

# *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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  - ▶ Personal reflections and confessions 😊



*Part 2*

# *Why Research?*

# Alice's Adventures





# Alice's Adventures



*Through the Looking Glass*

Author: Lewis Carroll

Illustration: John Tenniel

## Alice's Adventures



*Through the Looking Glass*

Author: Lewis Carroll

Illustration: John Tenniel

'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?



# Why Do People Do Research?

- Is this the main reason why people do research?
- 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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  - ▶ **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

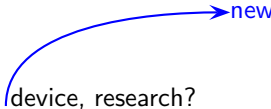


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- Is building a device, research?



# The Essence of Research

- Is building a device, research?
- new
- 



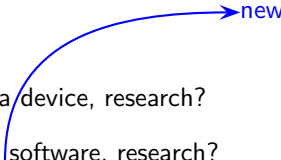
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Research could involve any of the above, or none of the above



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- Creation of ideas vs. execution of ideas  
Reflection vs. action





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- Significance
  - ▶ Beauty
  - ▶ Utility
  - ▶ Enhancement of knowledge



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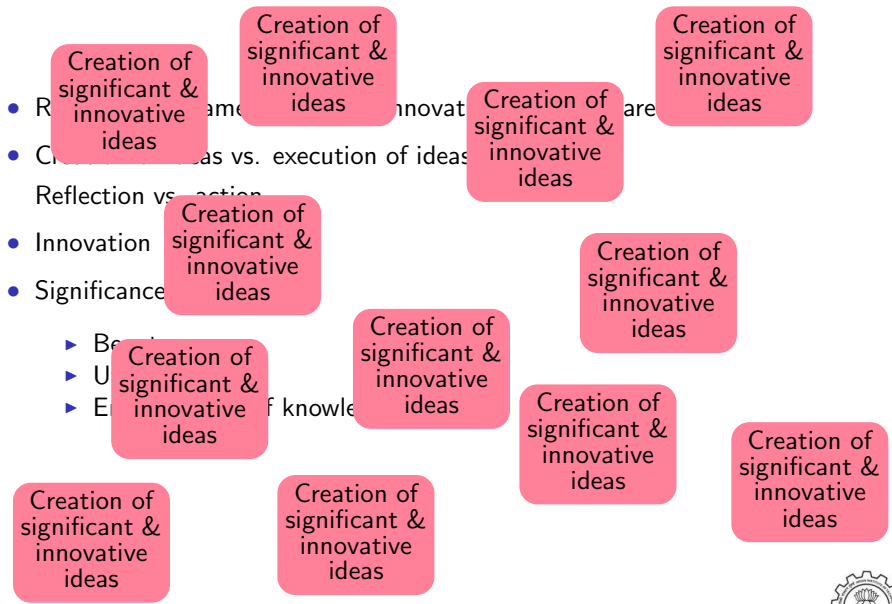
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# The Essence of Research



- Research is a systematic and innovative activity
- Creation of ideas vs. execution of ideas
- Reflection vs. action
- Innovation
- Significance
  - ▶ Basic research
  - ▶ Utilitarian research
  - ▶ Exploration of knowledge



# What is an Idea?



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- An idea is not an isolated thing in a vacuum, it has a context
- The context often decides its significance





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*Discovery, Invention, or Creation?*
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- Sometimes, we know what the puzzle would be like before getting the idea  
Some other times the picture emerges as we start discovering the ideas



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## *Important disclaimer*

- ▶ Discover

Discover

- ▶ An ide

- ▶ The m

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



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# Ingredients of Good Research

- Innovation



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- Innovation
- Aesthetics



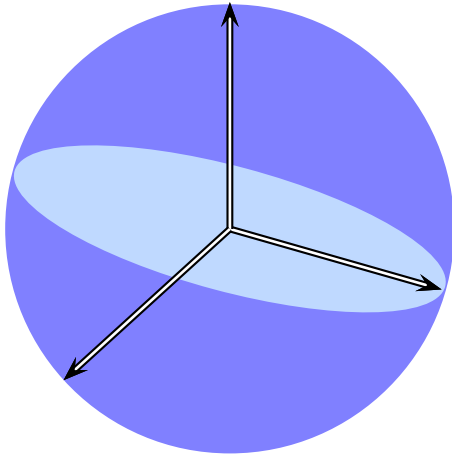


# Ingredients of Good Research

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

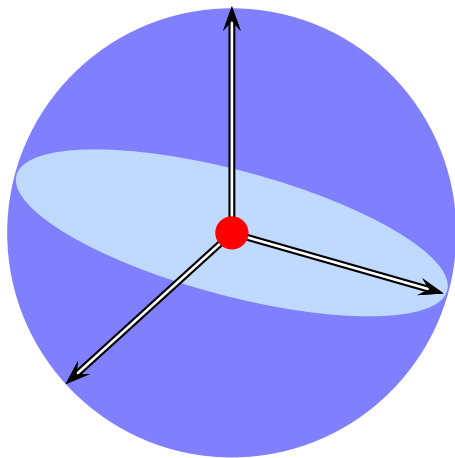


# Innovation



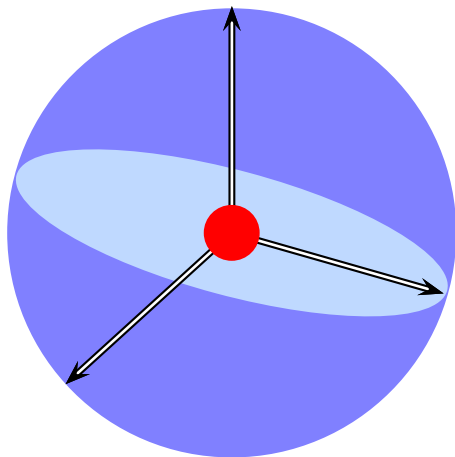
- The sphere of knowledge

# Innovation



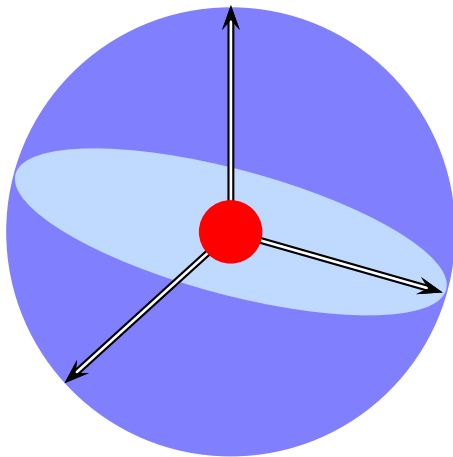
- The sphere of knowledge
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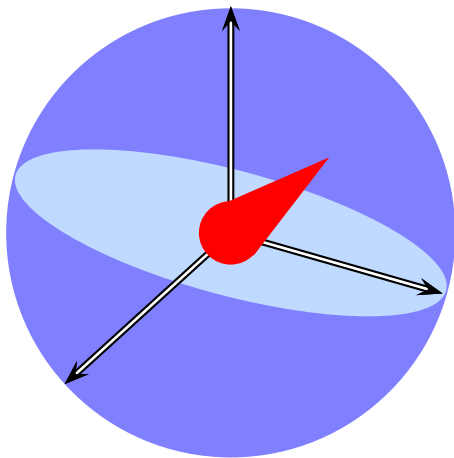
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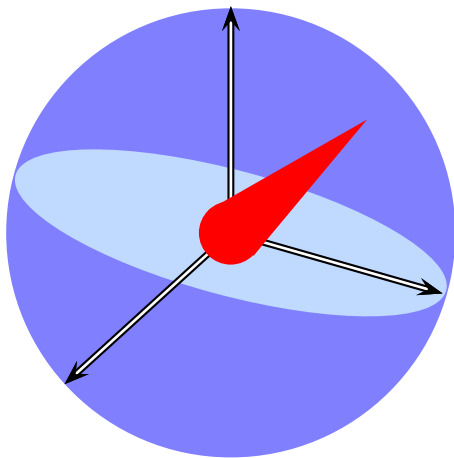
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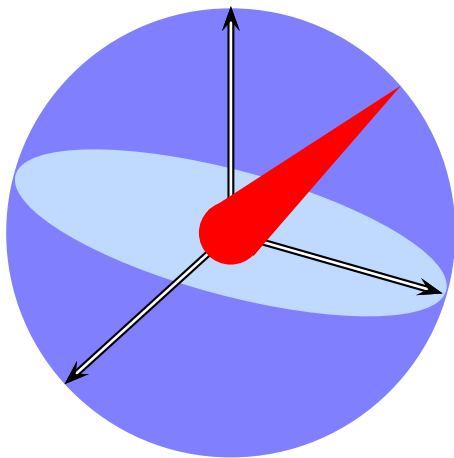
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# Innovation



