# *What is Research?*

Uday Khedker

(www.cse.iitb.ac.in/~uday)

Department of Computer Science and Engineering,

Indian Institute of Technology, Bombay

February 2013

# 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"

# Disclaimers

- General concepts
- No "cook book" or "how to do it yourself"
  - Attempt to explicate what most researchers implicitly believe and may not articulate
  - Views expressed through examples



# Disclaimers

- General concepts
- No "cook book" or "how to do it yourself"
  - Attempt to explicate what most researchers implicitly believe and may not articulate
  - Views expressed through examples
  - Personal reflections and confessions ☺



*Part 2*

# *Why Research?*

# Alice's Adventures

*Through the Looking Glass*
Author: Lewis Carroll

# Alice's Adventures

*Through the Looking Glass*
Author: Lewis Carroll

Situation:
Alice Running with the Red Queen

# Alice's Adventures

*Through the Looking Glass*
Author: Lewis Carroll

Situation:
Alice Running with the Red Queen

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

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

# Surviving in a World of Rapidly Developing Technologies

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

- Hard (Technical) Skills
- Soft Skills

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

# 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.)
- Ability to acquire new skills

# 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.)
- Ability to acquire new skills

  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

# What is Research?

- Carving Statues out of stones
- Methods and tools

# What is Research?

- Carving Statues out of stones
- Methods and tools
- Attempt to improve the methods and tools leads to
  - Better statues
  - Better methods and tools



# What is Research?

- Carving Statues out of stones
- Methods and tools
- Attempt to improve the methods and tools leads to
  - Better statues
  - Better methods and tools
  - **Better sculptors**



# In Search of Research?

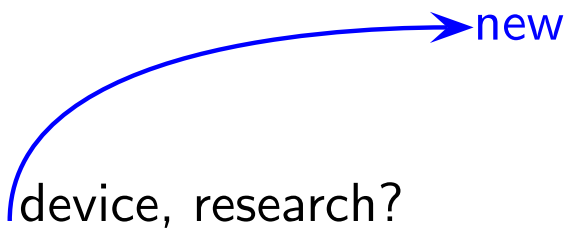
- Observed Phenomena with no explanations
  - Puzzles and mysteries
- Lacunae in the known theory and/or practice
  - The need of a better understanding/method
  - Innovative ideas
- Innovative ideas waiting for new applications
  - Discovery of new puzzles, mysteries and/or lacunae



# The Essence of Research

- Is building a device, research?

# The Essence of Research

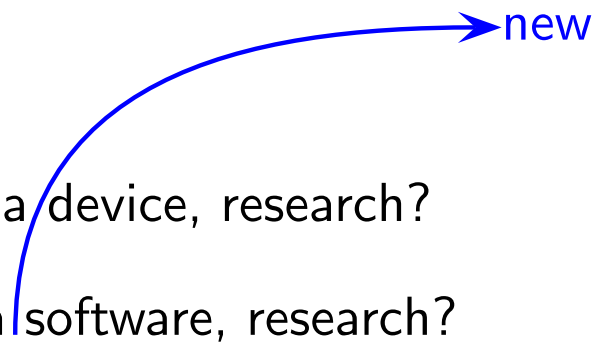



- Is building a device, research?

# The Essence of Research

- Is building a device, research?
- Is writing a software, research?

# The Essence of Research




- Is building a device, research?
- Is writing a software, research?

# The Essence of Research

- Is building a device, research?
- Is writing a software, research?
- Is repairing a device or debugging a software, research?



# The Essence of Research

- Is building a device, research?
- Is writing a software, research?
- Is repairing a device or debugging a software, research?
- Is drawing a conclusion from a lot of data, research?



# The Essence of Research

- Is building a device, research?
- Is writing a software, research?
- Is repairing a device or debugging a software, research?
- Is drawing a conclusion from a lot of data, research?
- Is proving a theorem, research?

# The Essence of Research

- Is building a device, research?
- Is writing a software, research?
- Is repairing a device or debugging a software, research?
- Is drawing a conclusion from a lot of data, research?
- Is proving a theorem, research?
- Is formulating a theorem, research?

# The Essence of Research

- Is building a device, research?
- Is writing a software, research?
- Is repairing a device or debugging a software, research?
- Is drawing a conclusion from a lot of data, research?
- Is proving a theorem, research?
- Is formulating a theorem, research?

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

# The Essence of Research

- Research is a game of innovative ideas that are significant

# The Essence of Research

- Research is a game of innovative ideas that are significant
- The significance of ideas could lie in any of the following:
  - Beauty
  - Utility
  - Enhancement of knowledge

# The Essence of Research

- Research is a game of innovative ideas that are significant
- The significance of ideas could lie in any of the following:
  - Beauty
  - Utility
  - Enhancement of knowledge

A game of significant & innovative ideas



# The Essence of Research

- Research is a game of innovative ideas that are significant
- The significance of ideas could lie in any of the following:
  - Beauty
  - Utility
  - Enhancement of knowle

A game of significant & innovative ideas



# The Essence of Research

- Research is a game of innovative ideas ficant

A game of significant & innovative ideas

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



# The Essence of Research

- Research is a game of innovative ideas that are significant
- The significance of ideas could lie in any of the following:
  - Beauty
  - Utility
  - Enhancement of knowledge

A game of significant & innovative ideas



# The Essence of Research

A game of significant & innovative ideas

- Research is a game of innovative ideas that are significant
- The significance of ideas could lie in any of the following:
  - Beauty
  - Utility
  - Enhancement of knowledge

# The Essence of Research

- Research is a game of innovative ideas that are significant
- The significance of ideas could lie in any of the following:
  - Beauty
  - Utility
  - Enhancement of knowledge

A game of significant & innovative ideas

# The Essence of Research

- Research is a game of innovative ideas that are significant
- The significance of ideas could lie in any of the following:
  - Beauty
  - Utility
  - Enhancement of knowledge

A game of significant & innovative ideas

# The Essence of Research

- Research is a game of innovative ideas that are significant
- The significance could lie in any of the following:
  - Beauty
  - Utility
  - Enhancement of knowledge

A game of significant & innovative ideas



# The Essence of Research

A game of significant & innovative ideas

- Research is a game of innovative ideas that are significant
- The significance of ideas could lie in any of the following:
  - Beauty
  - Utility
  - Enhancement of knowledge

# The Essence of Research

- Research is a game of innovative ideas that are significant
- The significance of ideas could lie in any of the following:
  - Beauty
  - Utility
  - Enhancement of knowledge

A game of significant & innovative ideas

# The Essence of Research

A game of significant & innovative ideas

- Research is a game of innovative ideas that are significant
- The significance of ideas could lie in any of the following:
  - Beauty
  - Utility
  - Enhancement of knowledge

# The Essence of Research

- Research is a game of innovative ideas ficant
- The signific could lie in any of the following:
  - Beauty
  - Utility
  - Enhancement of knowle

# What is an Idea?

# What is an Idea?

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

# What is an Idea?

- An idea is not an isolated thing in a vacuum, it has a context
- The context often decides its significance
- An idea is like a missing piece in a jigsaw puzzle
  - Discovery of an idea completes at least some part of the puzzle



# What is an Idea?

- An idea is not an isolated thing in a vacuum, it has a context
- The context often decides its significance
- An idea is like a missing piece in a jigsaw puzzle
  - Discovery of an idea completes at least some part of the puzzle

Discovery, Invention, or Creation?



# What is an Idea?

- An idea is not an isolated thing in a vacuum, it has a context
- The context often decides its significance
- An idea is like a missing piece in a jigsaw puzzle
  - Discovery of an idea completes at least some part of the puzzle
    Discovery, Invention, or Creation?
  - An idea is a connection between other ideas



# What is an Idea?

- An idea is not an isolated thing in a vacuum, it has a context
- The context often decides its significance
- An idea is like a missing piece in a jigsaw puzzle
  - Discovery of an idea completes at least some part of the puzzle
    Discovery, Invention, or Creation?
  - An idea is a connection between other ideas
  - The more unlikely the connection, the more beautiful the idea is



# What is an Idea?

- An idea is not an isolated thing in a vacuum, it has a context
- The context often decides its significance
- An idea is like a missing piece in a jigsaw puzzle
  - Discovery of an idea completes at least some part of the puzzle
    Discovery, Invention, or Creation?
  - An idea is a connection between other ideas
  - The more unlikely the connection, the more beautiful the idea is
- 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



# What is an Idea?

- An idea is not an isolated thing in a vacuum, it has a context
- The context often decides its significance
- An idea is li
  - Discov he puzzle
    Discov
  - An ide
  - The m the idea is
- 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

