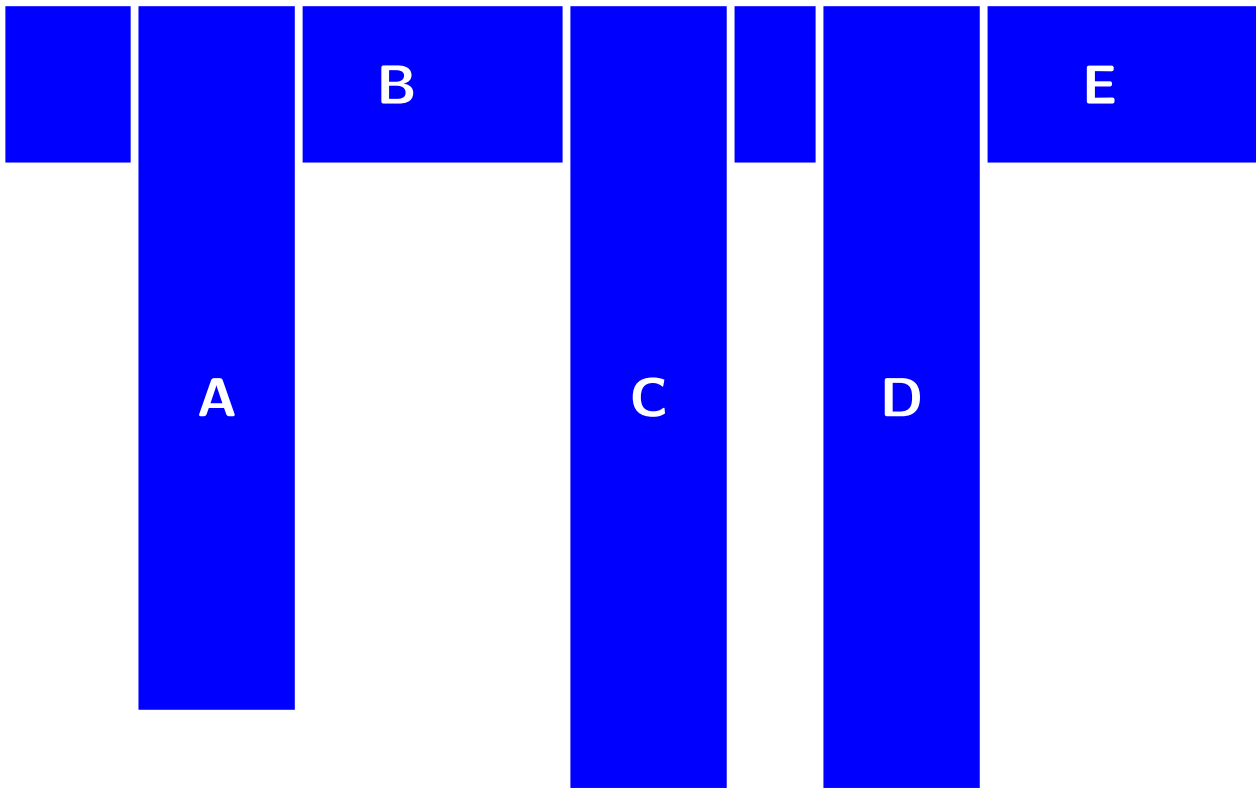

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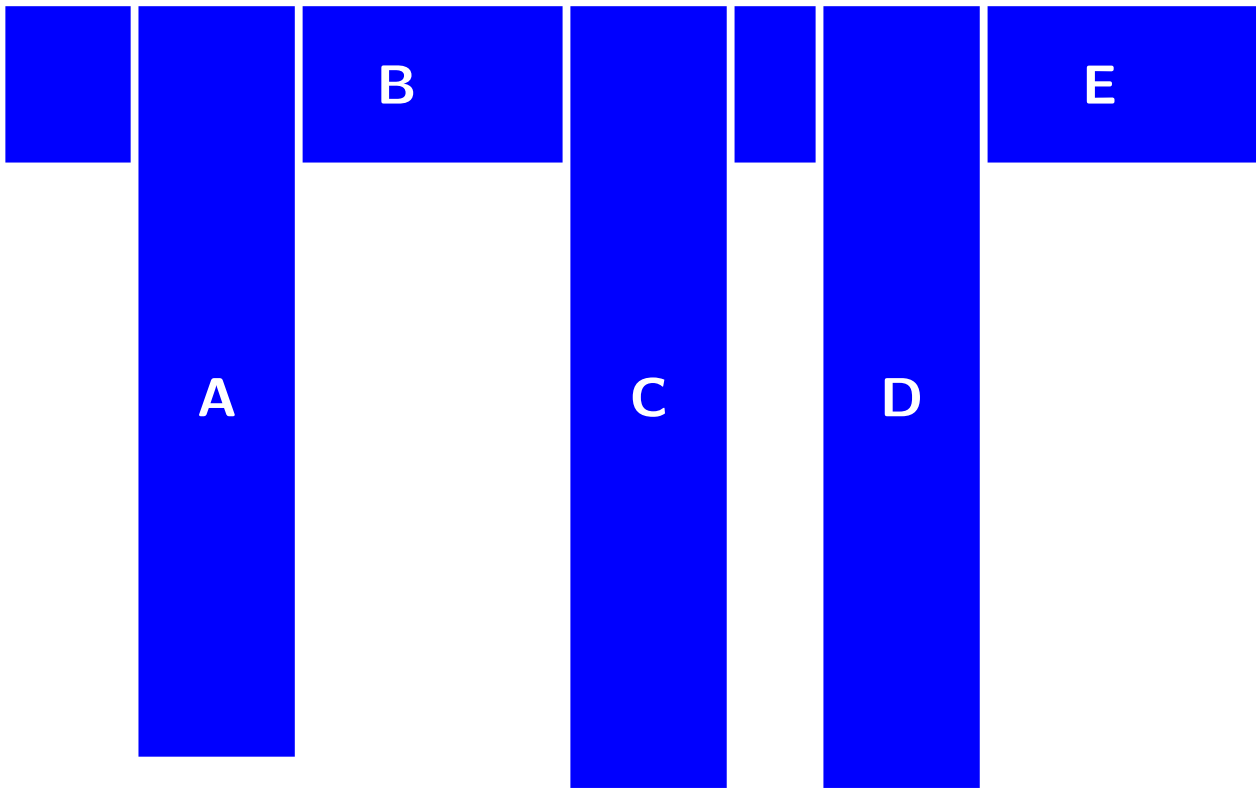

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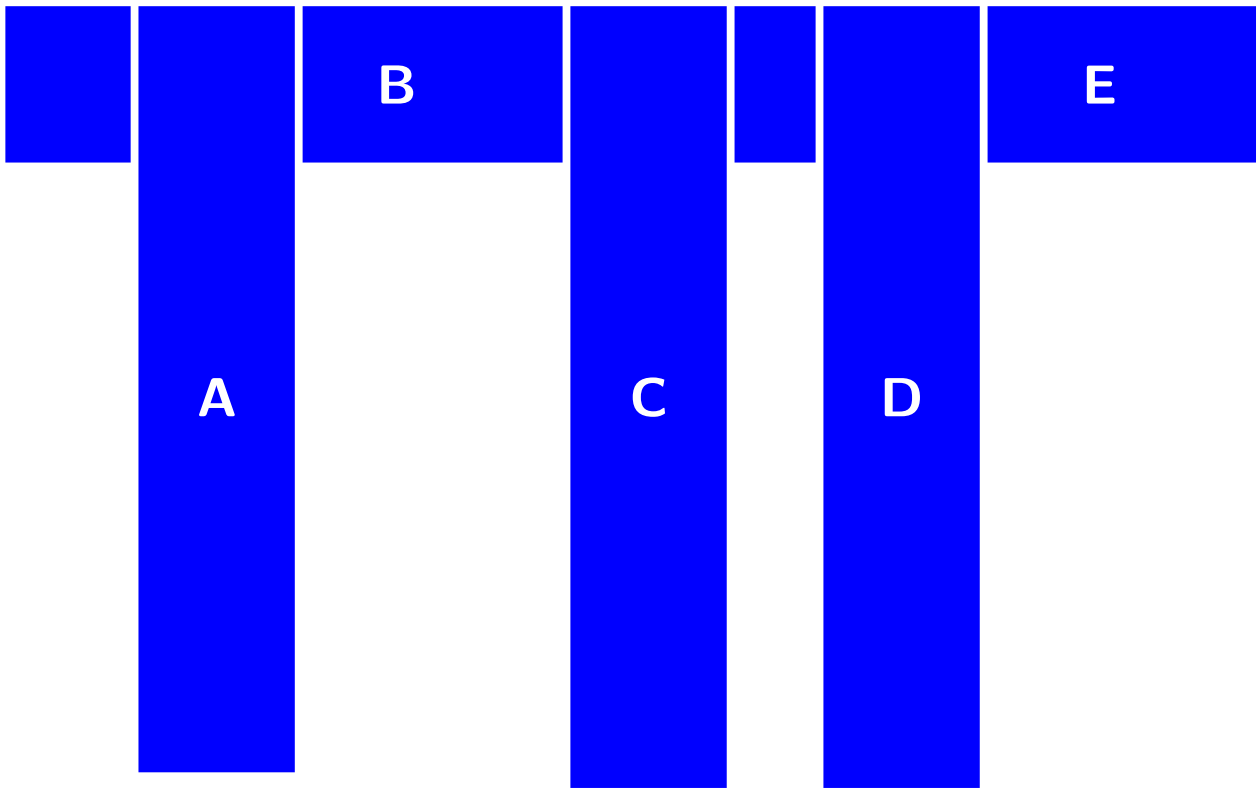