- 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

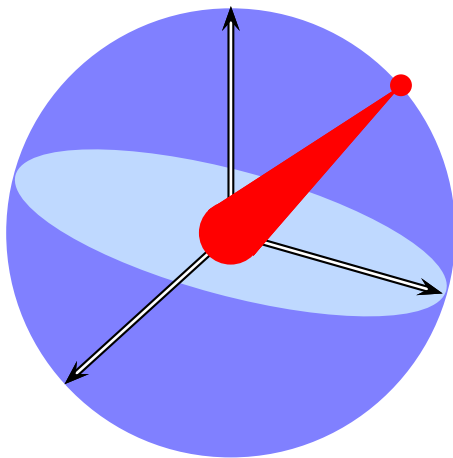
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# Innovation



- 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

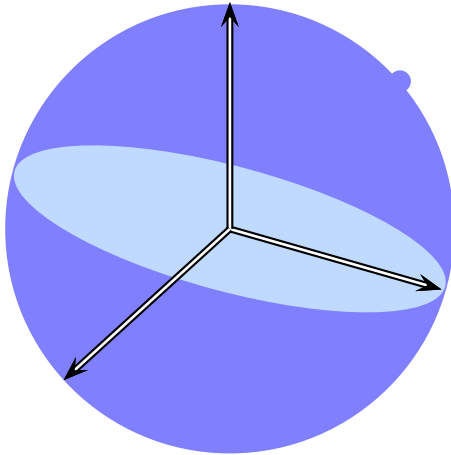
# Innovation



- 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/>

## 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

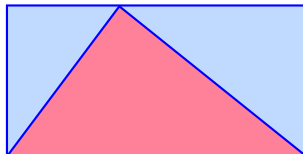
- Example : Painting

Proportion of colours Vs. their arrangements

- Casserole design



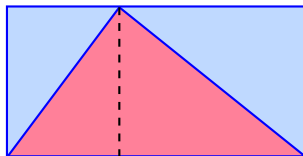
# Aesthetics and Beauty of an Idea



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



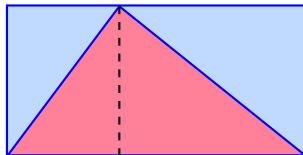
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- Idea: Draw a vertical line to divide the rectangle in two parts

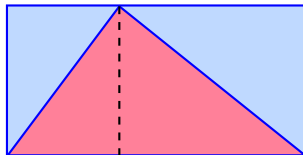


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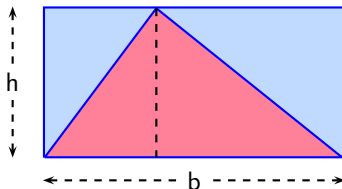
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- Exactly as much area outside of the triangle as there is inside

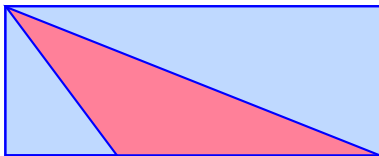
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- Area of a triangle =  $\frac{1}{2} \times b \times h$

# Food for Thought

What about this pink triangle?





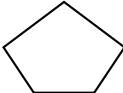
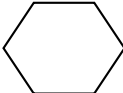
## Beauty of an Idea

- 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



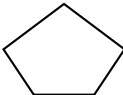
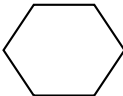
- Question: What is the sum of all internal angles of a polygon?



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
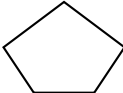
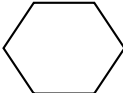
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	$180^\circ$
	
	
	



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
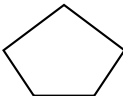
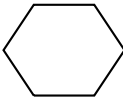
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	$360^\circ$
	
	





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
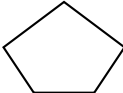
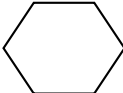
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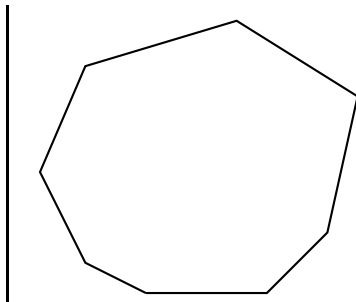
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	$180^\circ$
	$360^\circ$
	$540^\circ$
	$720^\circ$



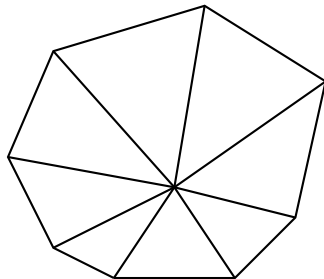
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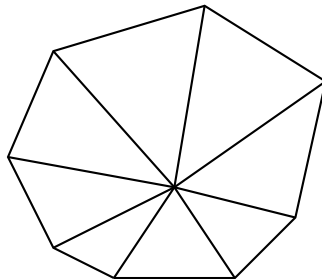
## Another Example of Beauty of an Idea

- Question: What is the sum of all internal angles of a polygon?
  - ▶ Consider an  $n$  sided polygon
  - ▶ Choose an arbitrary inner point and connect it to all vertices



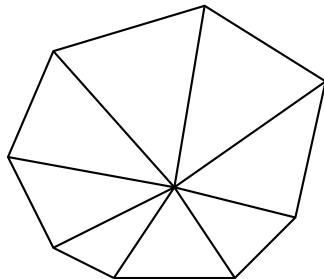
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- Question: What is the sum of all internal angles of a polygon?
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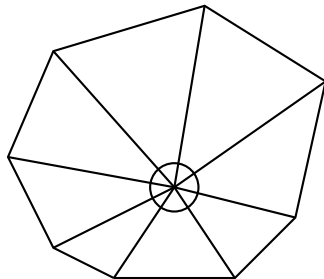
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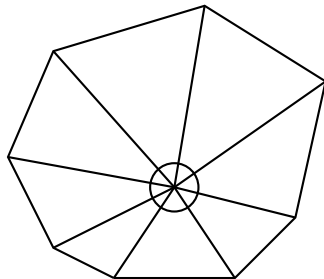
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- Answer:  $(n \cdot 180 - 360)^\circ$



## On the Role of Rigour in an Idea

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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”*



*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



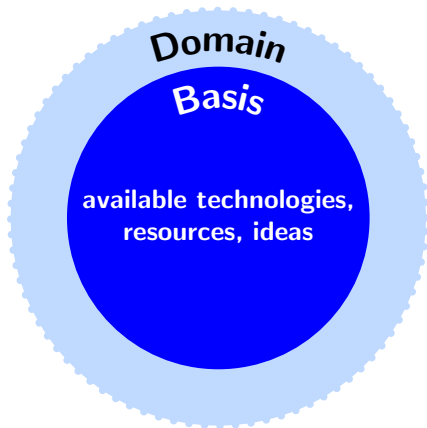
- Basis:

- Domain:





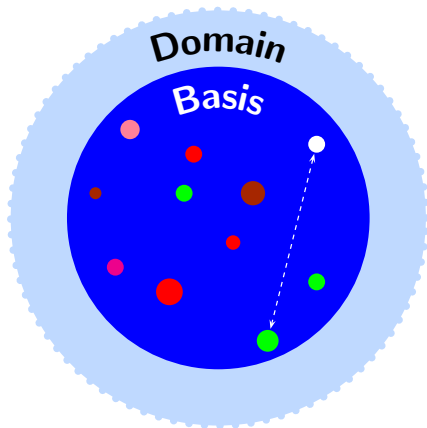
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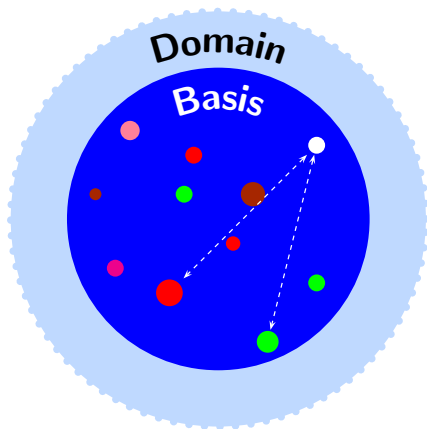