*Important disclaimer*

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

# Ingredients of Good Research

- Innovation

# Ingredients of Good Research

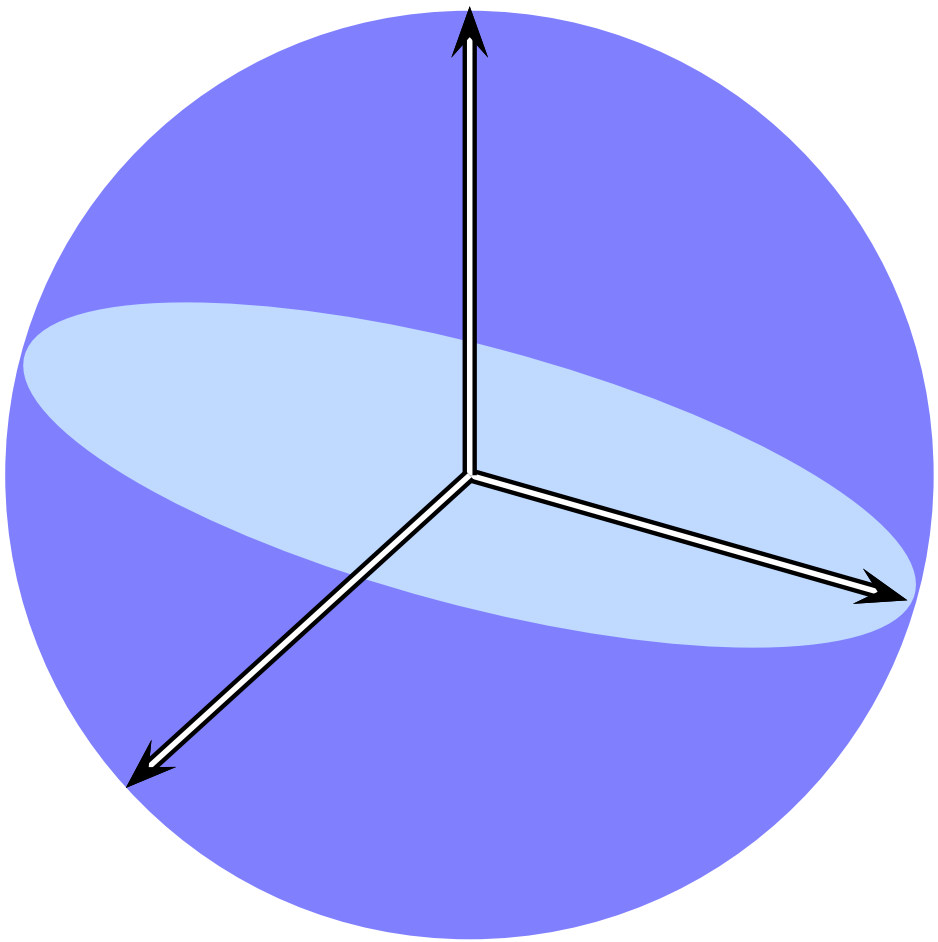
- Innovation
- Aesthetics

# Ingredients of Good Research

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

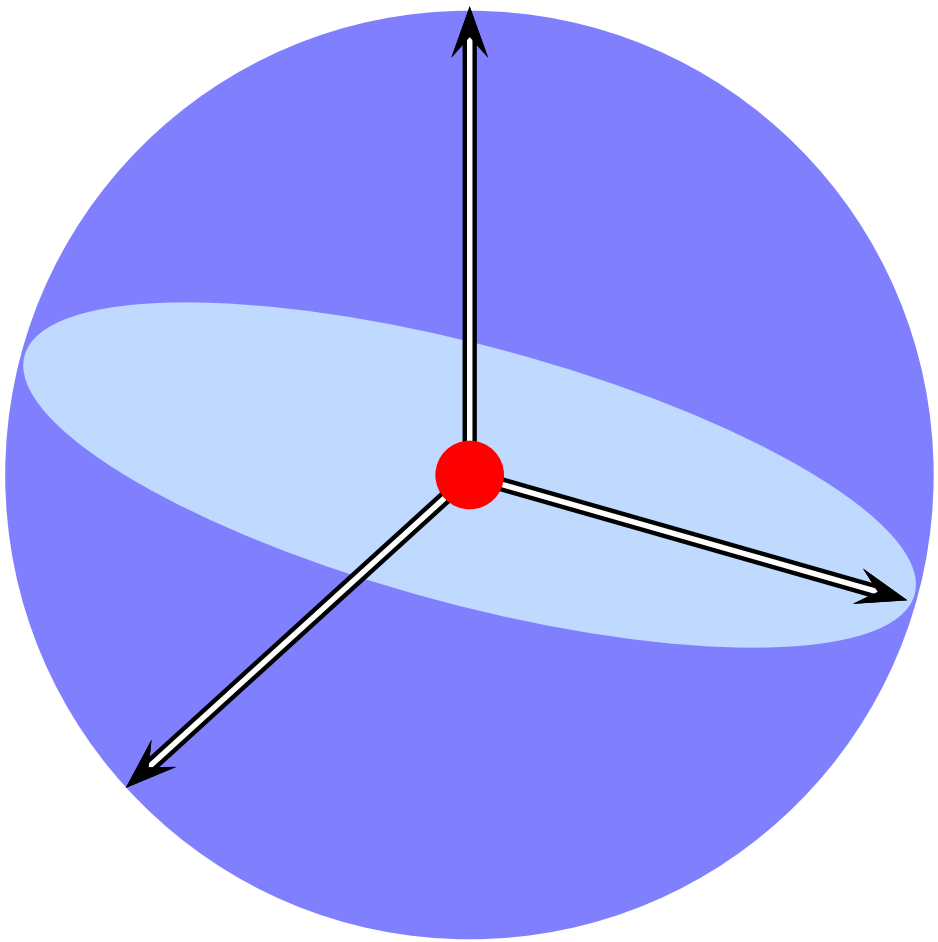


# Innovation



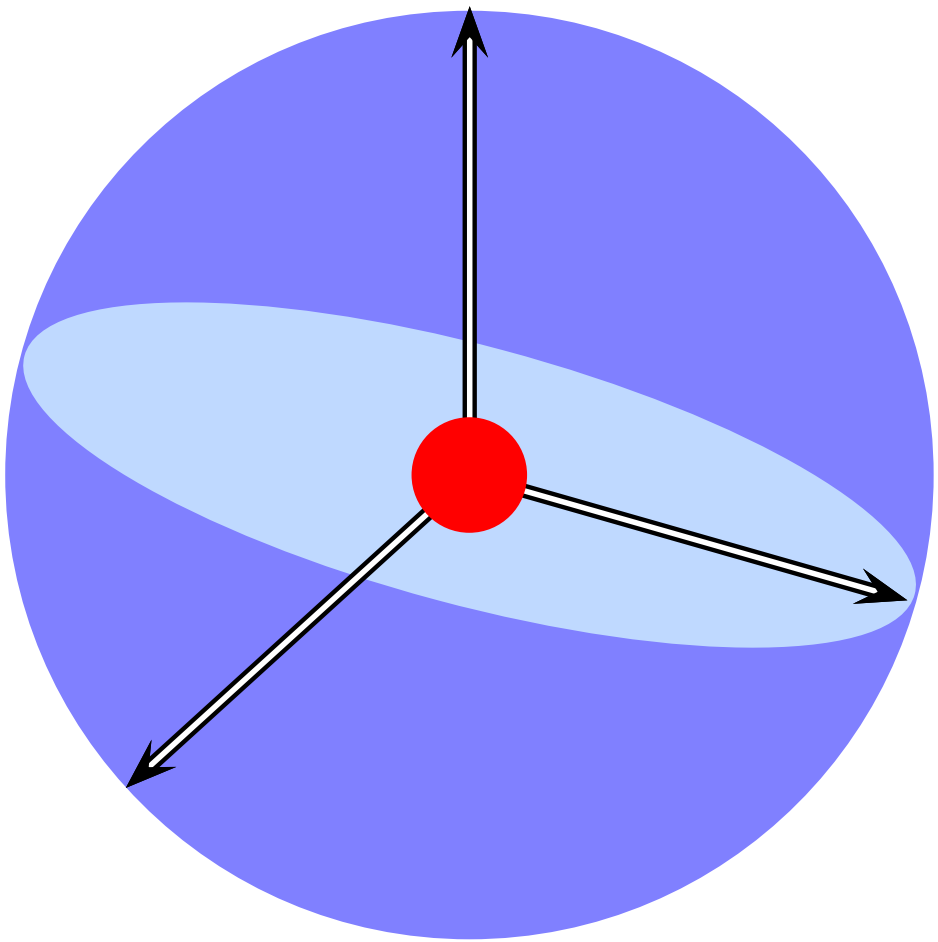
- The sphere of knowledge

# Innovation



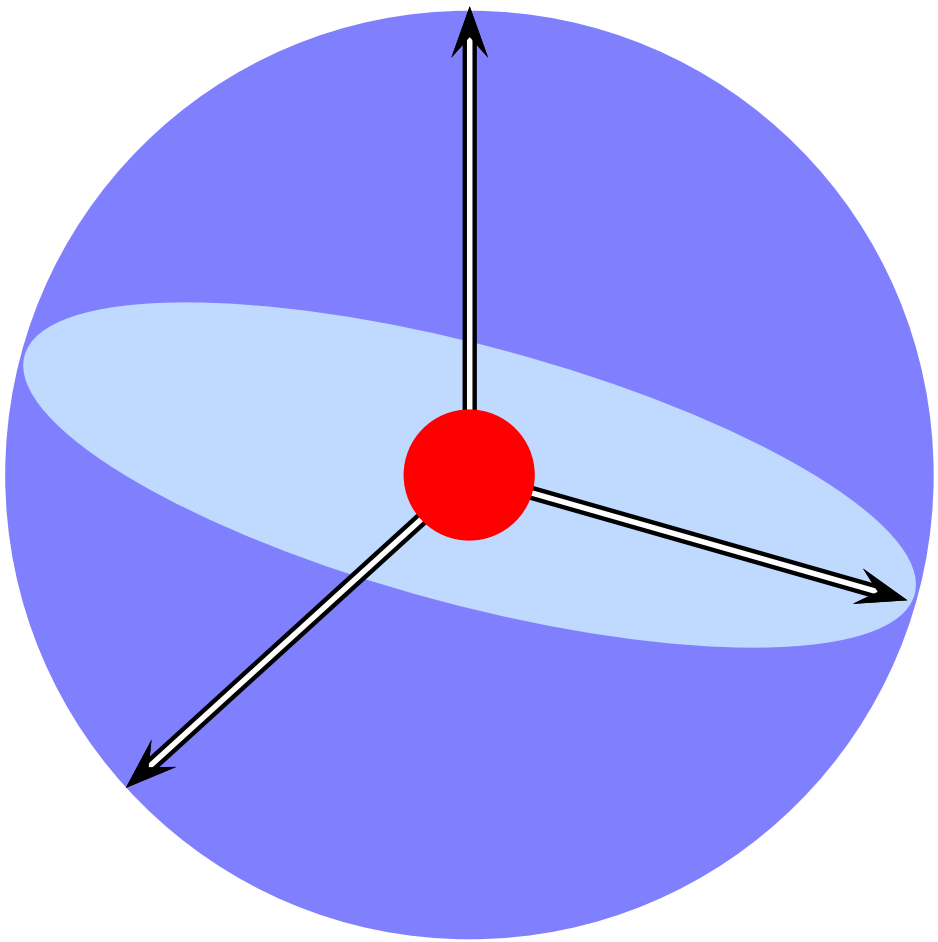
- The sphere of knowledge
- Initial general learning