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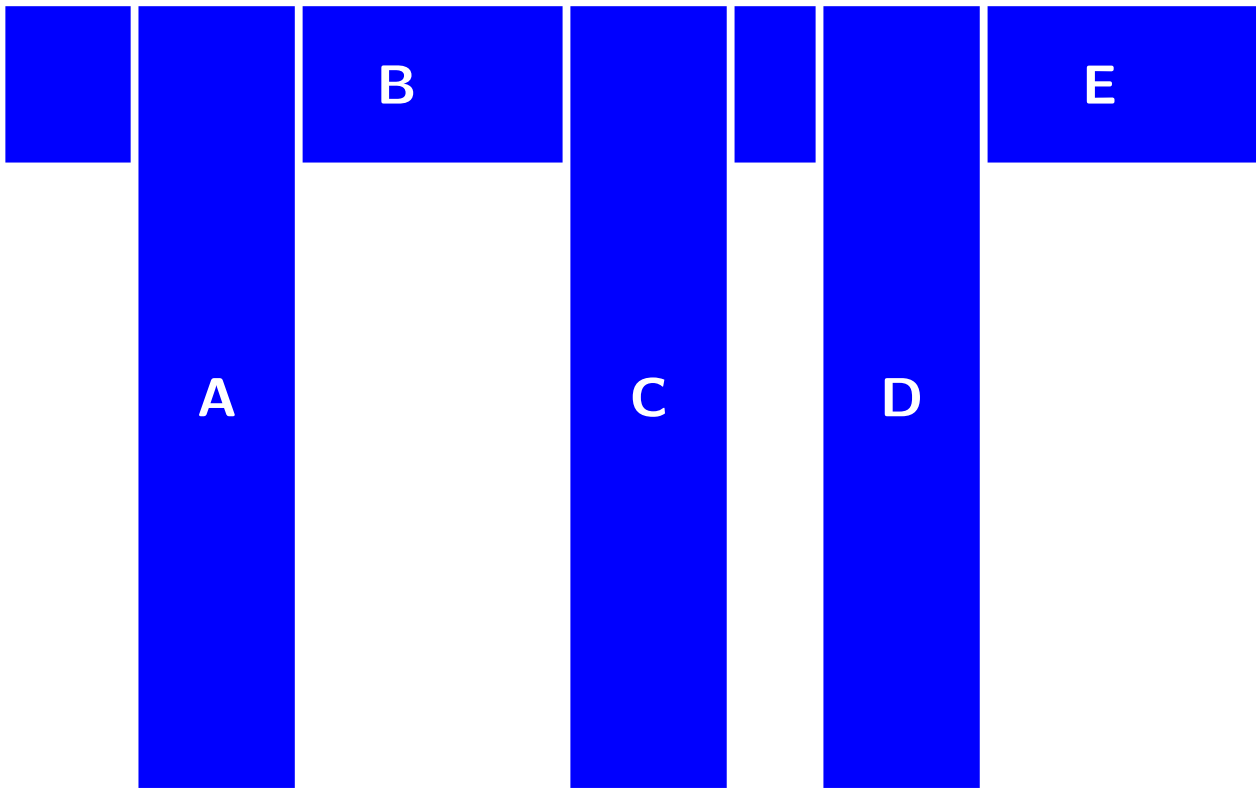

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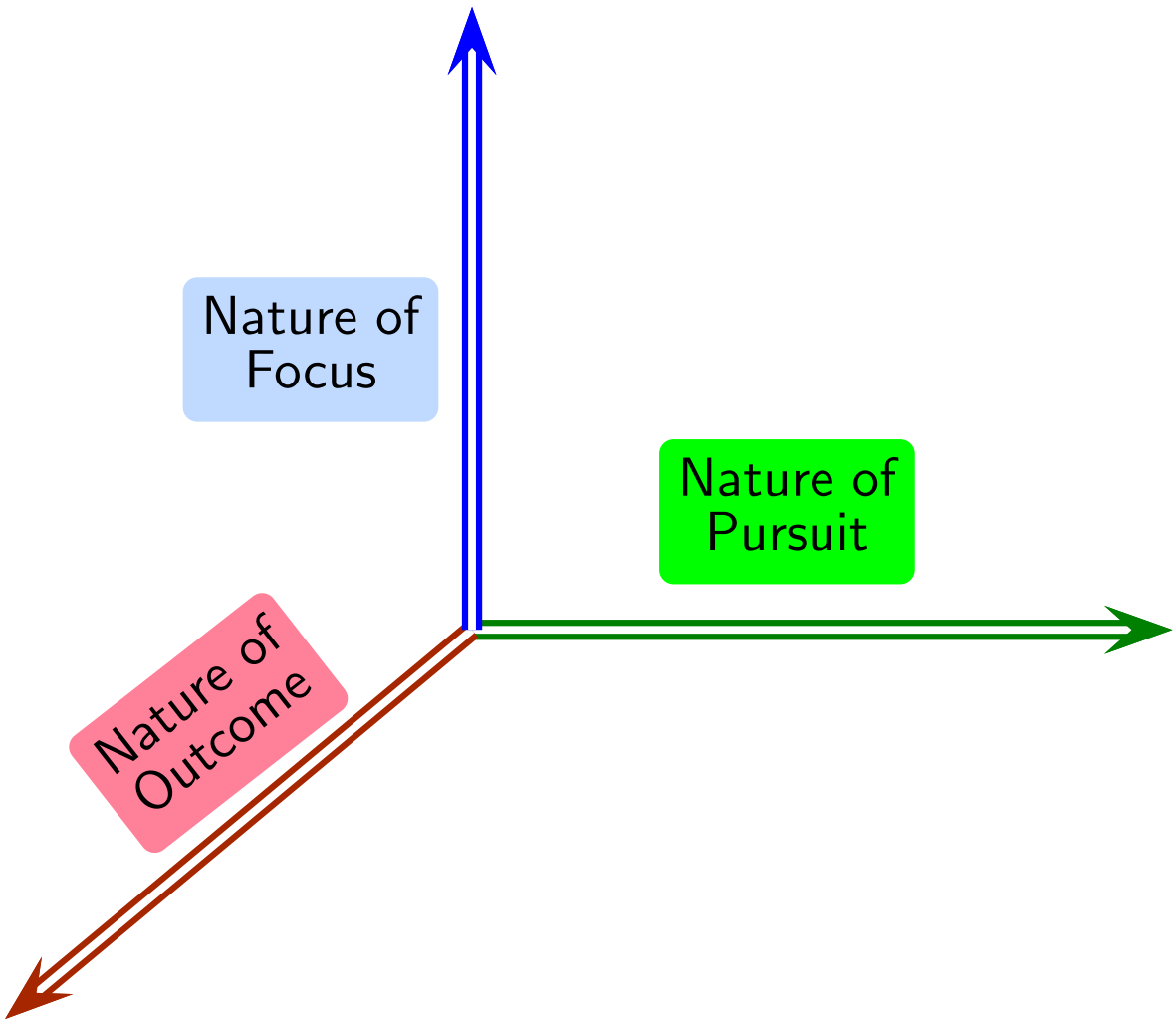
Positioning Your Research