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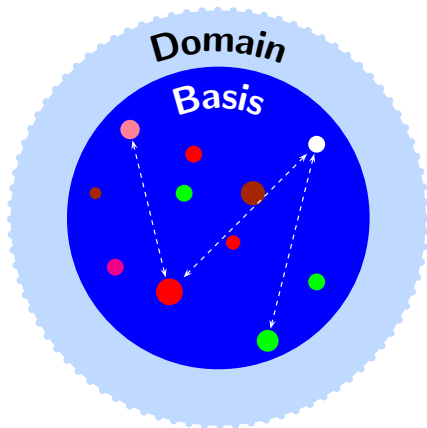
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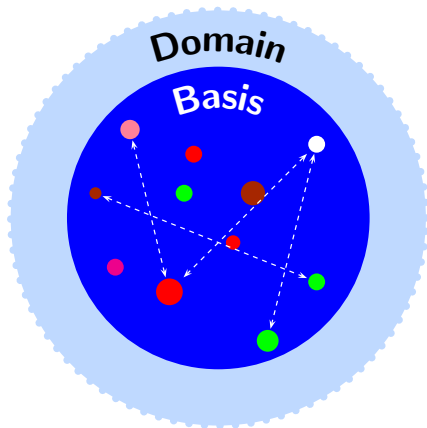
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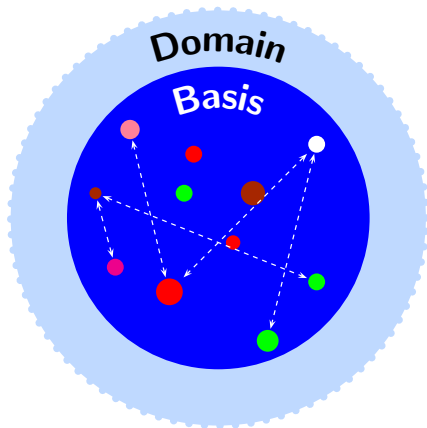
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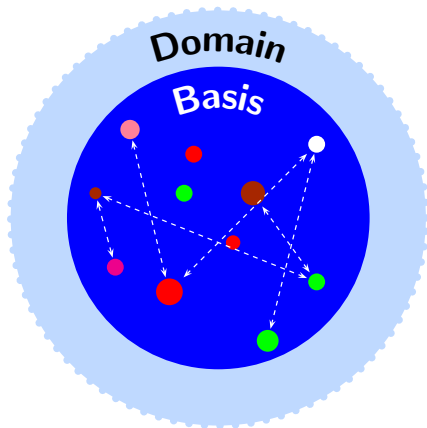
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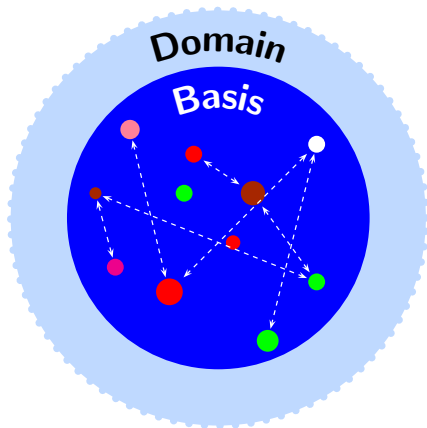
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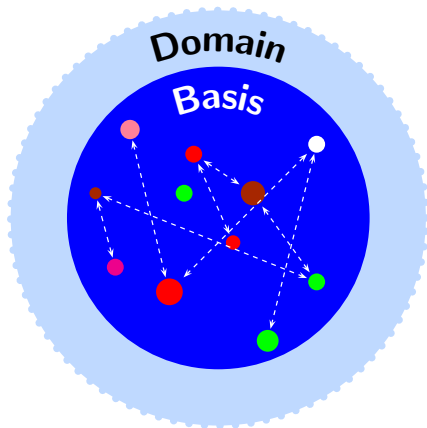
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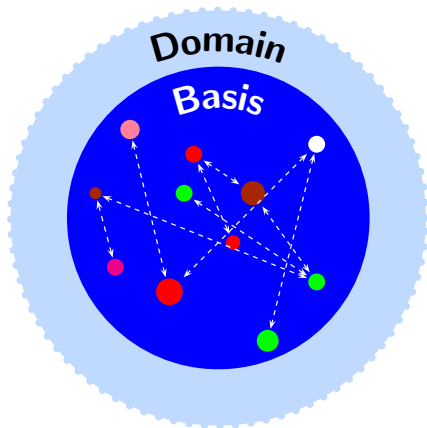


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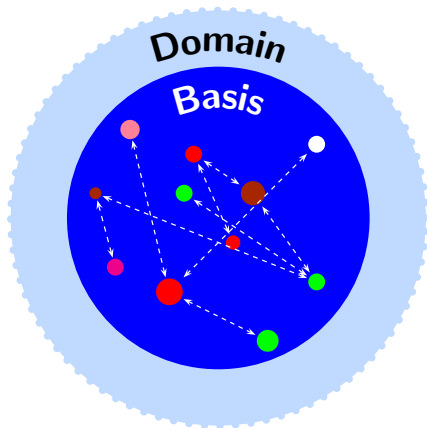
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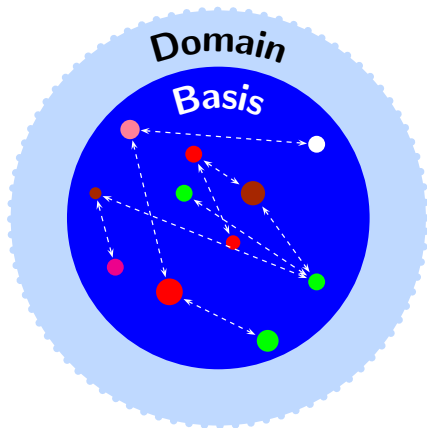
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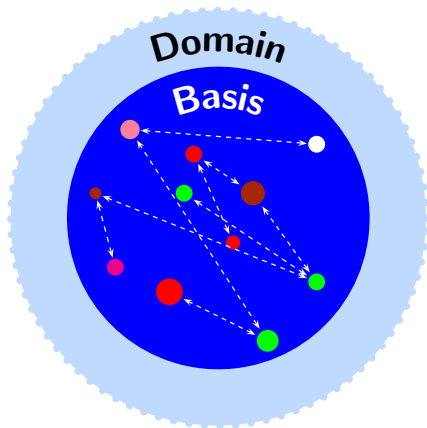
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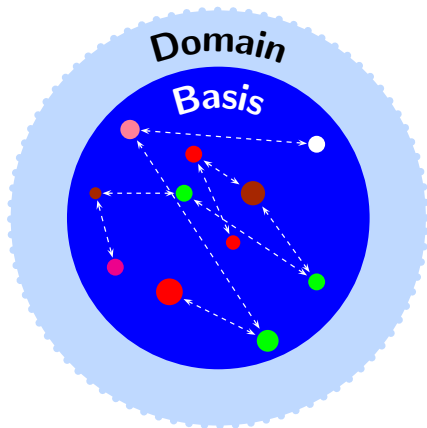
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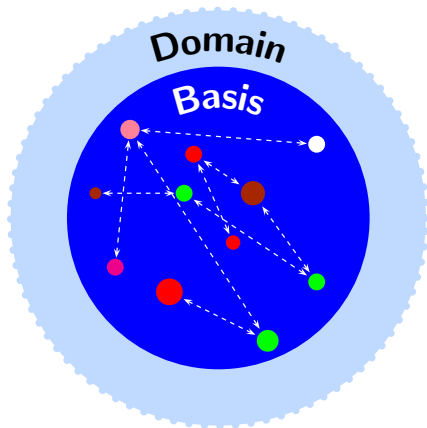
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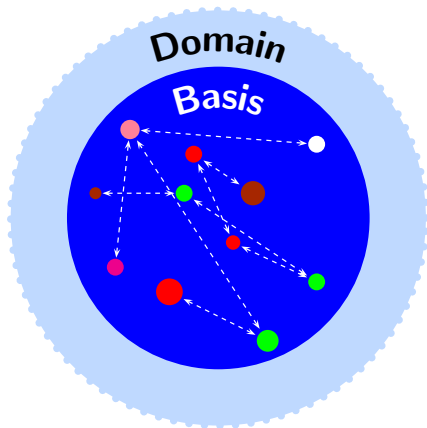
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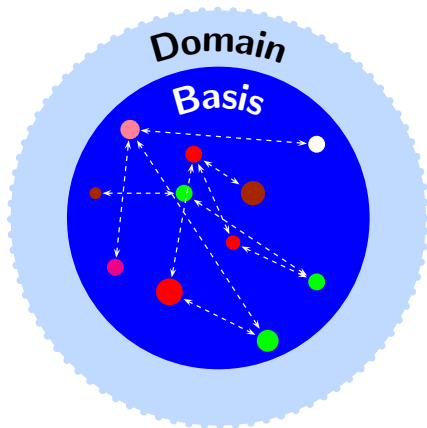
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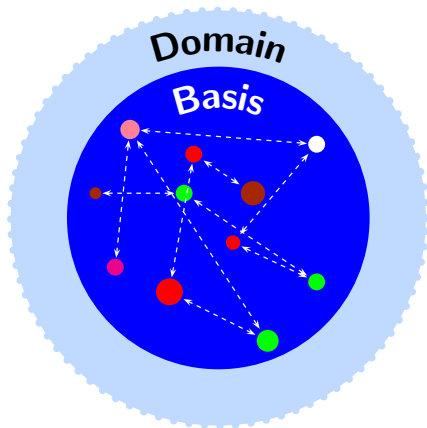