# Innovation



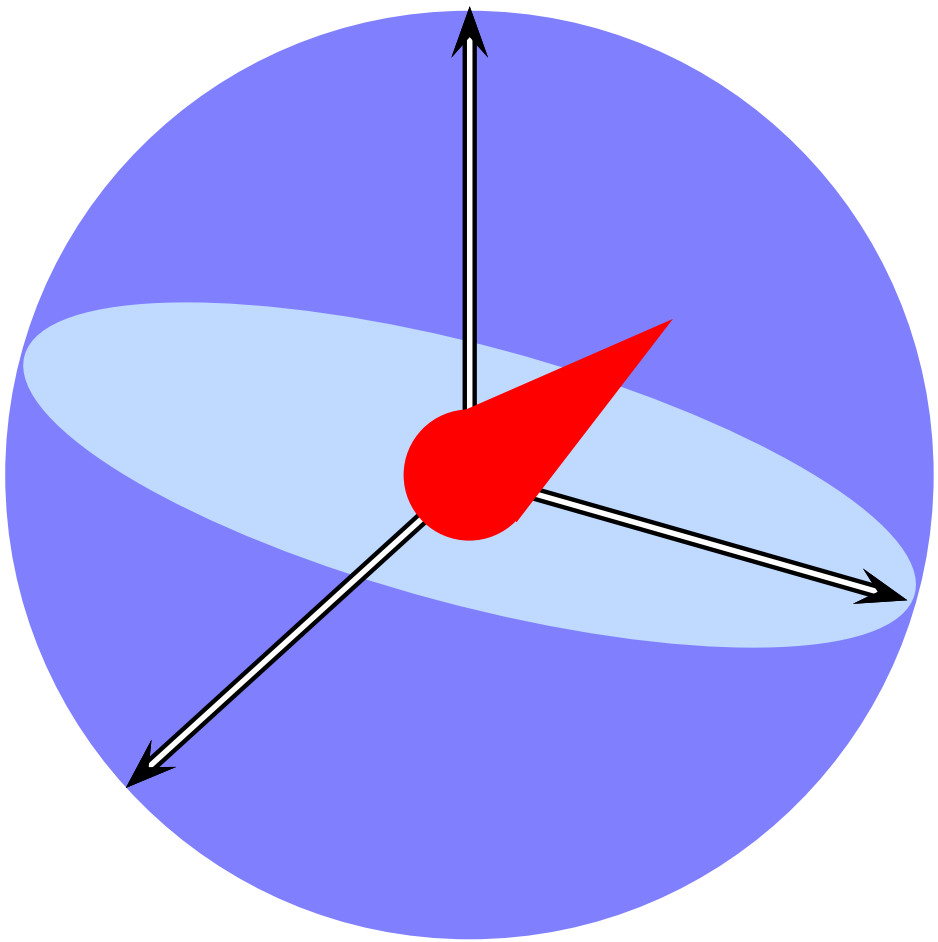
- The sphere of knowledge
- Initial general learning
- Learning increases with time

# Innovation



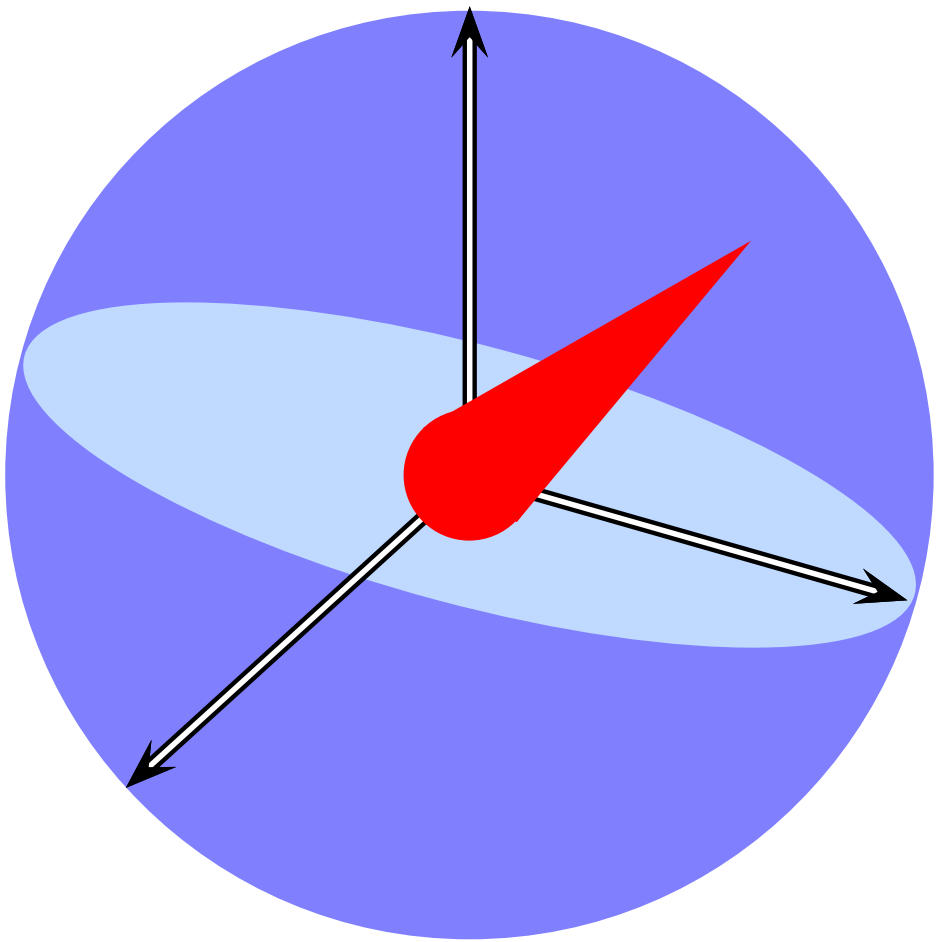
- The sphere of knowledge
- Initial general learning
- Learning increases with time

# Innovation



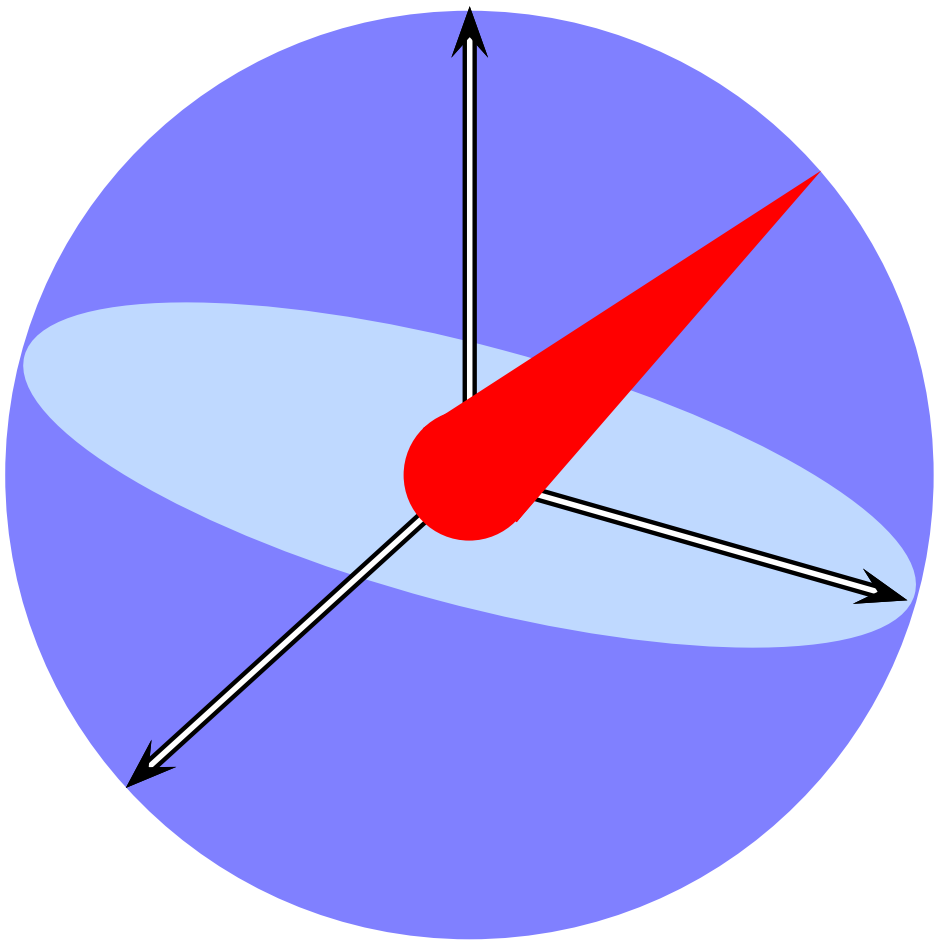
- The sphere of knowledge
- Initial general learning
- Learning increases with time
- Begin focussing and specializing