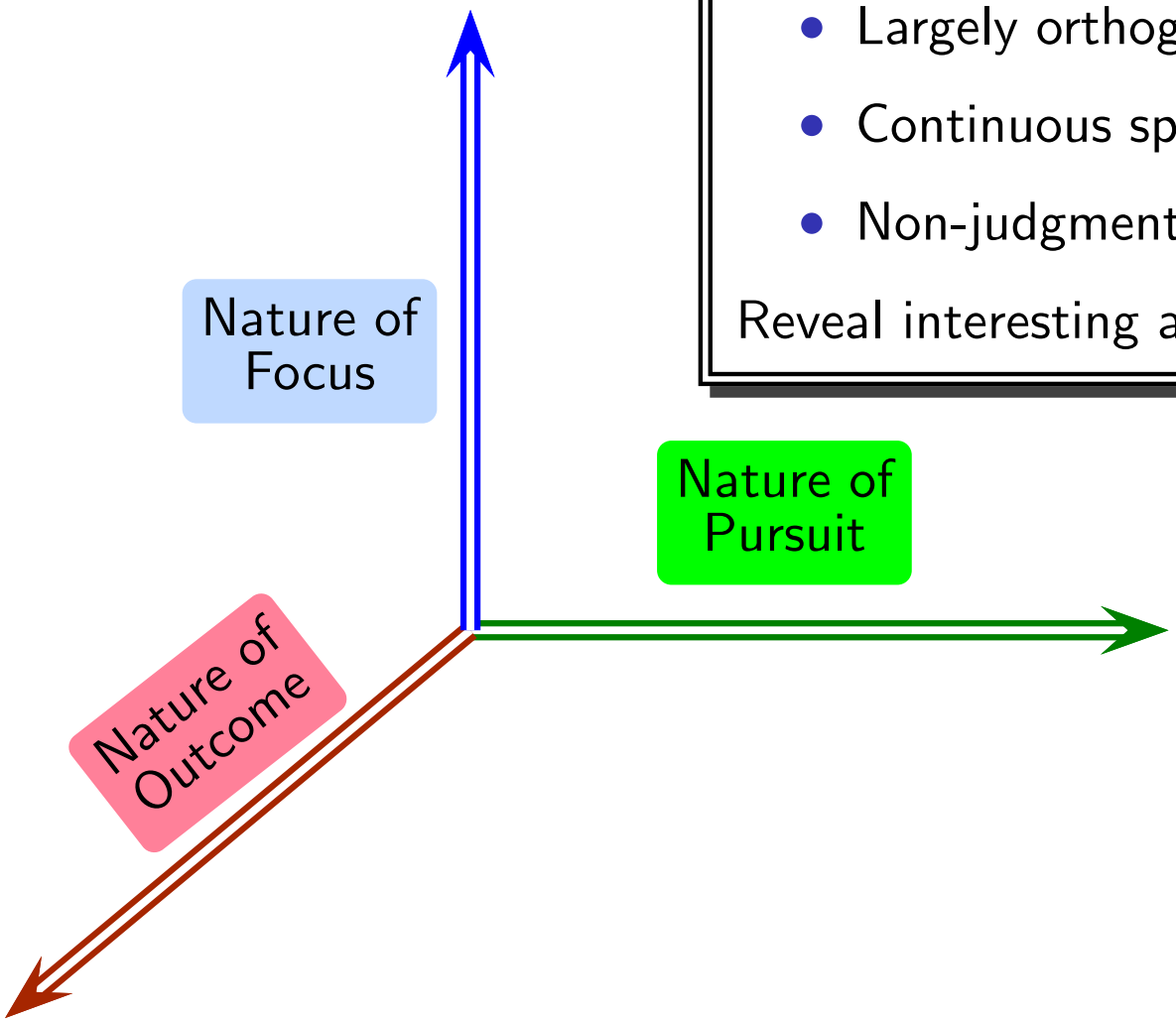


Positioning Your Research

Three ways of viewing research

- Largely orthogonal
- Continuous spectrum
- Non-judgmental

Reveal interesting aspects of research



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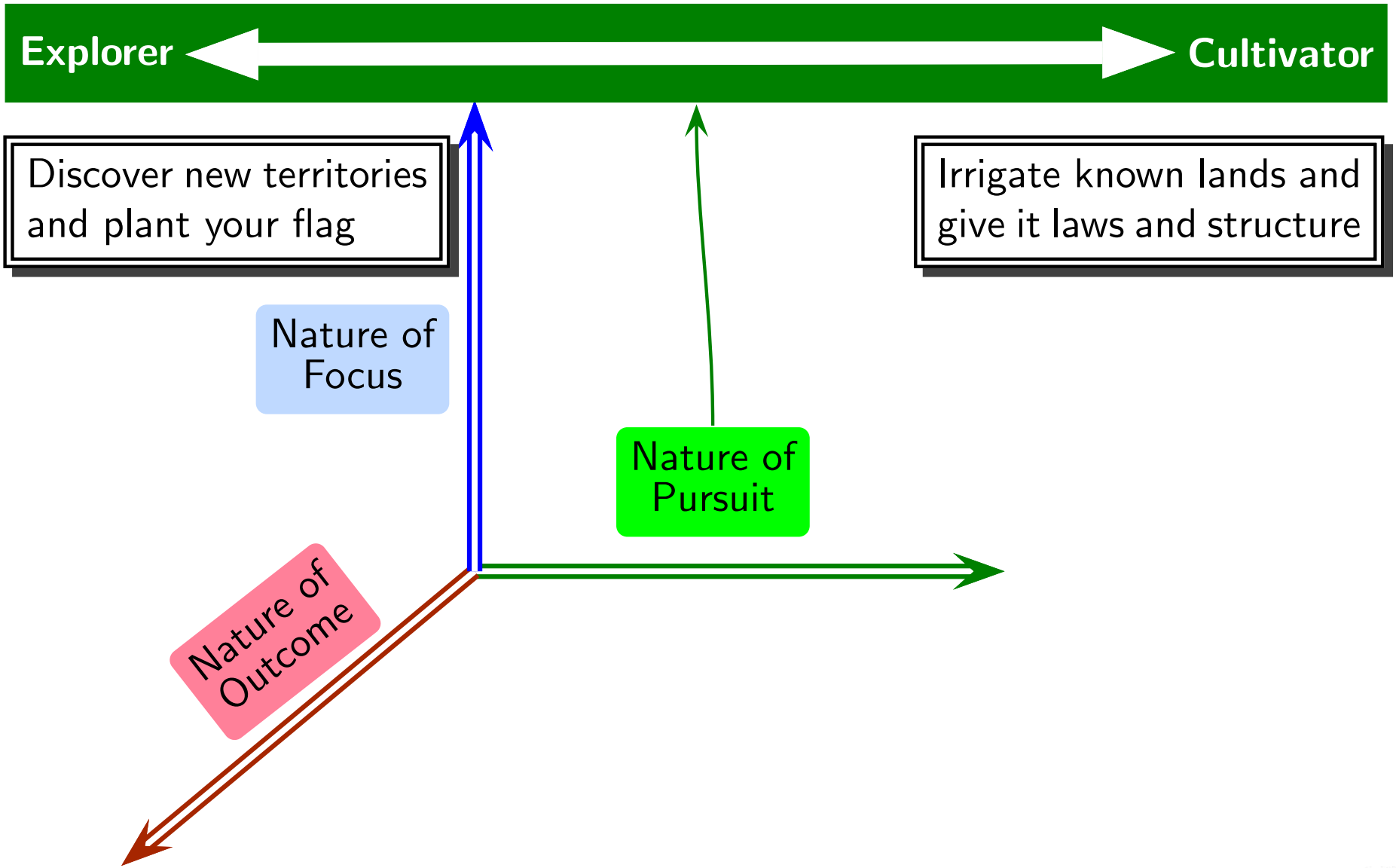