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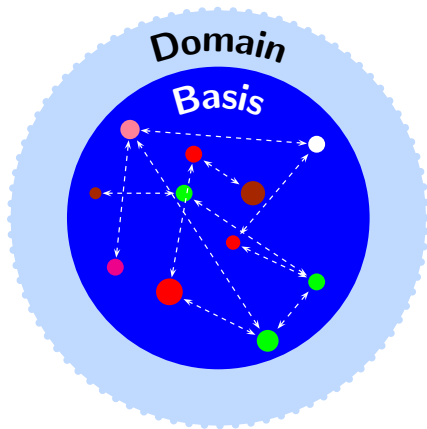
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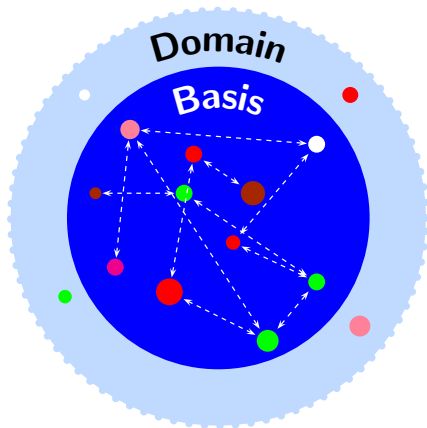
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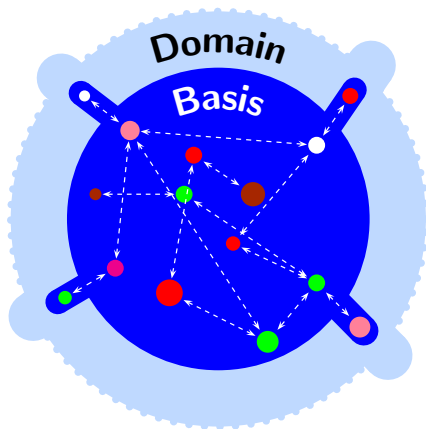
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  - ▶ Boundaries grow as we explore

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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 essence 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
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- 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

- Prevailing wisdom circa 1950s : Expressiveness Vs. Efficiency conflict



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  - ▶ *Economic problem.* Imbalance between the programming costs and computer costs
  - ▶ *Technical difficulty.* Inefficiency of translation of an expressive specification
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- Creation of FORTRAN is a triumph of the genius of AND over the tyranny of OR





## Adaptation

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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

- Adaptation Example 3:

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



## Slow Hunch

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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*”

- A happy coincidence, a chance meeting, unexpected connections made by neurons in the dreams  
(No wonder coffee table discussions in conferences are more productive than formal presentations)



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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*



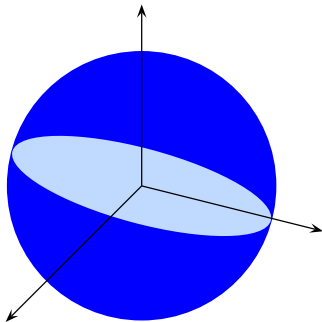
## The Spirit of Inquiry (1)

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



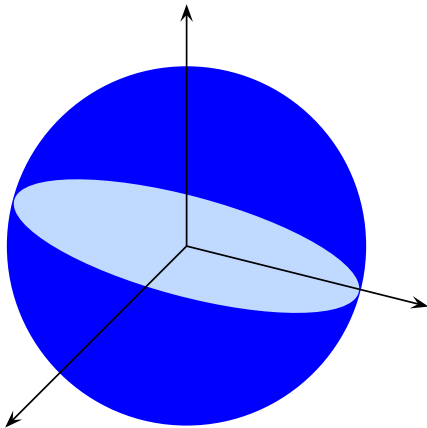
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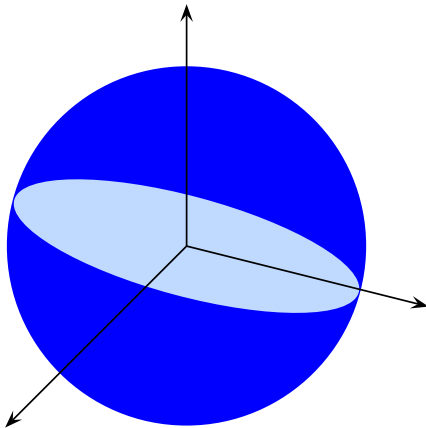
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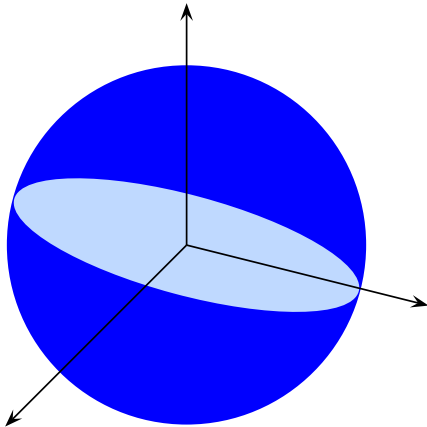
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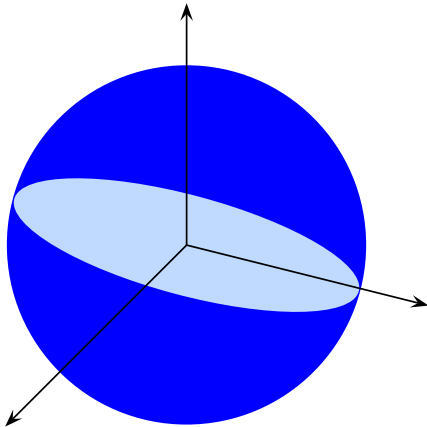
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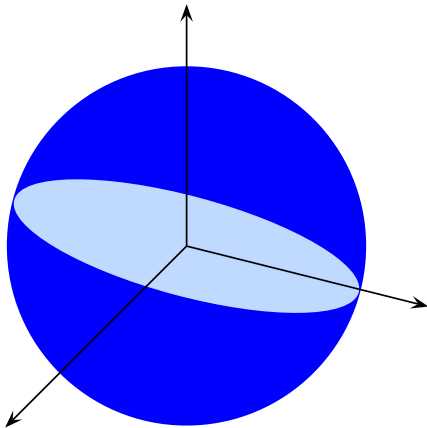
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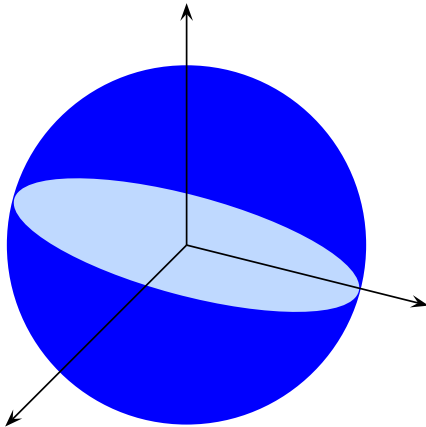
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- Productive stupidity:
  - ▶ No research is possible unless we are willing to feel vulnerable and stupid

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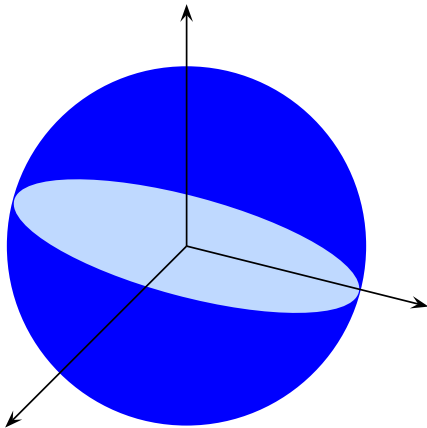


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- We are taught to feel bad about relative stupidity
- Productive stupidity:
  - ▶ No research is possible unless we are willing to feel vulnerable and stupid
  - ▶ If we don't feel stupid, we are not trying enough!



## The Spirit of Inquiry (1)

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



- Relative stupidity Vs. Productive stupidity
- We are taught to feel bad about relative stupidity
- Productive stupidity:
  - ▶ No research is possible unless we are willing to feel vulnerable and stupid
  - ▶ If we don't feel stupid, we are not trying enough!

*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 disrespectful?
- Is independent thinking disrespectful?
- Does respect require obedience of thoughts?