# Innovation



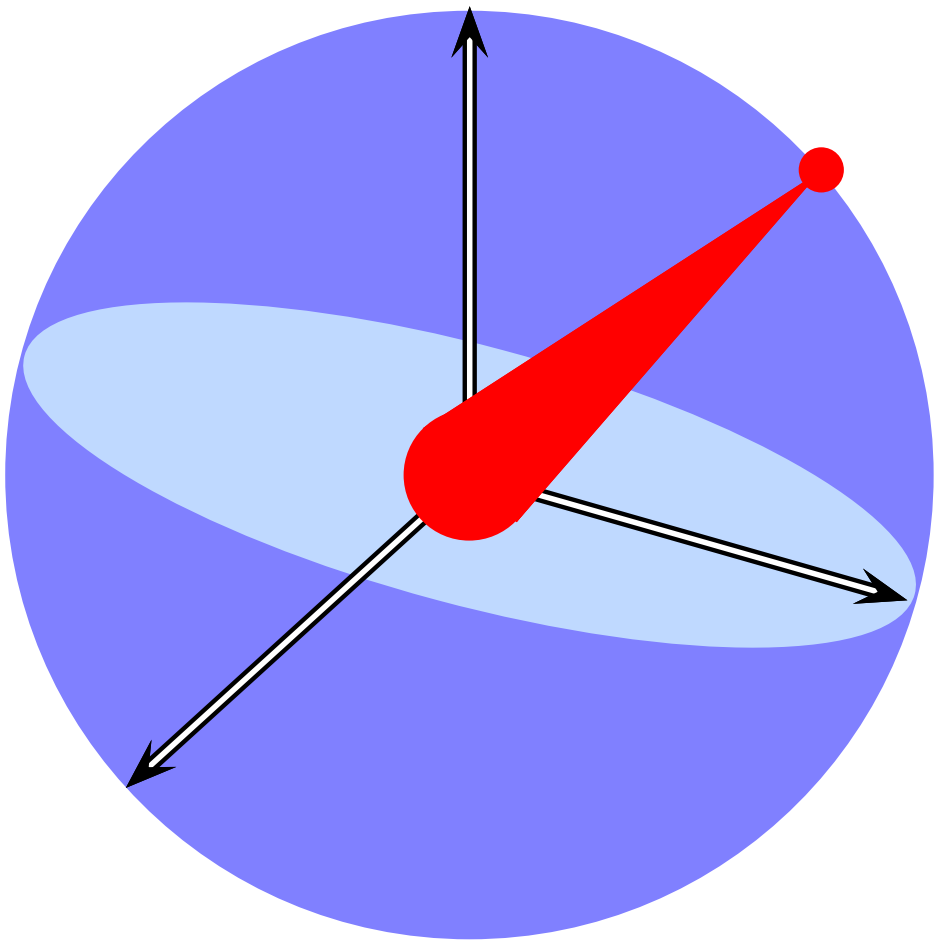
- The sphere of knowledge
- Initial general learning
- Learning increases with time
- Begin focussing and specializing
- Specialize more and more until you reach the unknown

# 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

# Innovation

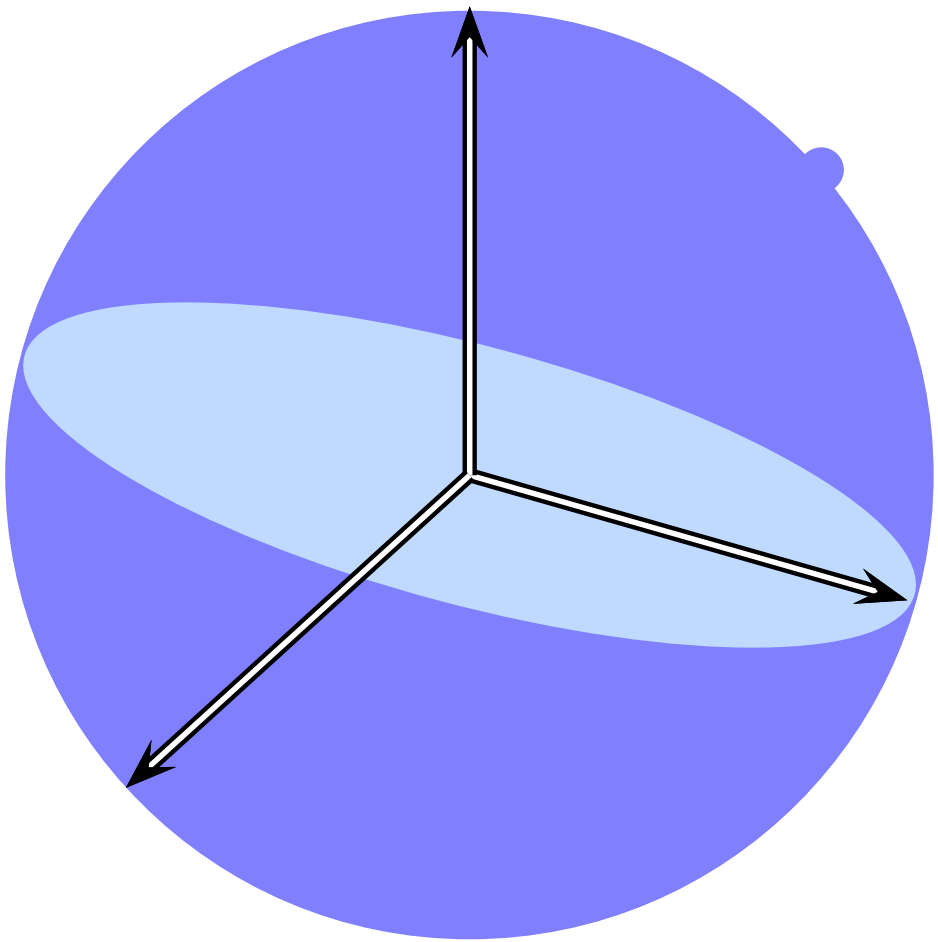


- The sphere of knowledge
- Initial general learning
- Learning increases with time
- Begin focussing and specializing
- Specialize more and more until you reach the unknown
- Try to push the boundary
- If you keep trying try hard enough, you may succeed

# 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/

# 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

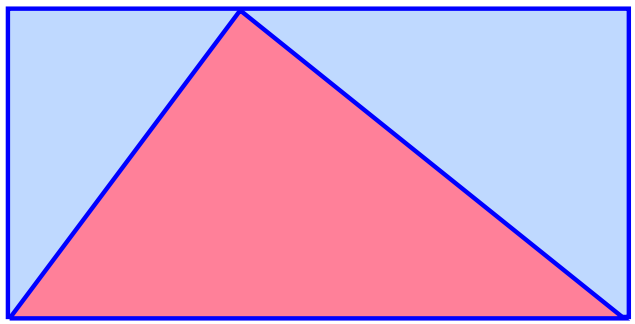
- Example : Painting

  Proportion of colours Vs. their arrangements

- Casserole design

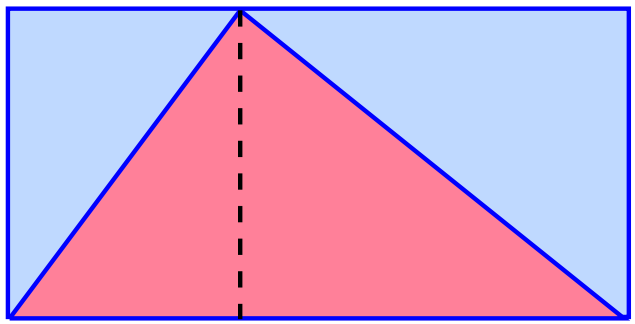


# Aesthetics and Beauty of an Idea



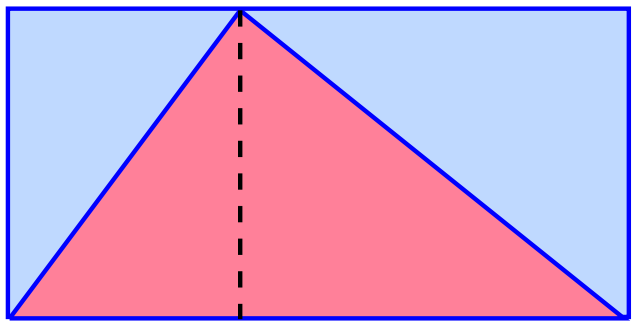
- What proportion of the box does the pink triangle occupy?
- Would the result hold for *any* triangle in a box?

# Aesthetics and Beauty of an Idea



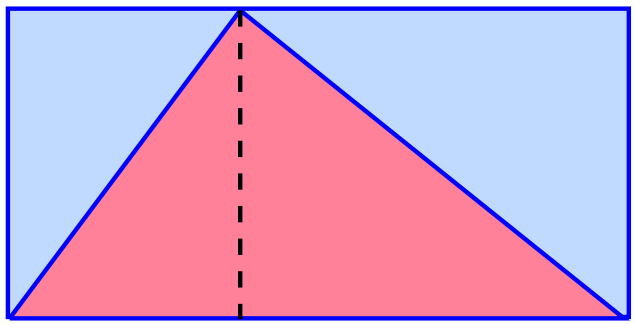
- Idea: Draw a vertical line to divide the rectangle in two parts

# Aesthetics and Beauty of an Idea



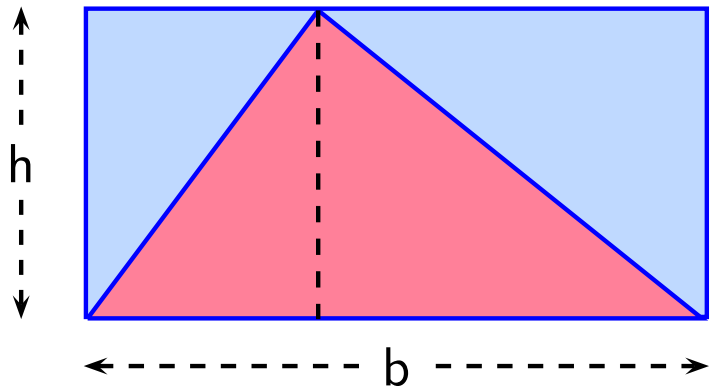
- Idea: Draw a vertical line to divide the rectangle in two parts
- The slanting lines now divide the two boxes in two equal parts

# Aesthetics and Beauty of an Idea



- Idea: Draw a vertical line to divide the rectangle in two parts
- The slanting lines now divide the two boxes in two equal parts
- Exactly as much area outside of the triangle as there is inside