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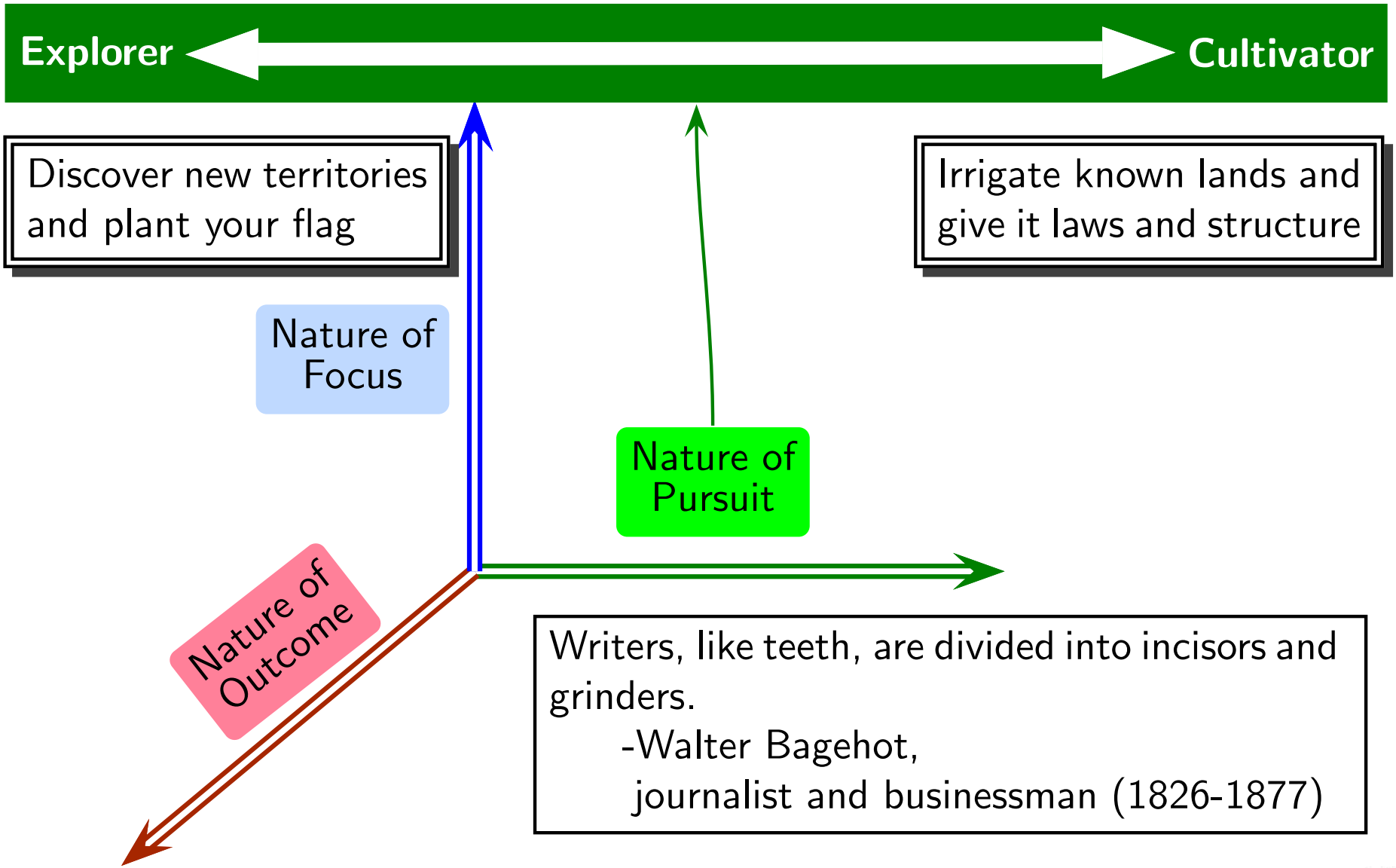
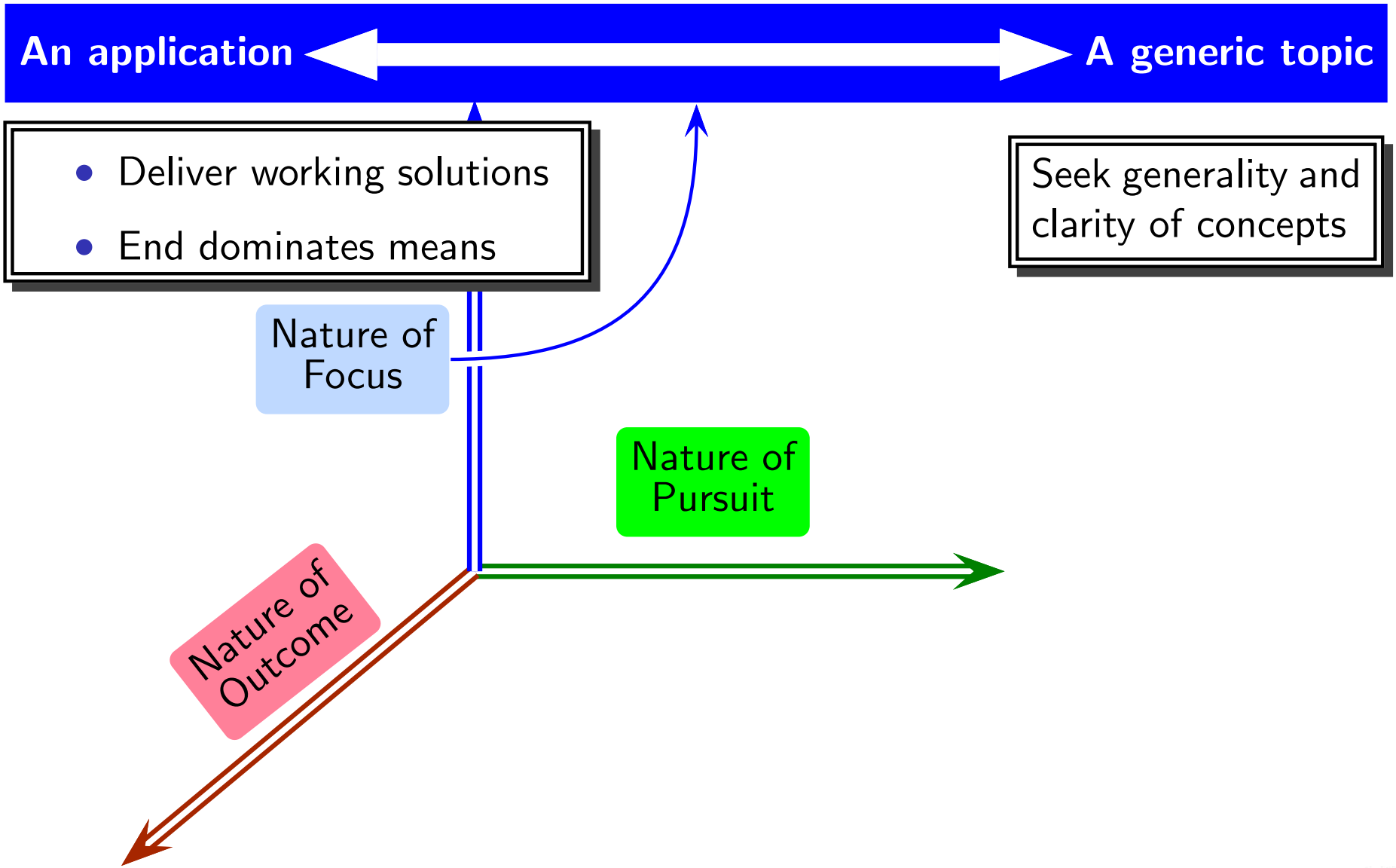


Writers, like teeth, are divided into incisors and grinders.

-Walter Bagehot,
journalist and businessman (1826-1877)