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We end up mixing



- criticism of an idea with criticism of the person



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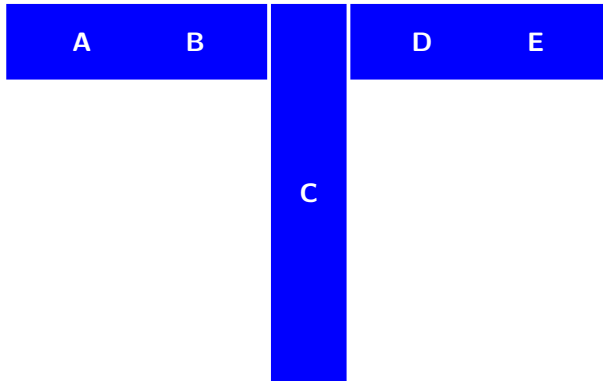
- criticism of an idea with criticism of the person 
- appreciation of an idea with appreciation of the person 



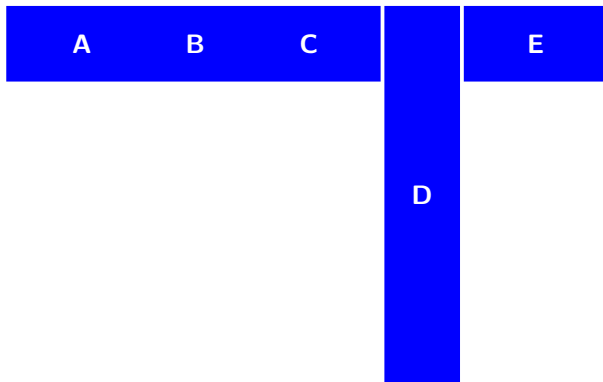
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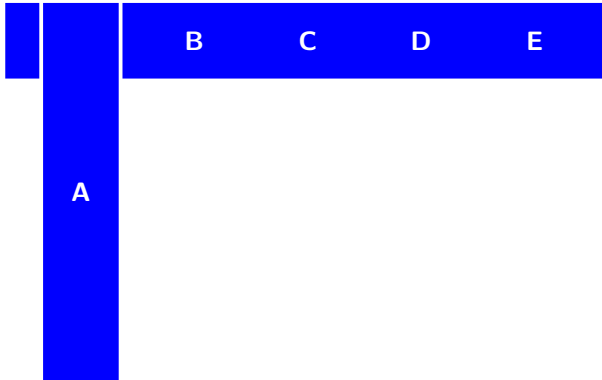
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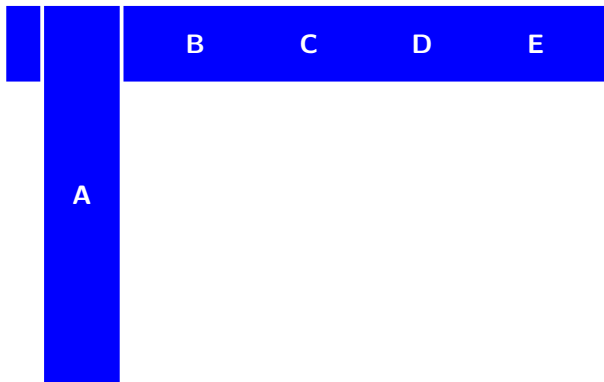


# Breadth Vs. Depth





## Breadth Vs. Depth



Breadth or Depth?



## Breadth Vs. Depth



Achieve depth in one area and overall breadth



## Breadth Vs. Depth



Achieve depth in one area and overall breadth



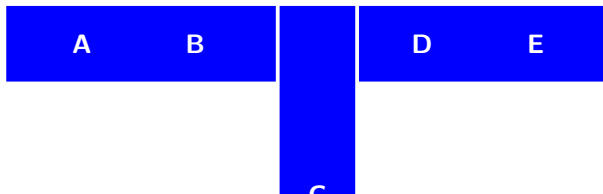
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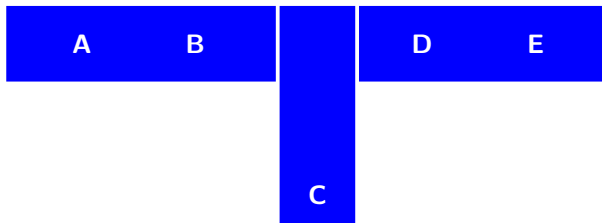
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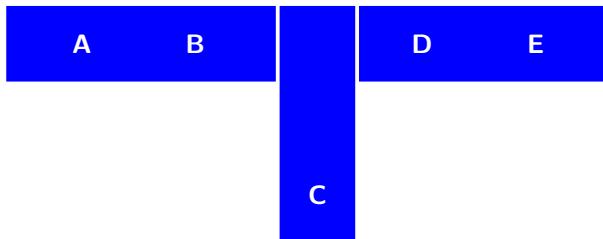
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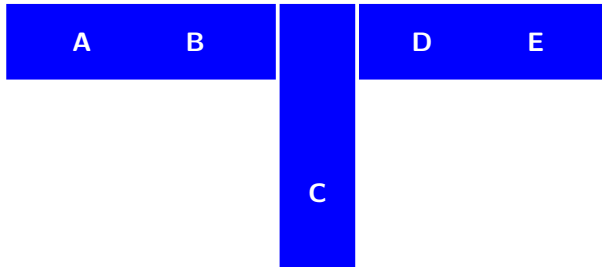
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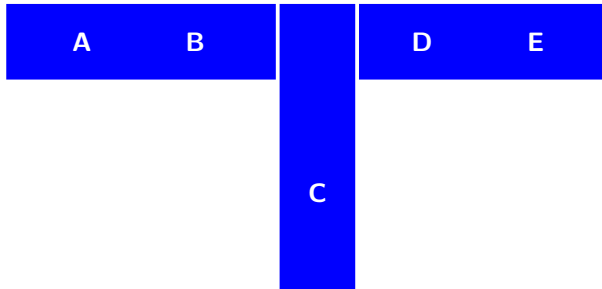


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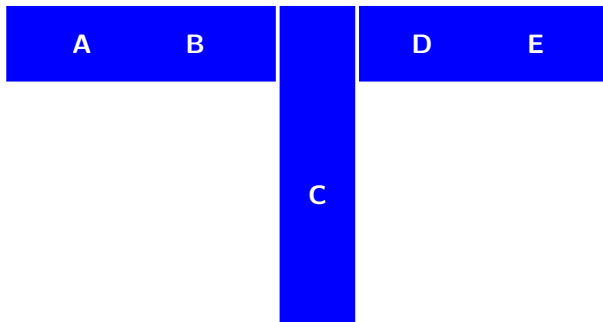
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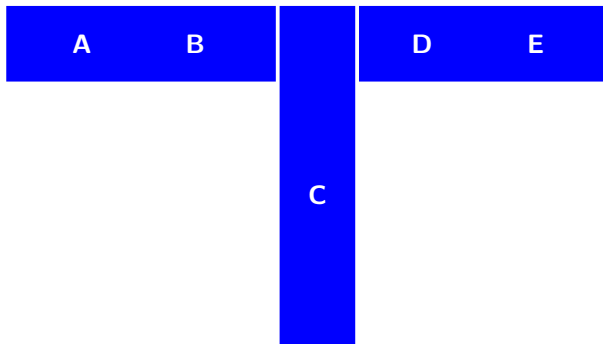
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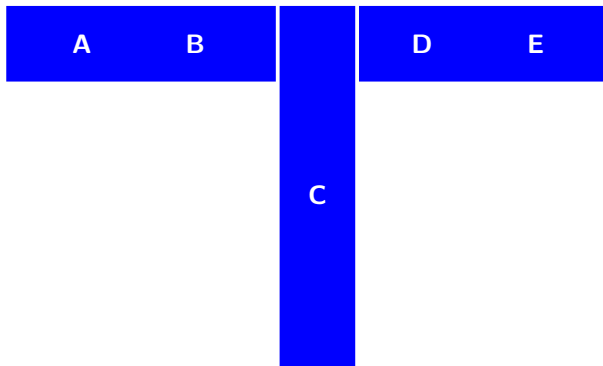
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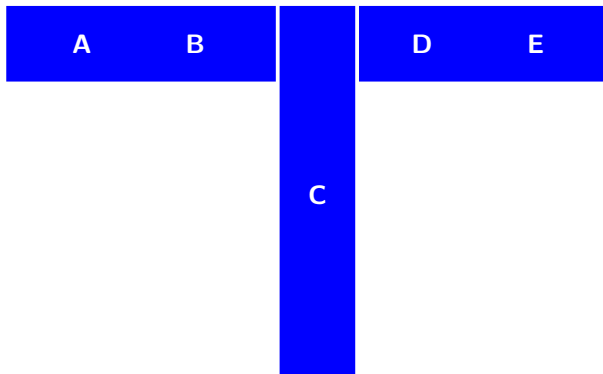
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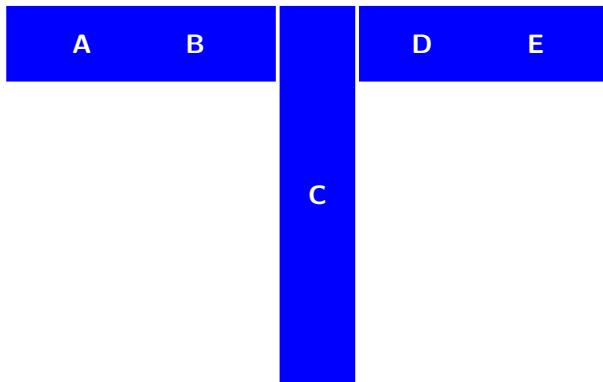
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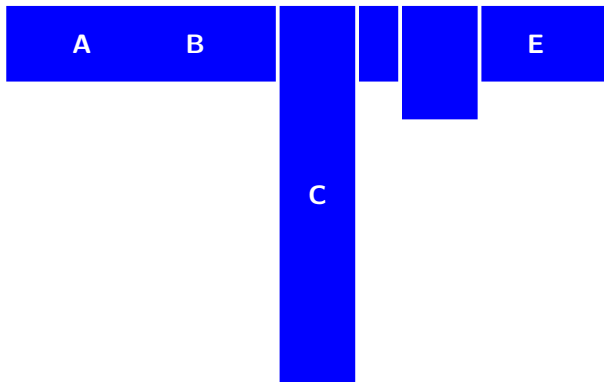
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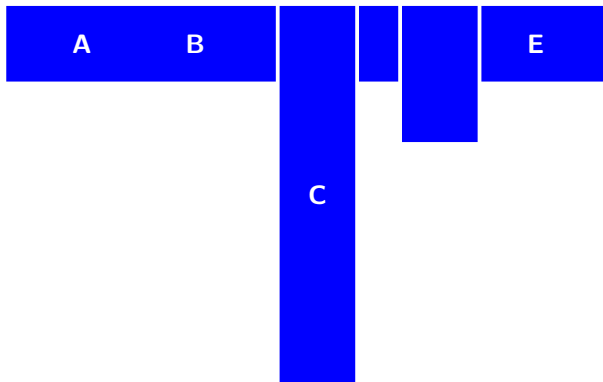
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Achieve depth in one area and overall breadth  
Other areas can be understood on need basis relatively quickly