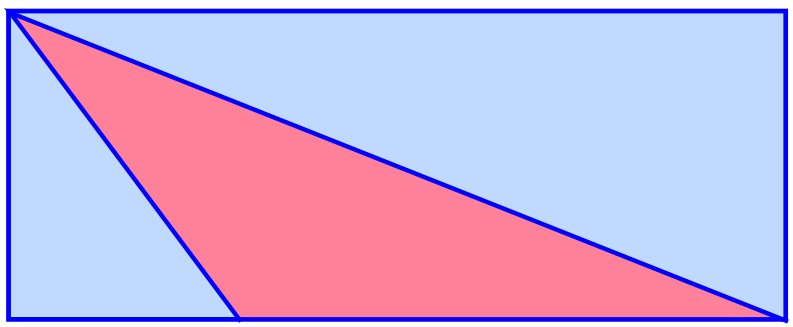
# Aesthetics and Beauty of an Idea




- Idea: Draw a vertical line to divide the rectangle in two parts
- The slanting lines now divide the two boxes in two equal parts
- Exactly as much area outside of the triangle as there is inside
- 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

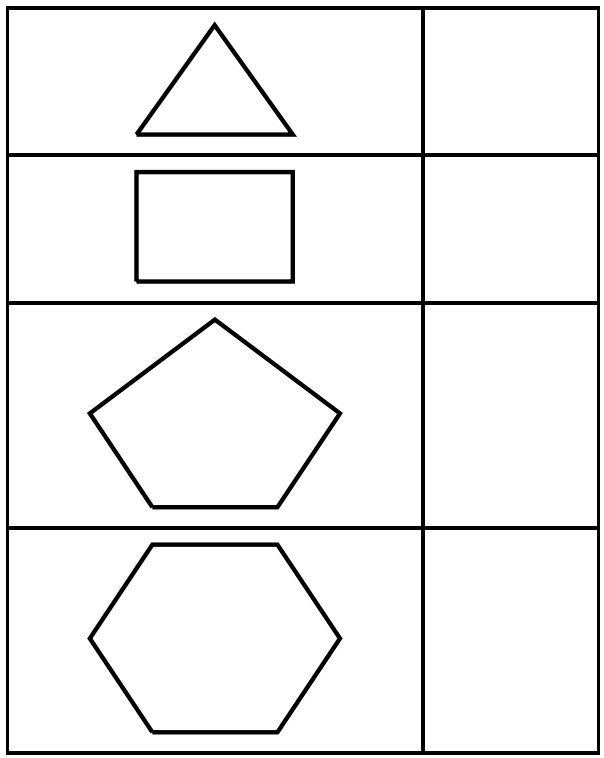
- Beauty lies in creating simple ideas that
  - bring in unexpected implications
  - relate the seemingly unrelated things
  - illuminate and reveal much more than anticipated

- Total is greater than the sum of the parts



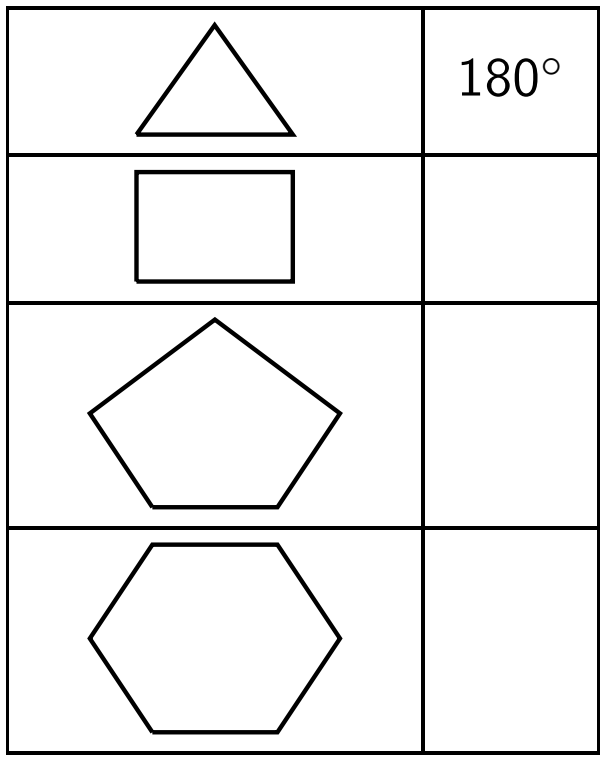
# Another Example of Beauty of an Idea

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



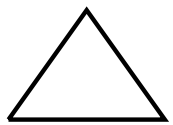
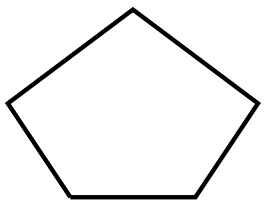
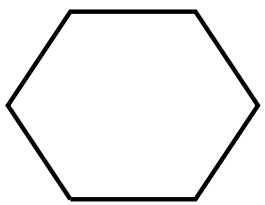
# Another Example of Beauty of an Idea

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



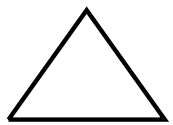
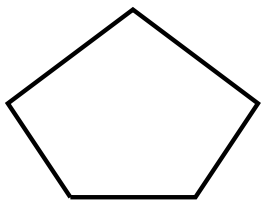
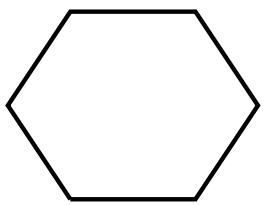
# Another Example of Beauty of an Idea

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

| | |
|---|---|
|  | 180° |
|  | 360° |
|  | |
|  | |

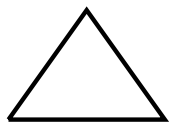
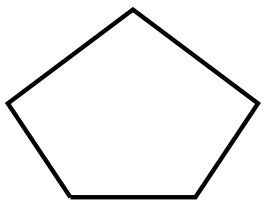
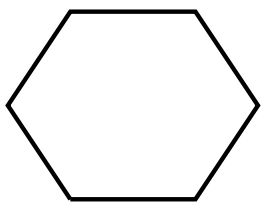
# Another Example of Beauty of an Idea

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

| | |
|---|---|
|  | 180° |
|  | 360° |
|  | 540° |
|  | |

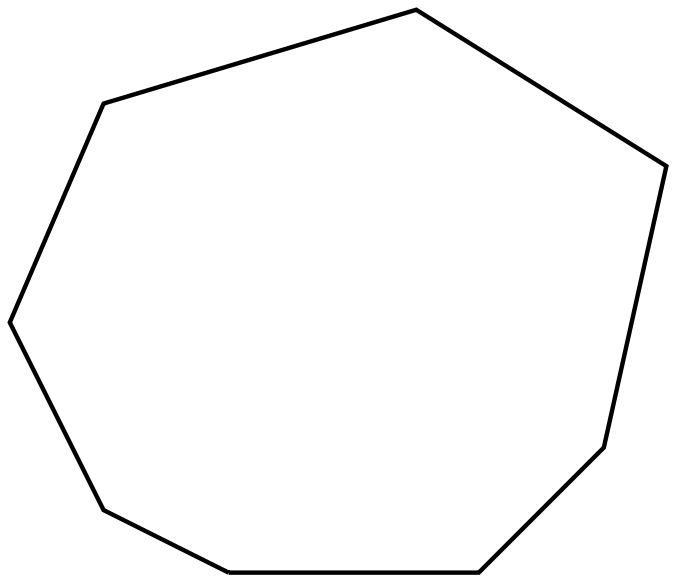
# Another Example of Beauty of an Idea

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

| | |
|---|---|
|  | 180° |
|  | 360° |
|  | 540° |
|  | 720° |

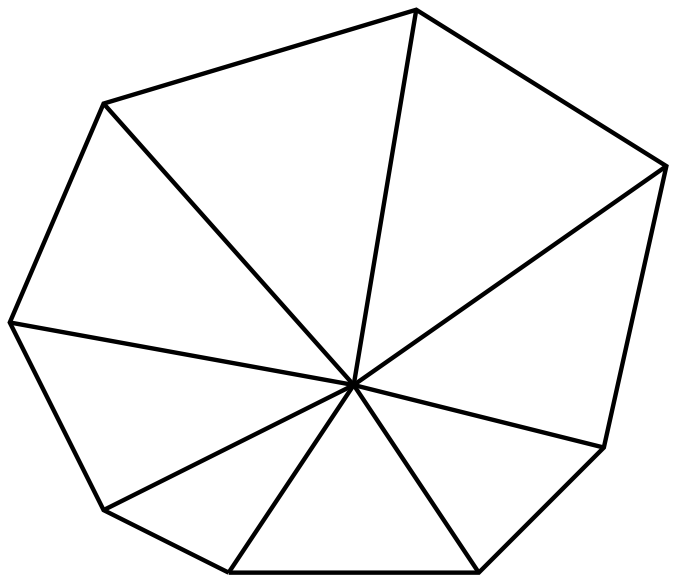
# Another Example of Beauty of an Idea

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



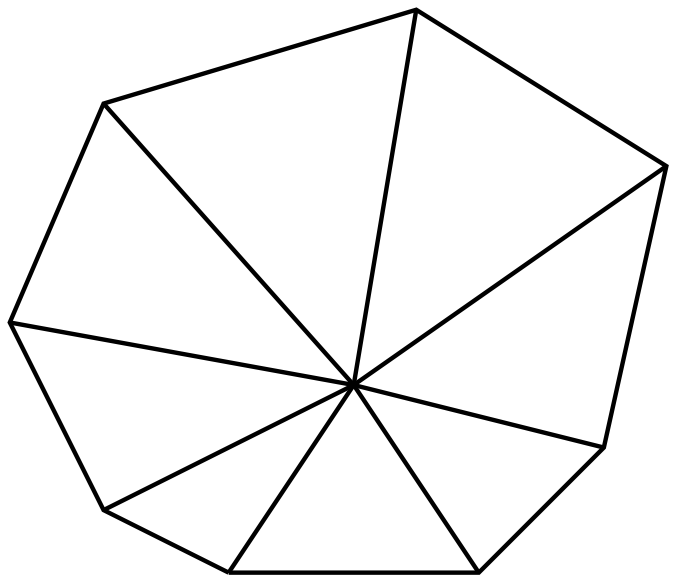
# Another Example of Beauty of an Idea

- 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



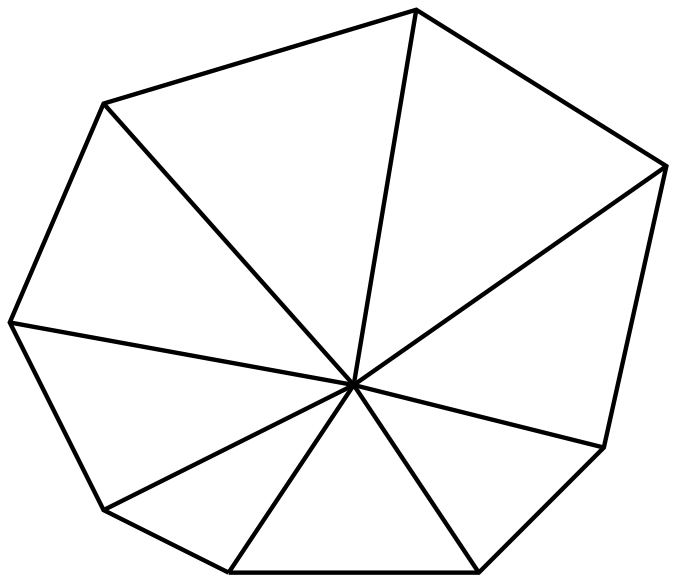
# Another Example of Beauty of an Idea

- 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
  - We have $n$ triangles