Positioning Your Research



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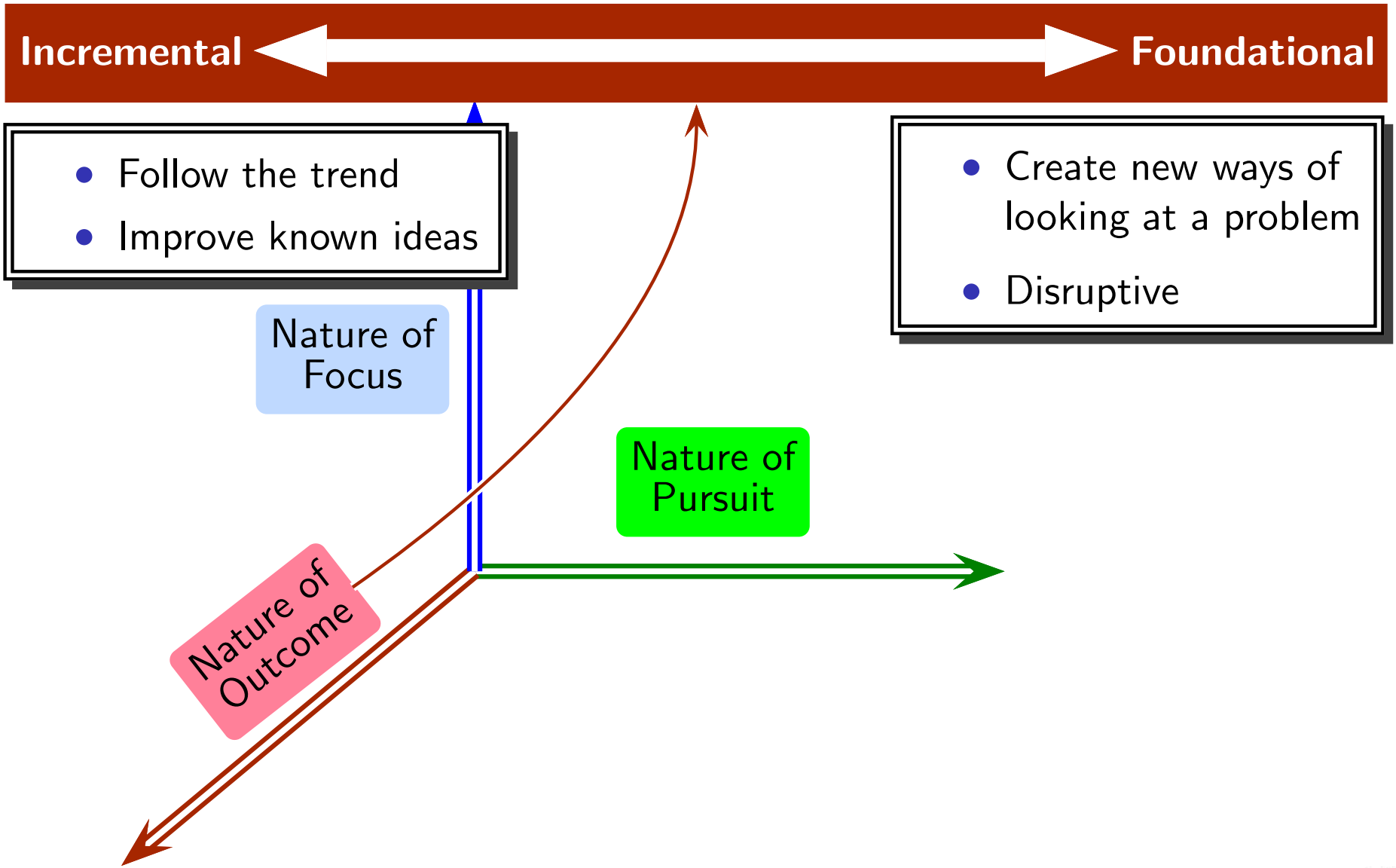

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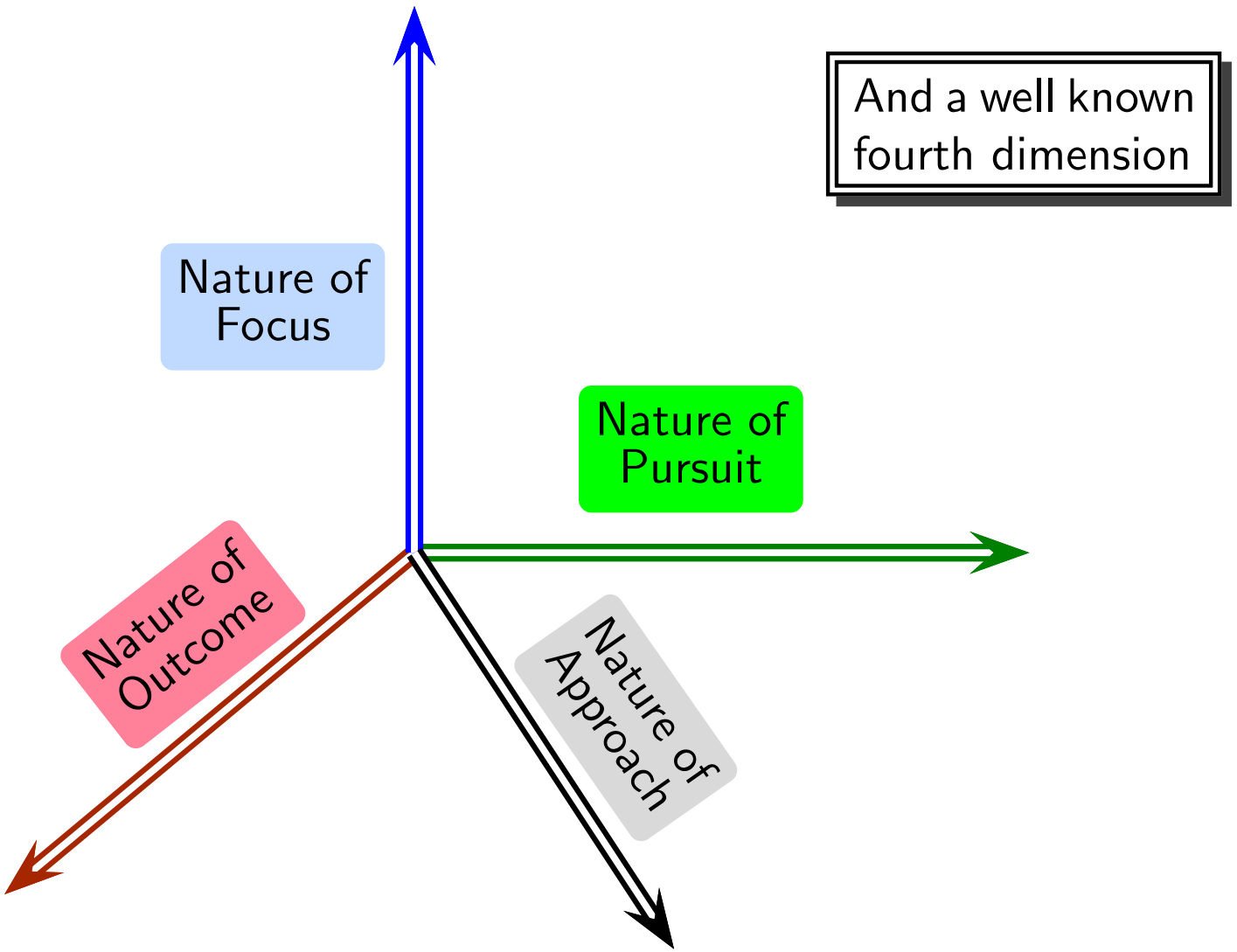
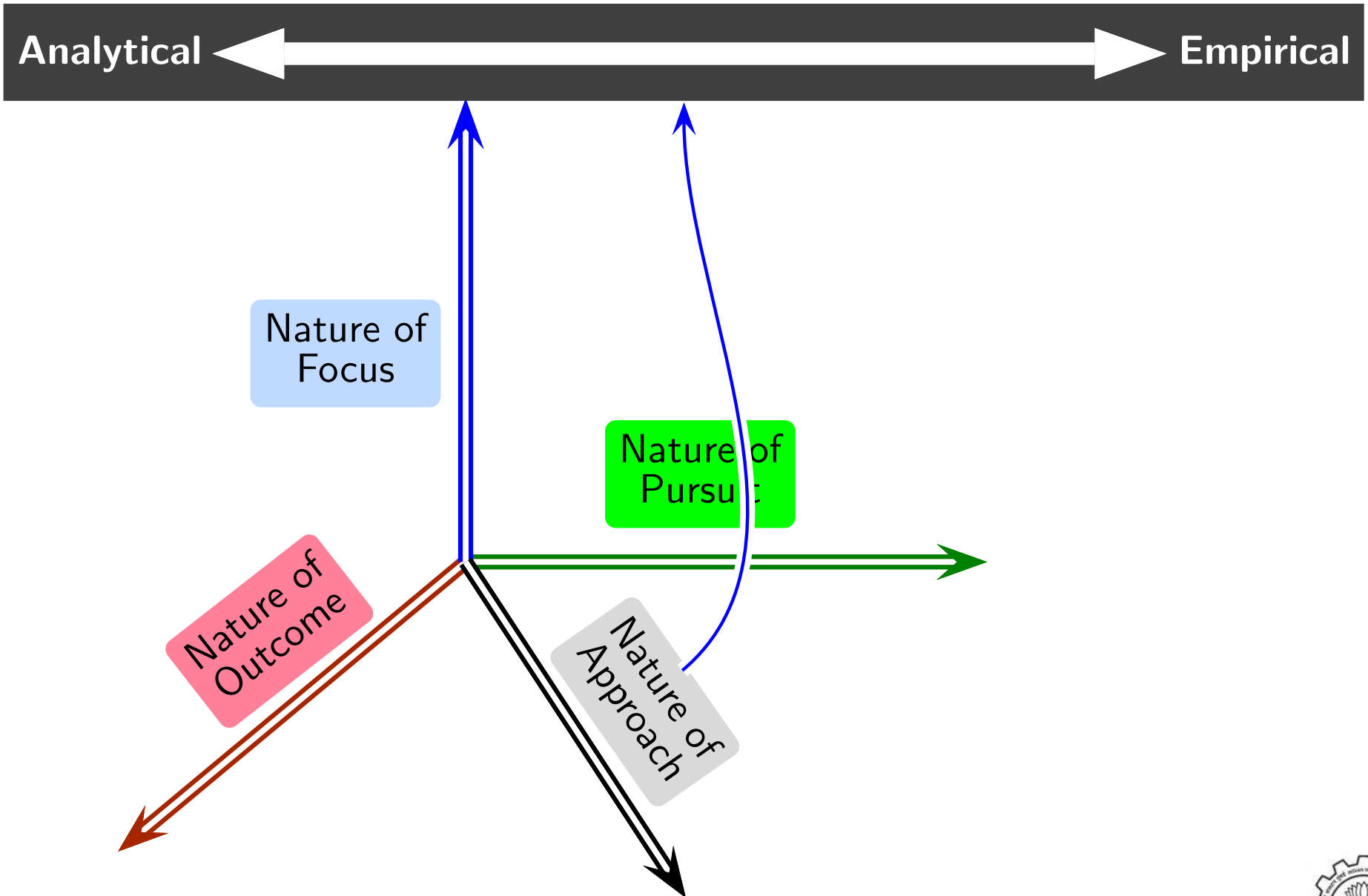