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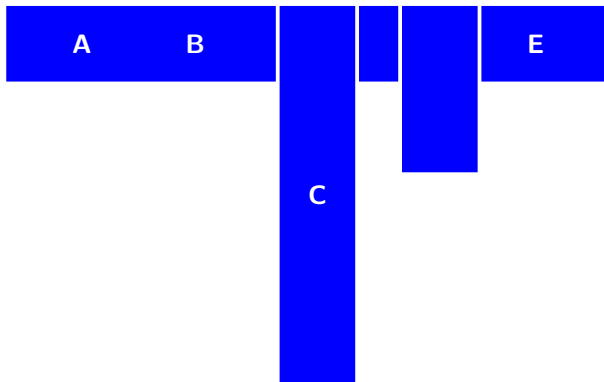


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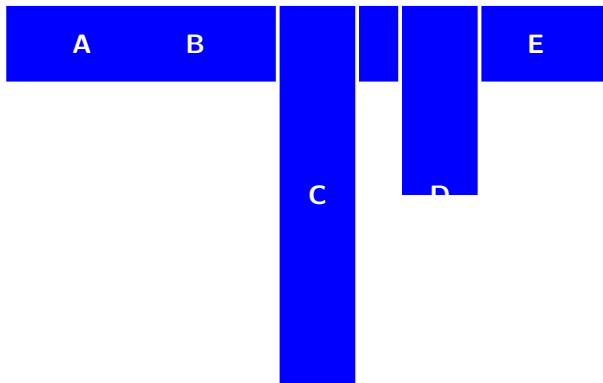
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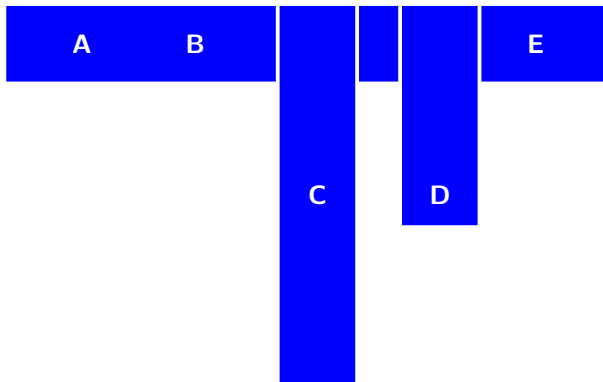
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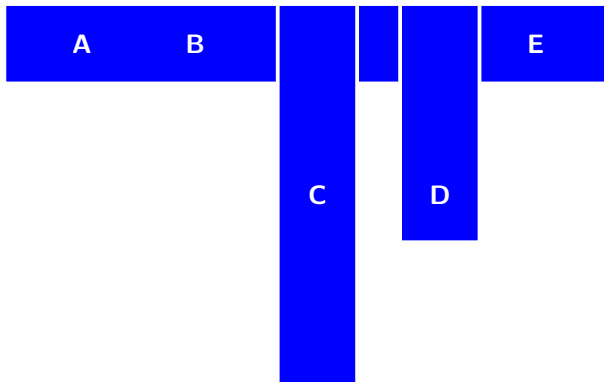
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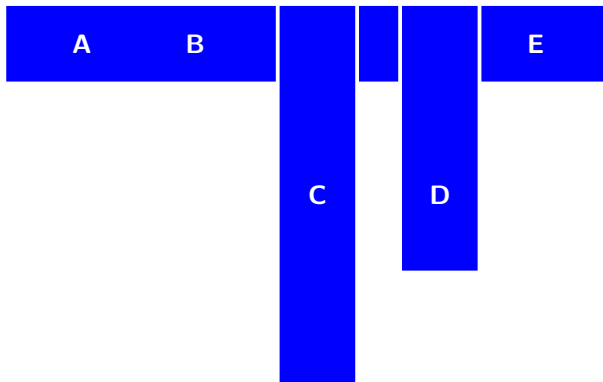
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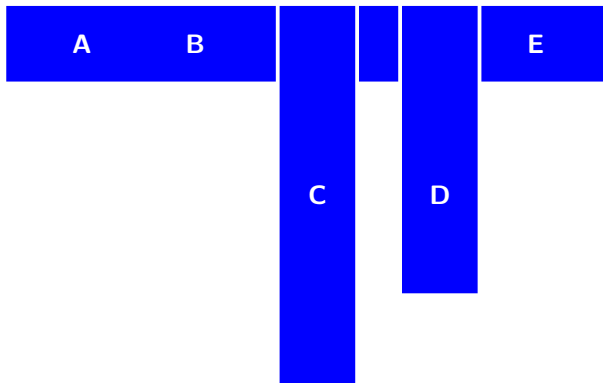
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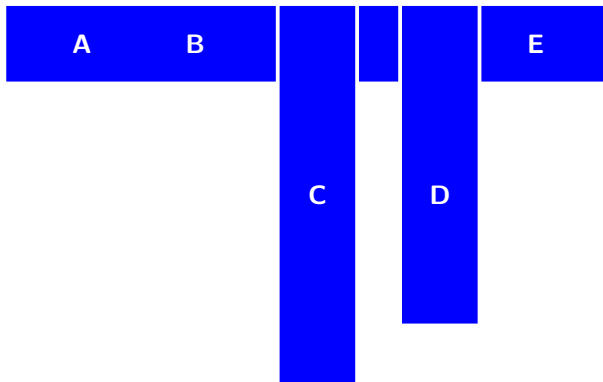
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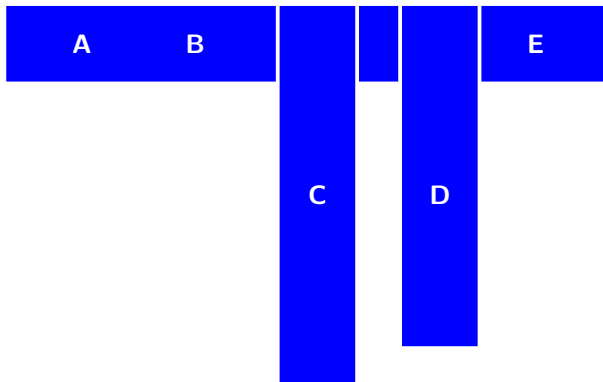
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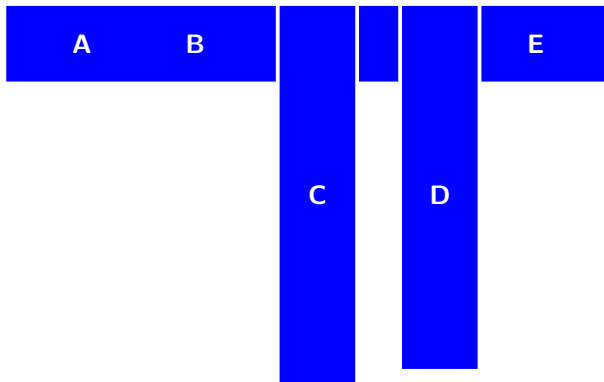