# Another Example of Beauty of an Idea

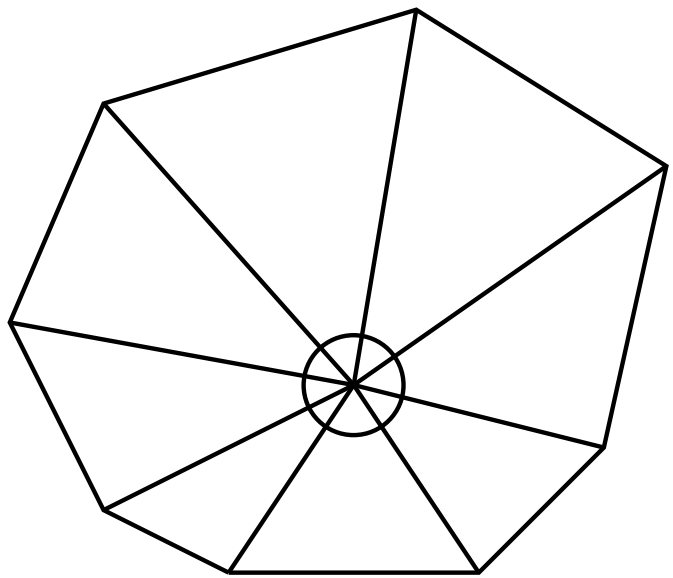
- Question: What is the sum of all internal angles of a polygon?
  - Consider an $n$ sided polygon
  - Choose an arbitrary inner point and connect it to all vertices
  - We have $n$ triangles
  - Sum of all angles $= n \cdot 180^\circ$



# Another Example of Beauty of an Idea

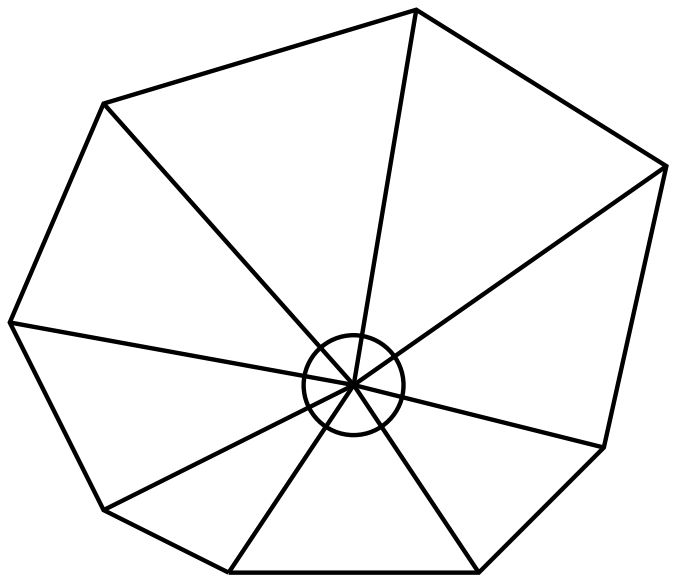
- Question: What is the sum of all internal angles of a polygon?

  - Consider an $n$ sided polygon
  - Choose an arbitrary inner point and connect it to all vertices
  - We have $n$ triangles
  - Sum of all angles $= n \cdot 180^\circ$
  - Exclude the sum of the angles incident on the chosen point



# 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
  - We have $n$ triangles
  - Sum of all angles $= n \cdot 180^\circ$
  - Exclude the sum of the angles incident on the chosen point



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

# On the Role of Rigour in an Idea

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

# On the Role of Rigour in an Idea

- Rigour removes imprecision and adds concreteness
- Makes an idea immune to personal interpretation
- Example: Divide 6 by 2



# On the Role of Rigour in an Idea

- Rigour removes imprecision and adds concreteness
- Makes an idea immune to personal interpretation
- Example: Divide 6 by 2

  "*Divide 6 into 2 parts and tell me the size of each part*"

# On the Role of Rigour in an Idea

- Rigour removes imprecision and adds concreteness
- Makes an idea immune to personal interpretation
- Example: Divide 6 by 2

  *"Divide 6 into 2 parts and tell me the size of each part"*
- Divide 6 by $\frac{1}{2}$

  *"Divide 6 into half part and tell me the size"*



# On the Role of Rigour in an Idea

- Rigour removes imprecision and adds concreteness
- Makes an idea immune to personal interpretation
- Example: Divide 6 by 2

  *"Divide 6 into 2 parts and tell me the size of each part"*
- Divide 6 by $\frac{1}{2}$

  *"Divide 6 into half part and tell me the size"*
- 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:

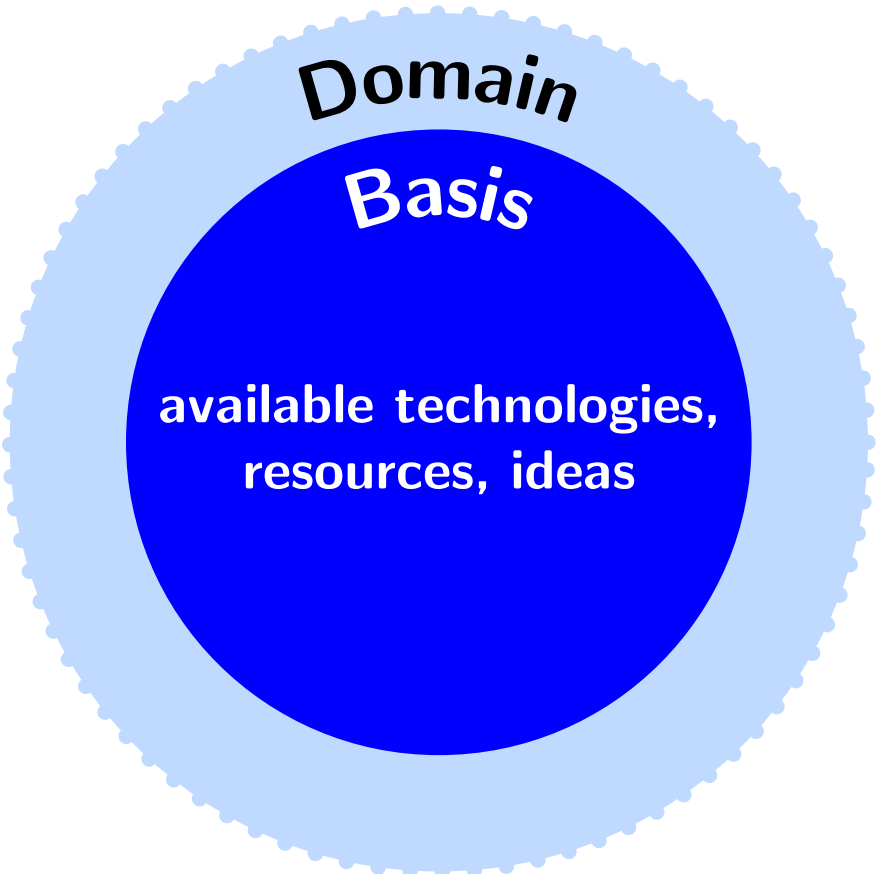
- The *basis* of good ideas.
- The *domain* of good ideas.
- The *heuristics* of exploring the domain of good ideas.
- The *facilitators* of good ideas.

# The Basis and the Domain of Good Ideas


- Basis:

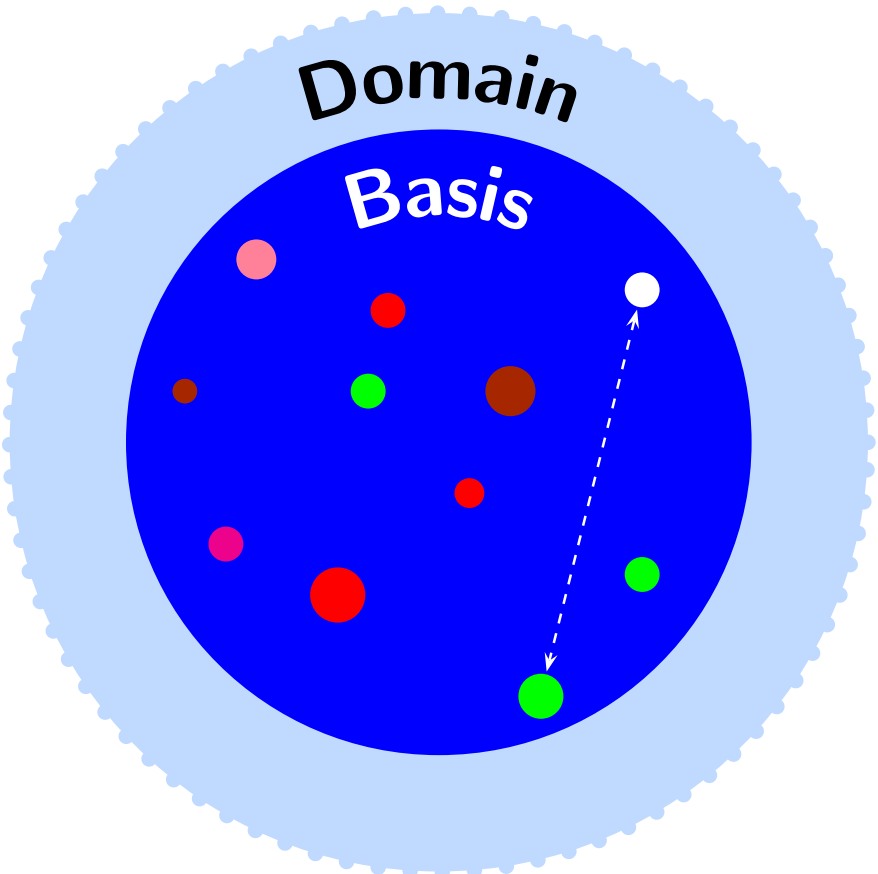
- Domain:

# The Basis and the Domain of Good Ideas



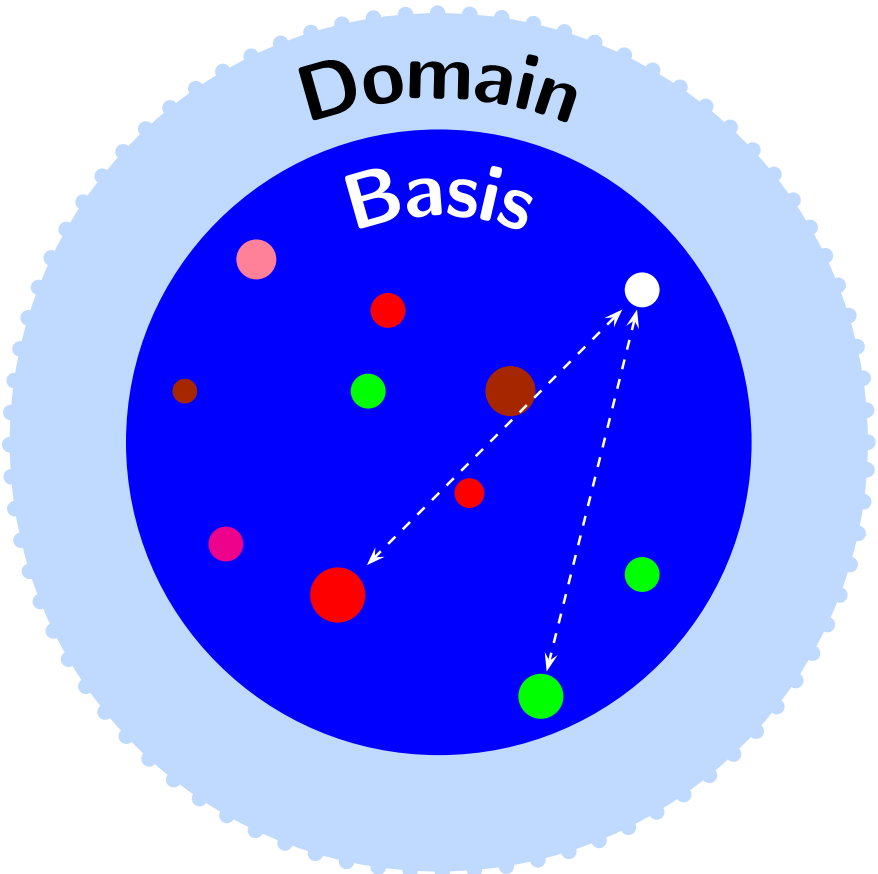

- Basis: Available resources
- Domain: *Adjacent Possible*

# The Basis and the Domain of Good Ideas



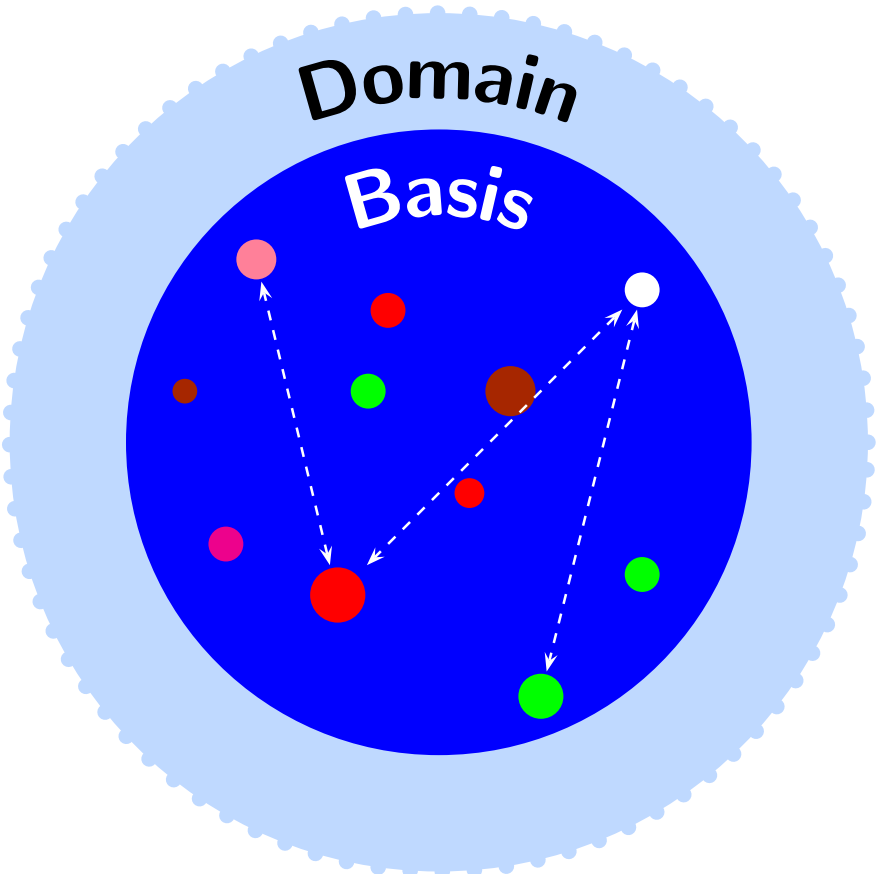

- Basis: Available resources with
  - mature prerequisite ideas/technologies
- Domain: *Adjacent Possible*

# The Basis and the Domain of Good Ideas



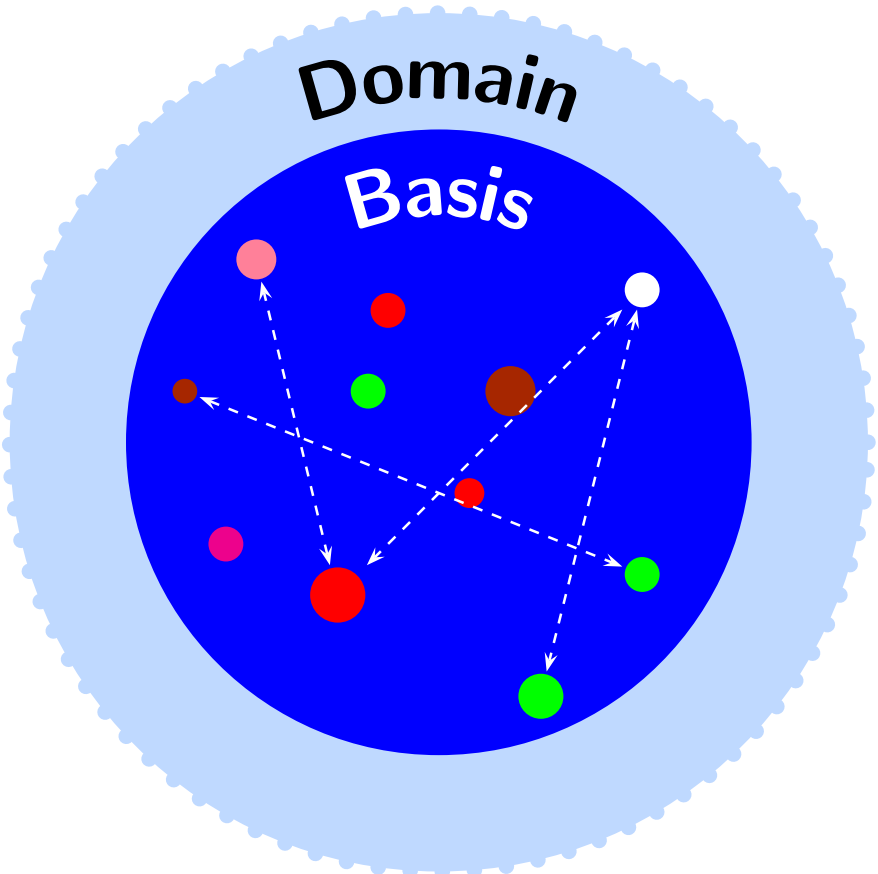

- Basis: Available resources with
  - mature prerequisite ideas/technologies
  - flexible connections
- Domain: *Adjacent Possible*