And a well known fourth dimension

Positioning Your Research



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

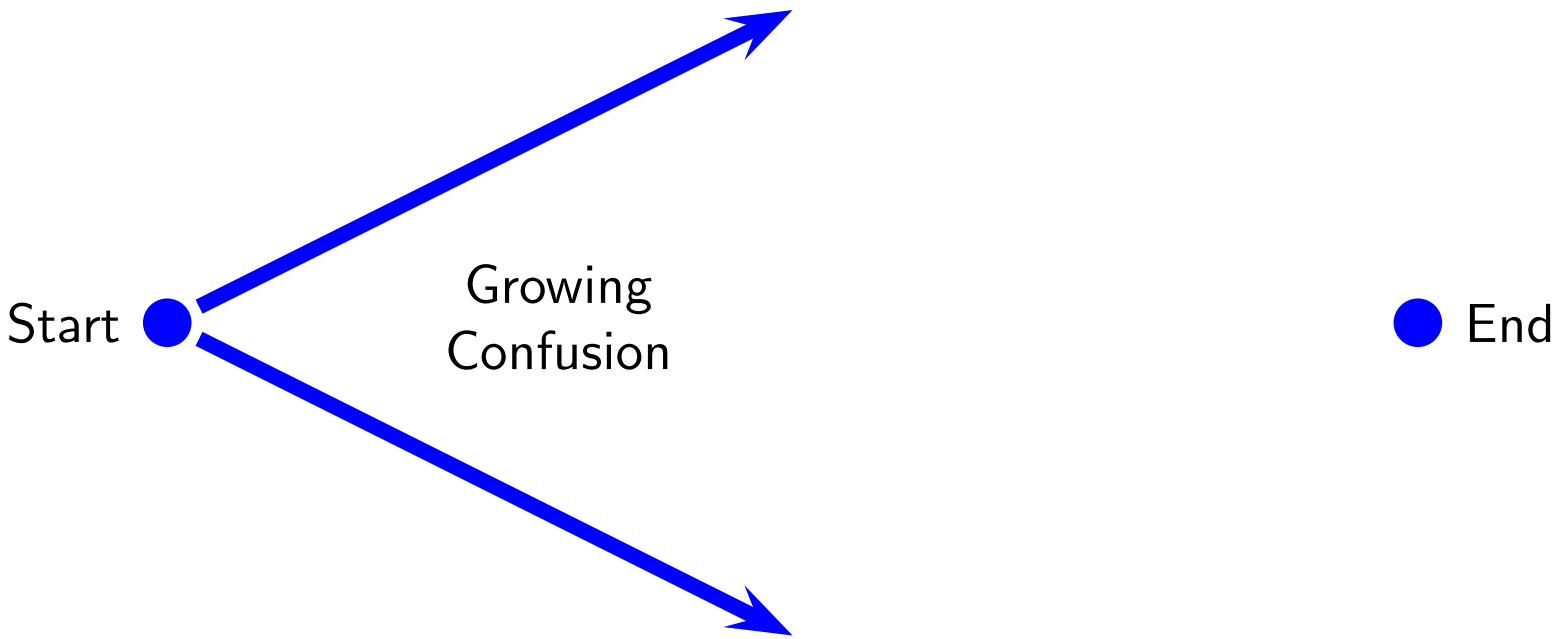
Each of the above views is **correct** and **complete** w.r.t to chosen level of abstraction

From Confusion to Conviction

Start End

From Confusion to Conviction

From Confusion to Conviction



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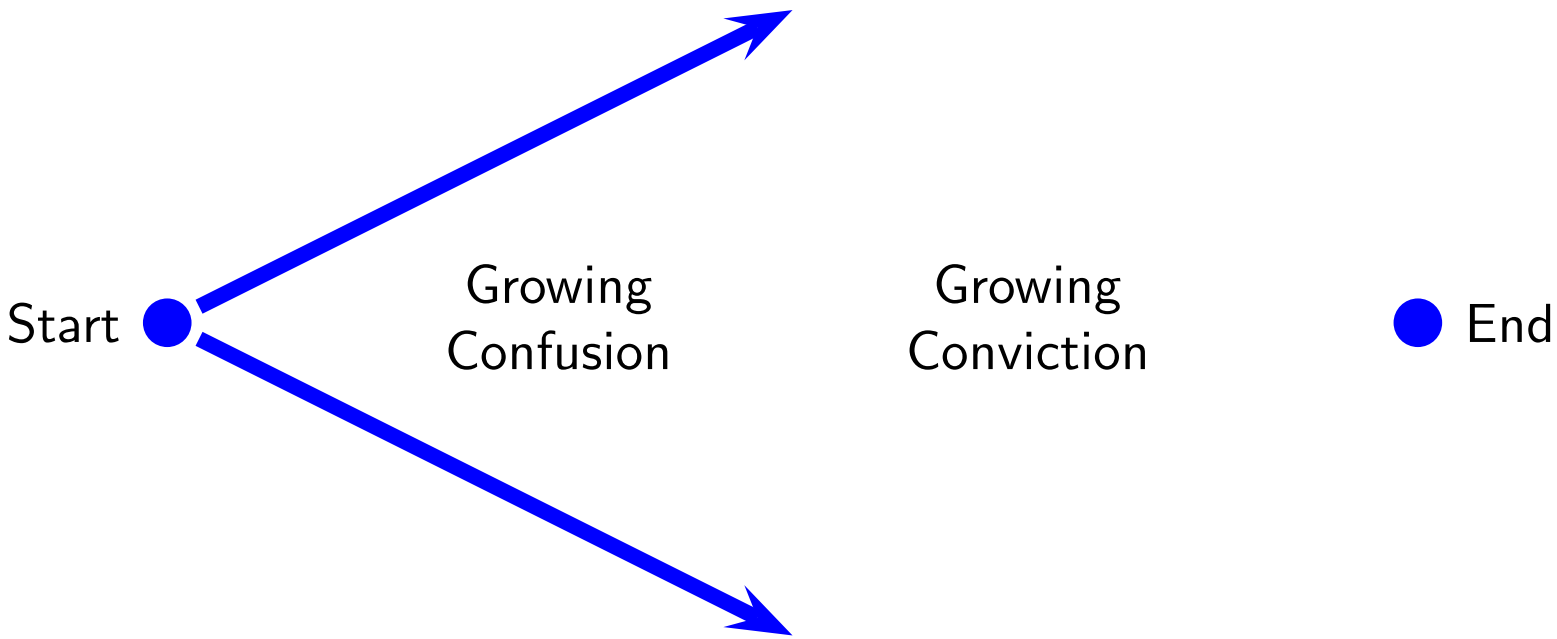