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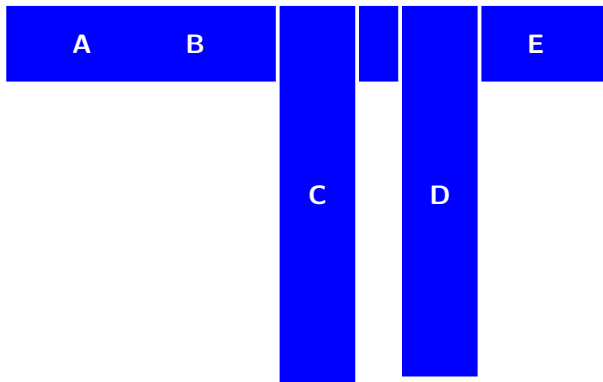
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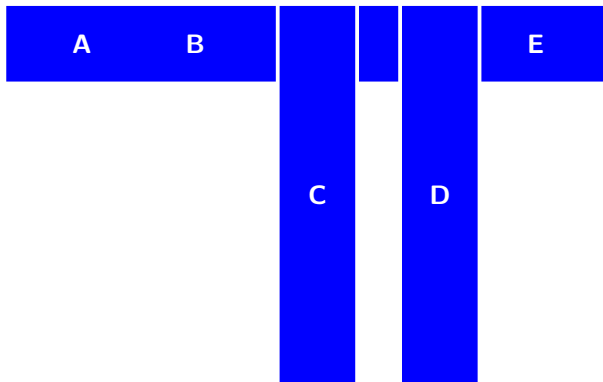
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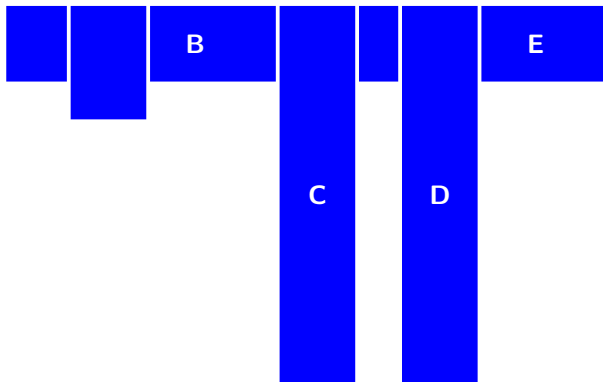
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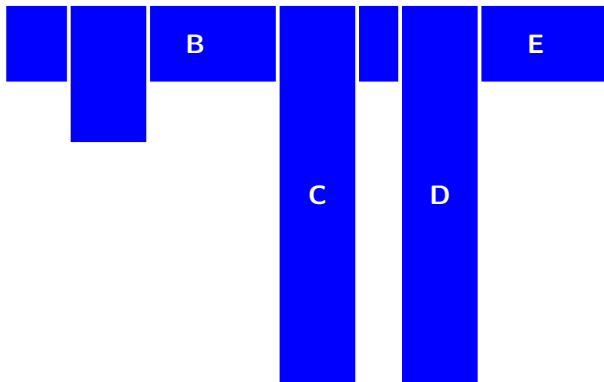
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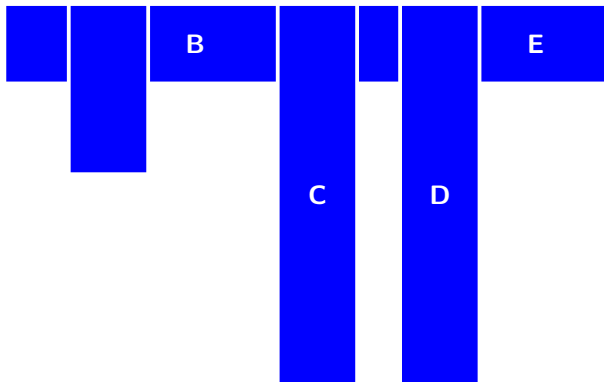
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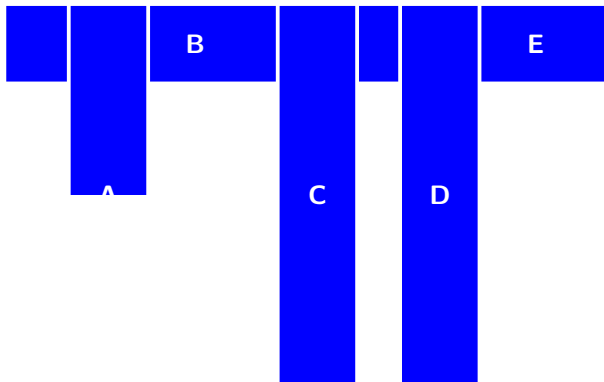
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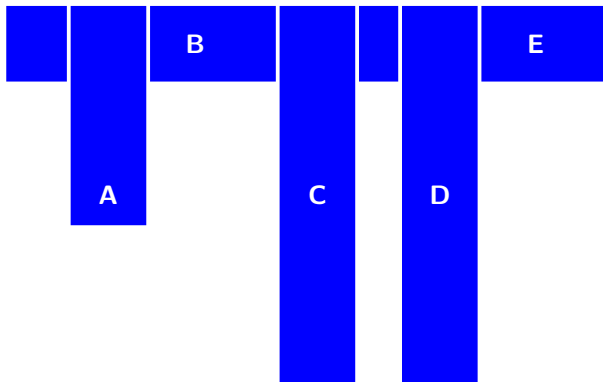
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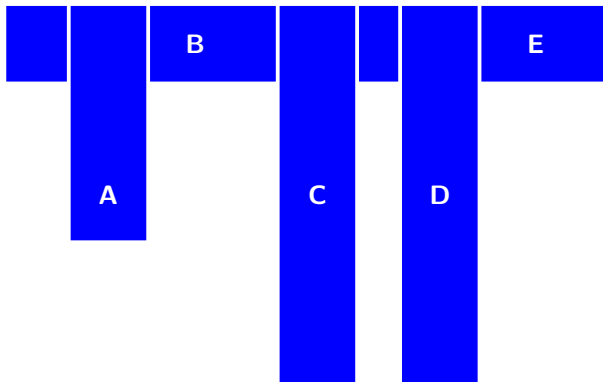