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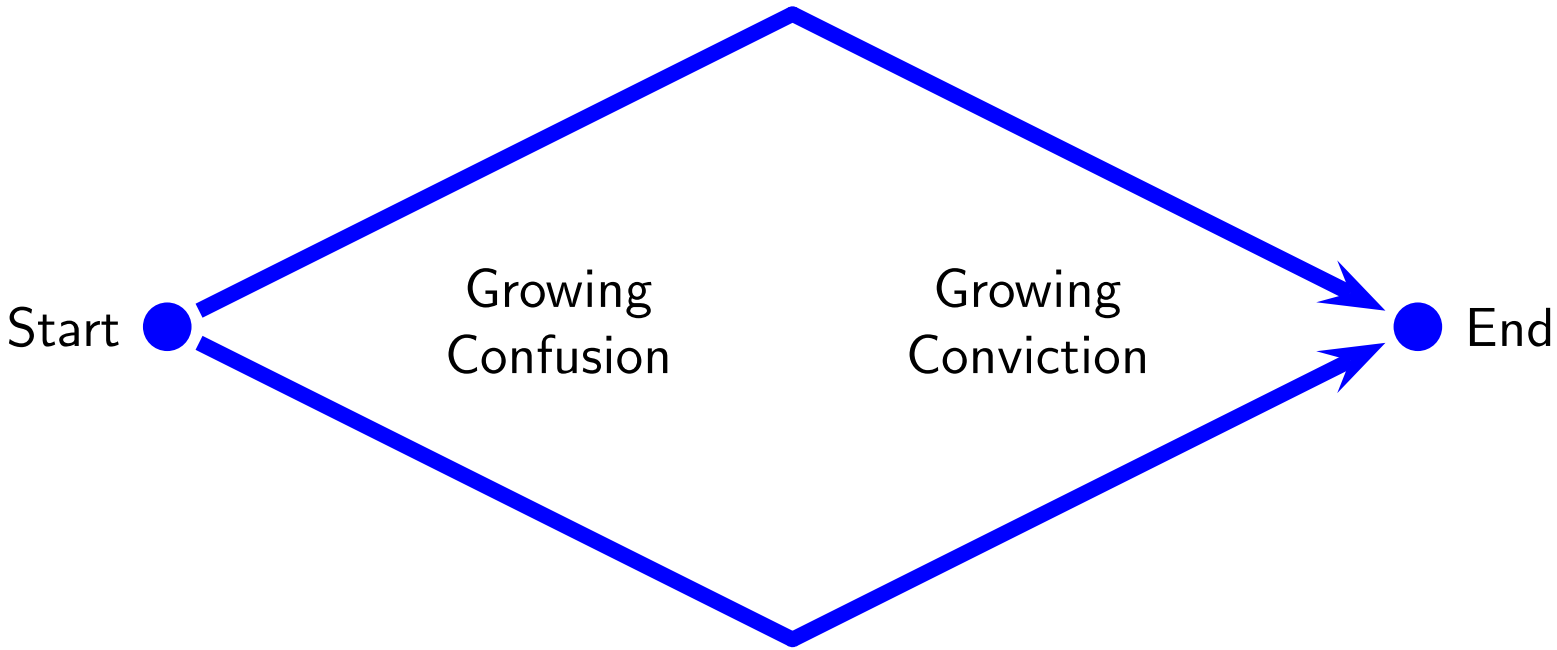
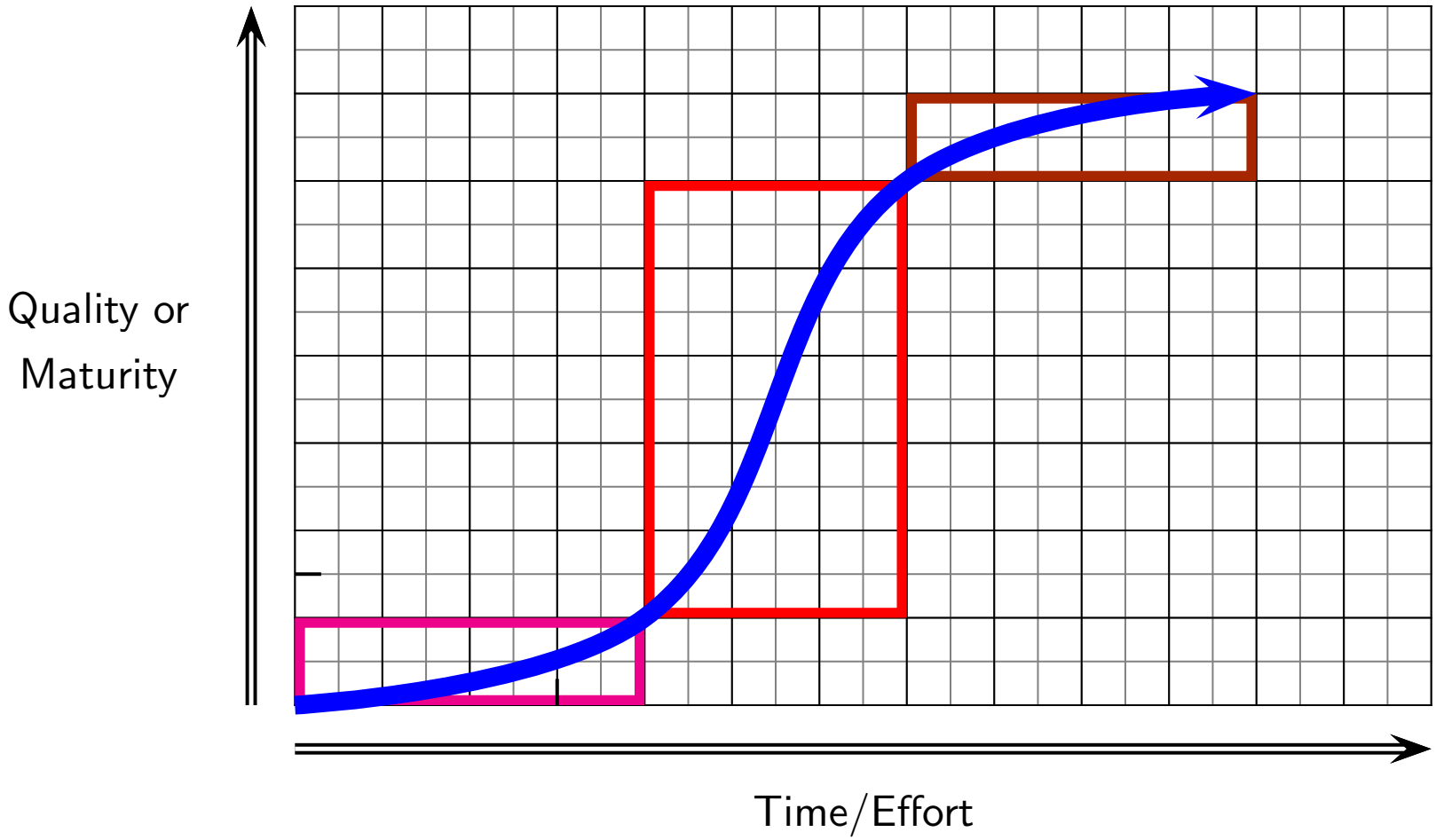
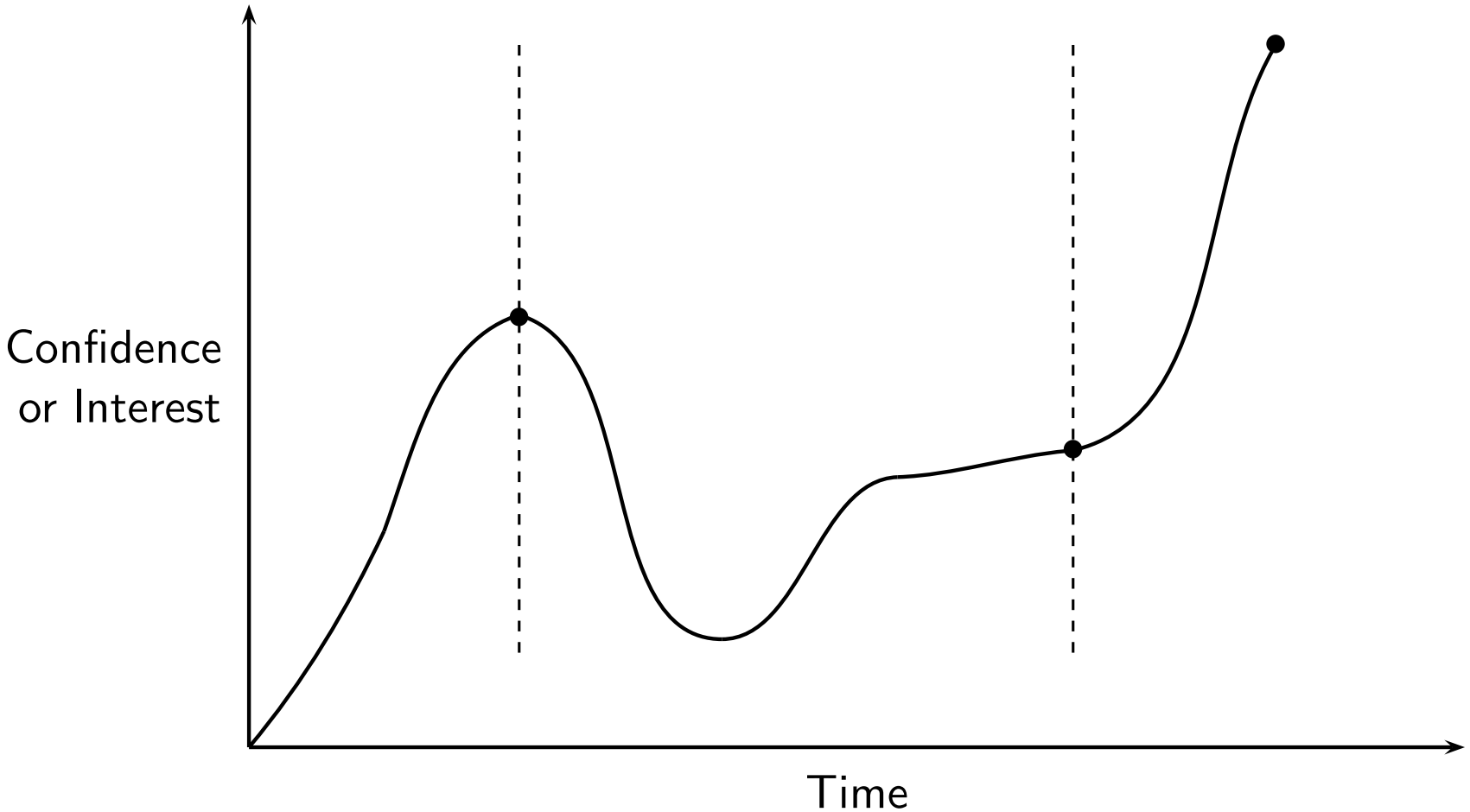


The "S" Curve of Research Life Cycle



Pitfalls in Hitting the Productive Zone



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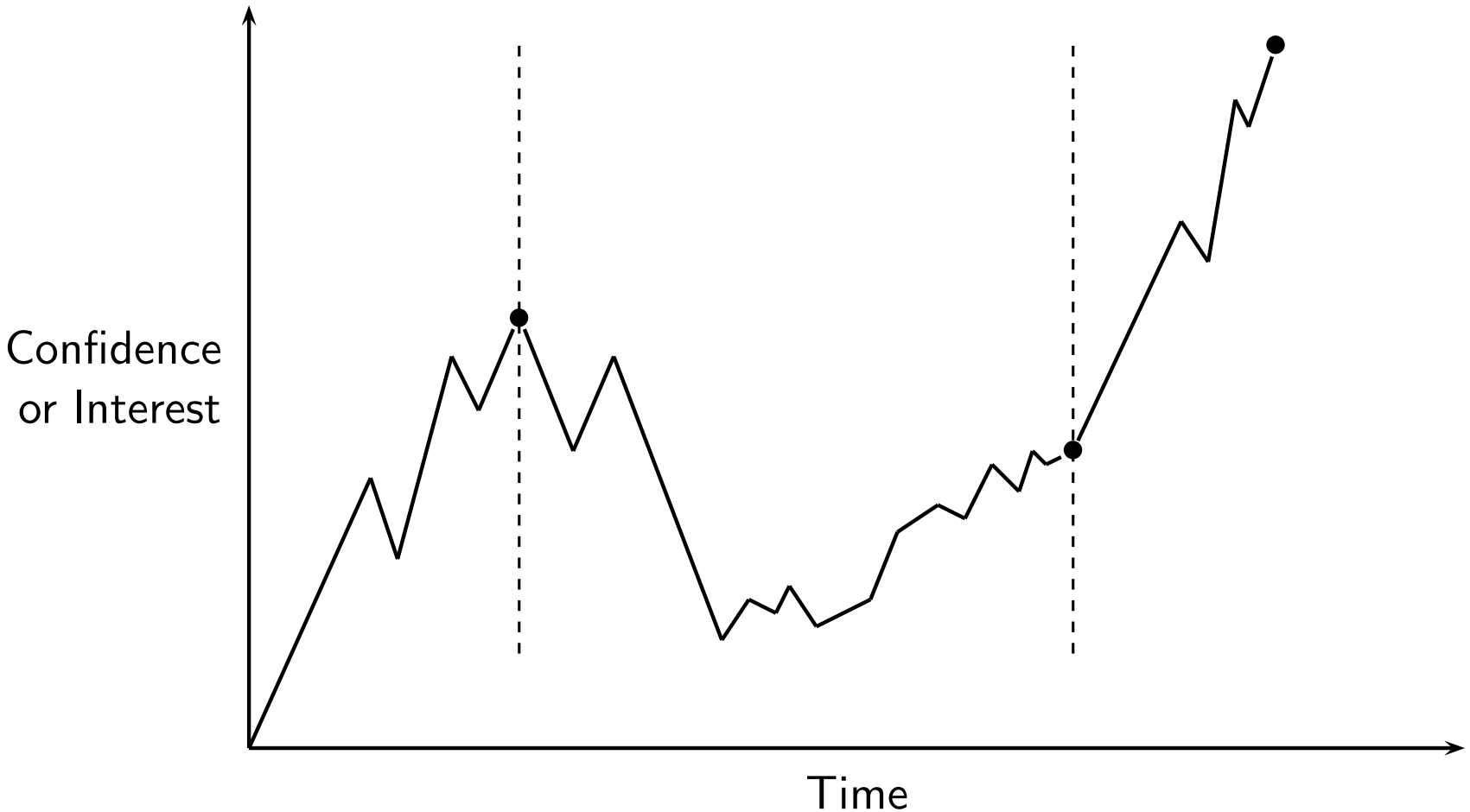

Research in Industry Vs. Research in Academia

Product driven research Vs. idea driven research

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A product is typically based on a large number of ideas

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  Deliverables exist but of a different nature

  Deadlines are usually as strict

Part 6

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. "

Doing research is a test in which you are allowed to write your own question paper and then answer it

The Role of Consolidation through 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 . . ."

The Role of Consolidation through Hard Work in Research

$$1.01^{365} =$$

$$0.99^{365} =$$

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$$1.01^{365} = 38.161$$

$$0.99^{365} =$$

The Role of Consolidation through Hard Work in Research

$$1.01^{365} = 38.161$$

$$0.99^{365} = 00.025$$

The Role of Consolidation through Hard Work in Research

- The physical time remains same but you are able to give deep attention with small conscious effort,

  "Getting into the zone" or "Getting into the flow"

- Consolidation through hard work helps you to reduce your conscious effort

The Role of Consolidation through Hard Work in Research

- The difference between ordinary and extraordinary is that little extra
- One needs
  - The initiative to find that extra
    Must be smart and relevant extra, not arbitrary extra (use controlled imagination)
  - The patience and discipline to keep doing that extra again and again
- Initiative and discipline helps you get into the zone

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.* "

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. "

Three Requirements of Creativity

- Deep knowledge
  - Keep your antennas tuned
  - You never know when and where the signals come from
- Holding a problem in the background thinking for a long time without acting on it
- Dealing with loosely structured ideas and structuring them over time

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 7

Conclusions

The Role of Research in Long Satisfying Technical Career

- In a rapidly changing world, 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

What Does it Take to Be a Researcher?

- 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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Why do mountaineers climb mountains?

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  - Personal goals
  - Philanthropic goals. Making a difference by

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  - Philanthropic goals. Making a difference by
    - Creating knowledge
    - Solving problems
    - Creating opportunities
    - Changing perceptions

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- Solving intellectually challenging problems

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  - Also requires creativity, perseverance, intellectual endurance etc.
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The Ten Commandments of Creativity in Research

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Also applicable to

- A practising engineer
- A student
- A teacher

. . . in all intellectual pursuits!

Last But Not the Least

Thank You!

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