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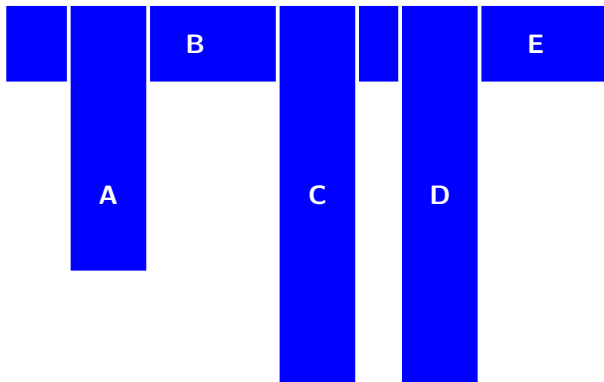
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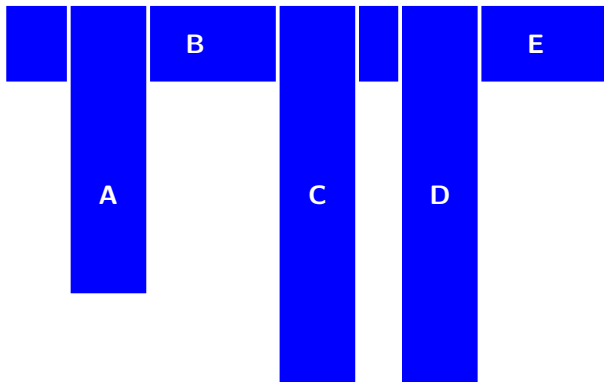
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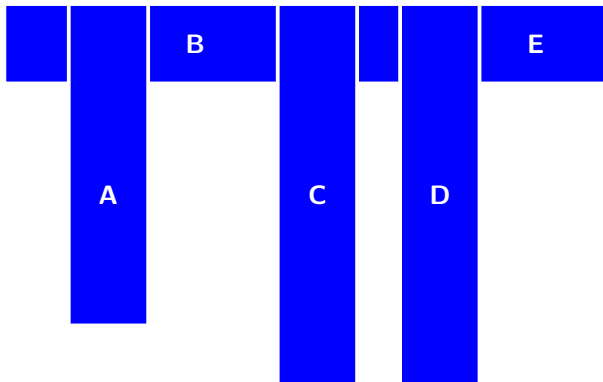
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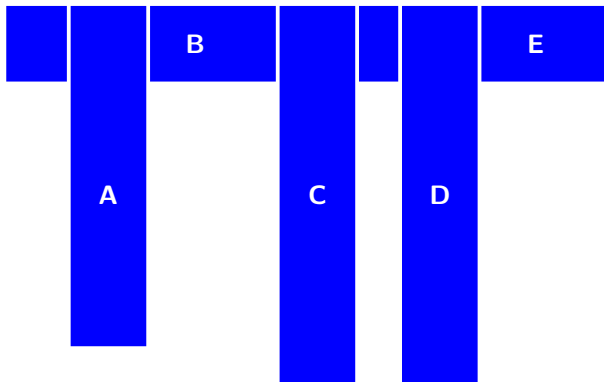
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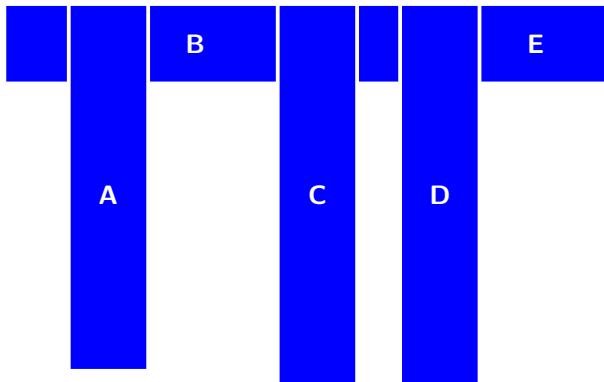
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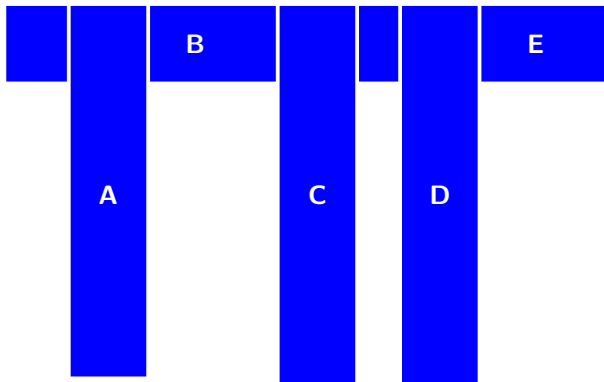
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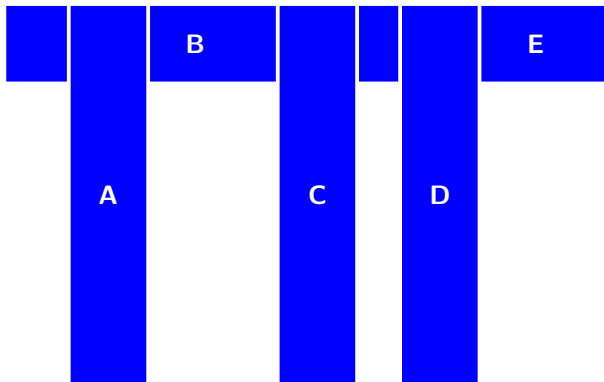
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## Ability to Abstract and Modularize

- 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 ●

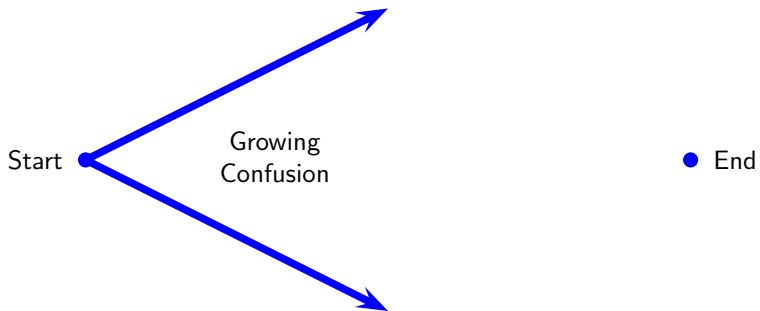
● End



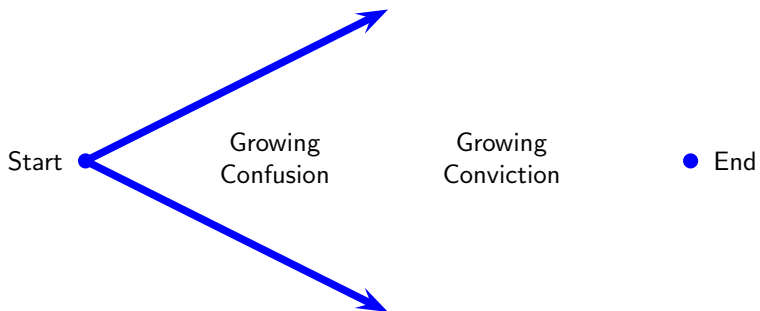
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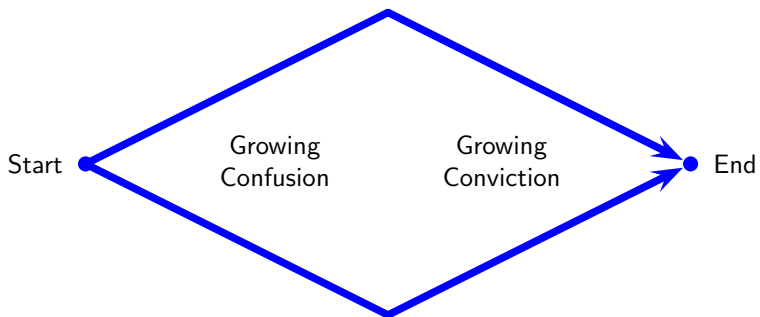
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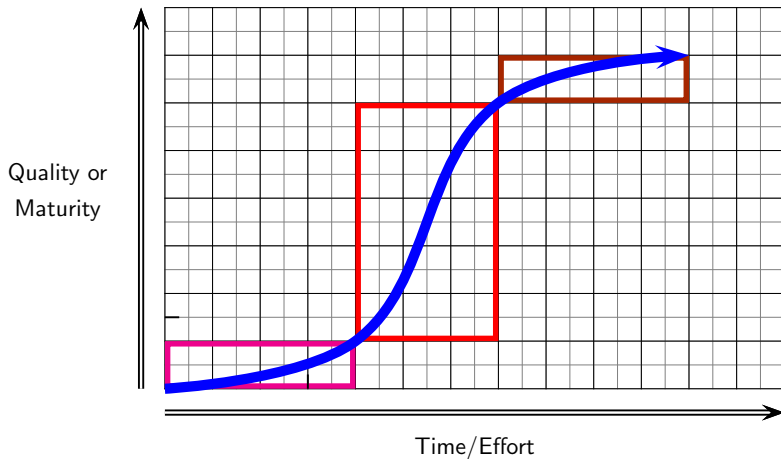
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# The "S" Curve of Research Life Cycle



# Research in Industry Vs. Research in Academia

Product driven research Vs. idea driven research





## Research in Industry Vs. Research in Academia

Product driven research Vs. idea driven research

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. ”



# 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.”



# 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.”

- 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 than 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
- Opportunity comes disguised as work



## 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 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



# Why Do People Do Research?



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Why do mountaineers climb mountains?





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- Money? Fame? Power? Security?



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Reply by a mountaineer: Because mountains exist

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- The real reward?

An unforgettable experience of nature in its purest form



## Why Do People Do Research?

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    - Creating knowledge
    - Solving problems
    - Creating opportunities
    - Changing perceptions



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- However, the questions addressed may not be new  
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- Research addresses questions that have not been addressed before  
(Or have not been addressed adequately before)
- Research has the potential of making the world better





# The Ten Commandments of Creativity in Research

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9. Build levels of abstractions and migrate between them
10. Mix deep thinking with routine mechanical work



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*(with the process, not with the results. Judge your day by the seeds you sow and not by the harvest you reap)*



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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!*



## Last But Not the Least

*Thank You!*

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