# The Basis and the Domain of Good Ideas



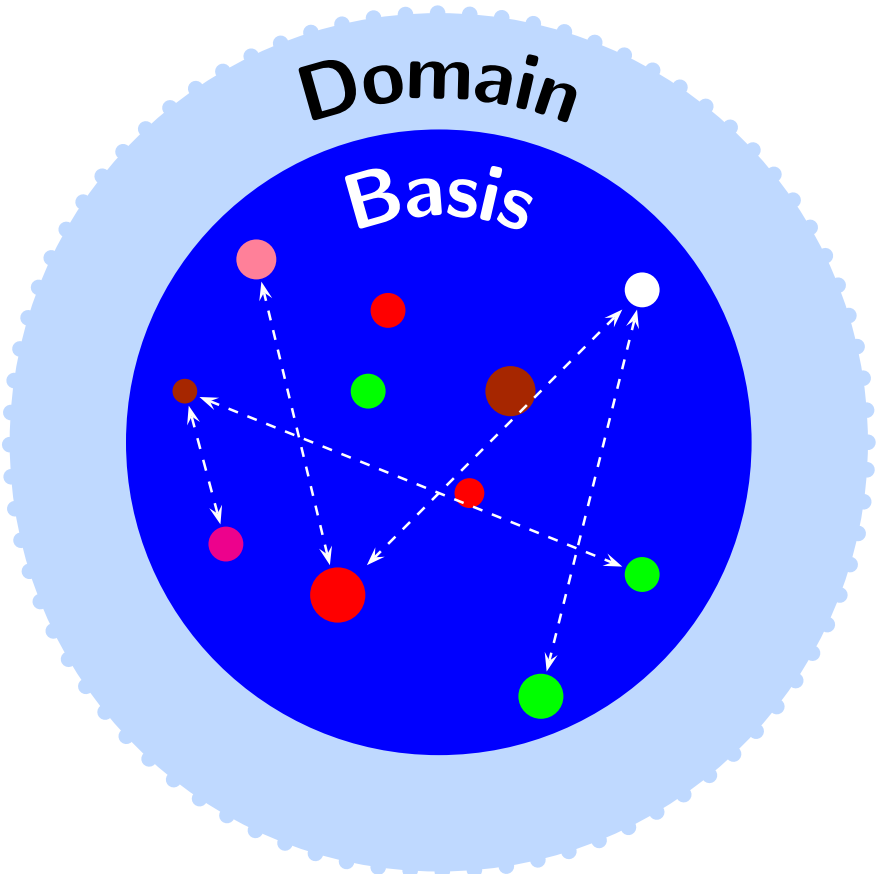

- Basis: Available resources with
  - mature prerequisite ideas/technologies
  - flexible connections
  - free flow of ideas
- Domain: *Adjacent Possible*

# The Basis and the Domain of Good Ideas



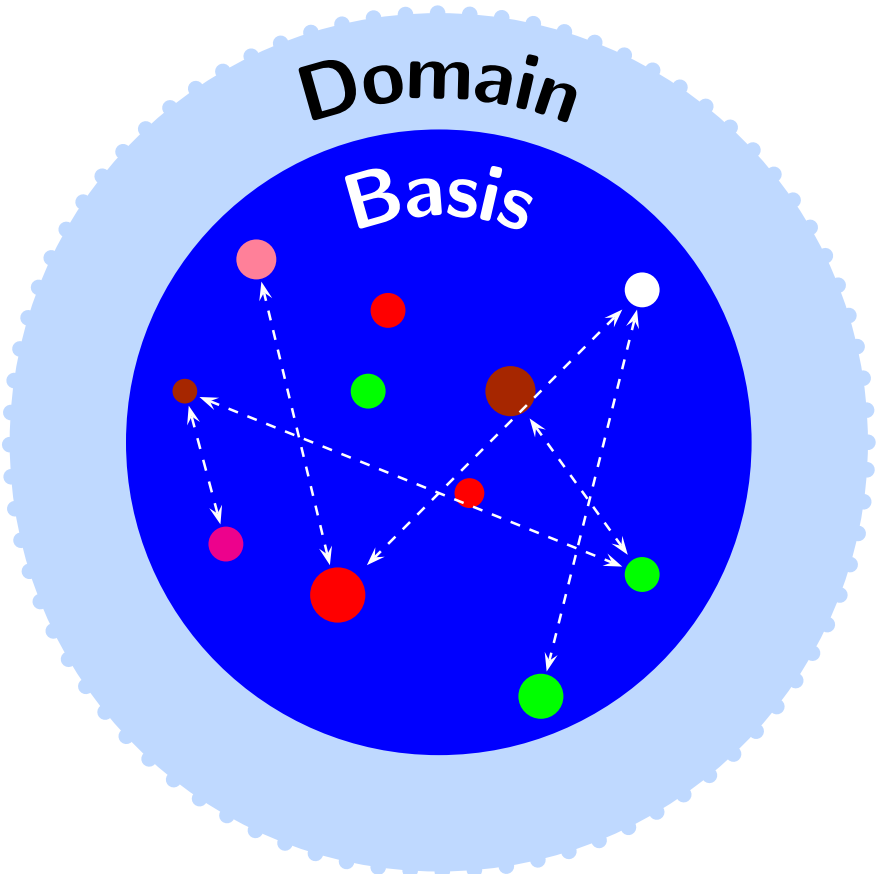

- Basis: Available resources with
  - mature prerequisite ideas/technologies
  - flexible connections
  - free flow of ideas
- Domain: *Adjacent Possible*

# The Basis and the Domain of Good Ideas



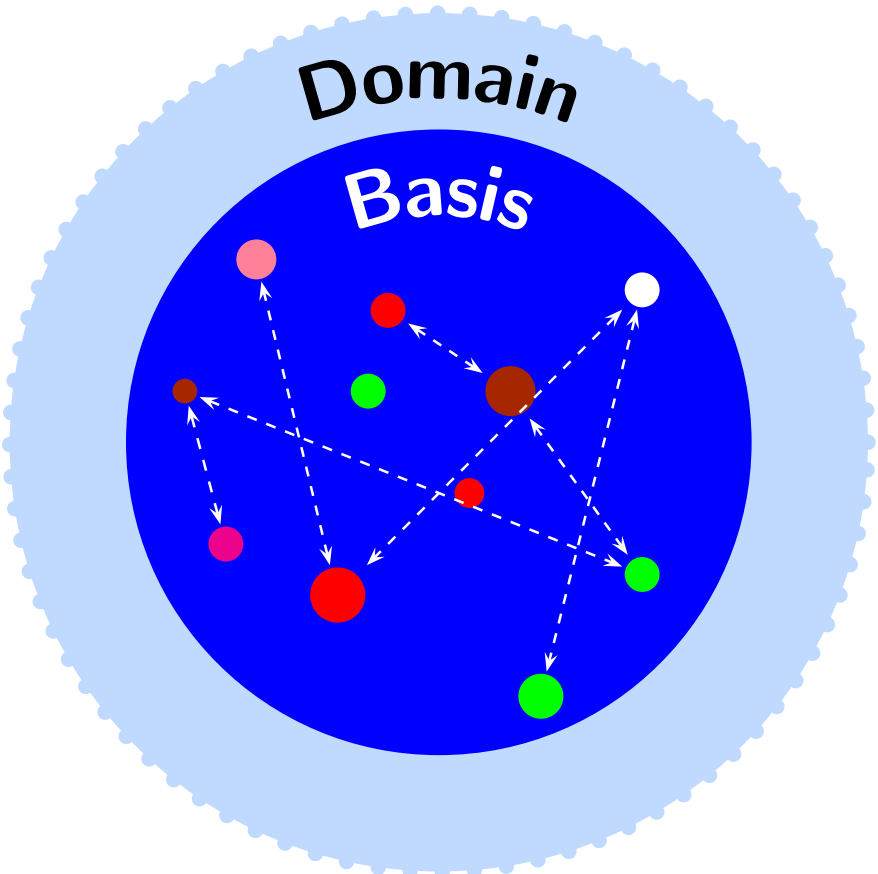

- Basis: Available resources with
  - mature prerequisite ideas/technologies
  - flexible connections
  - free flow of ideas
- Domain: *Adjacent Possible*

# The Basis and the Domain of Good Ideas



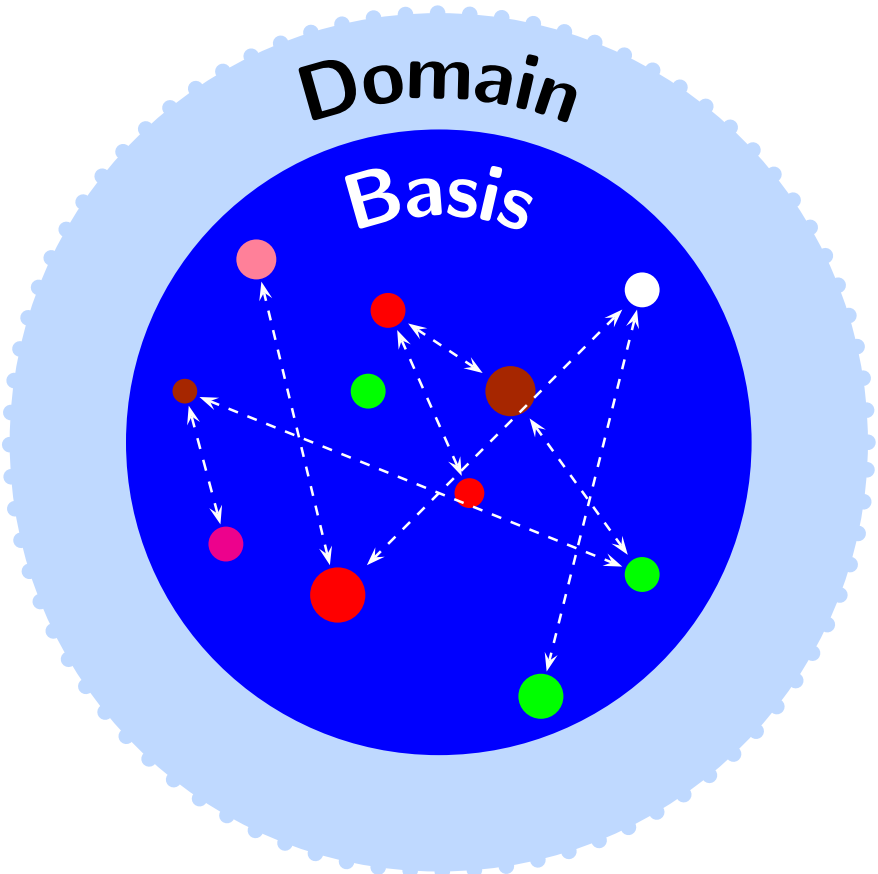

- Basis: Available resources with
  - mature prerequisite ideas/technologies
  - flexible connections
  - free flow of ideas
- Domain: *Adjacent Possible*

# The Basis and the Domain of Good Ideas



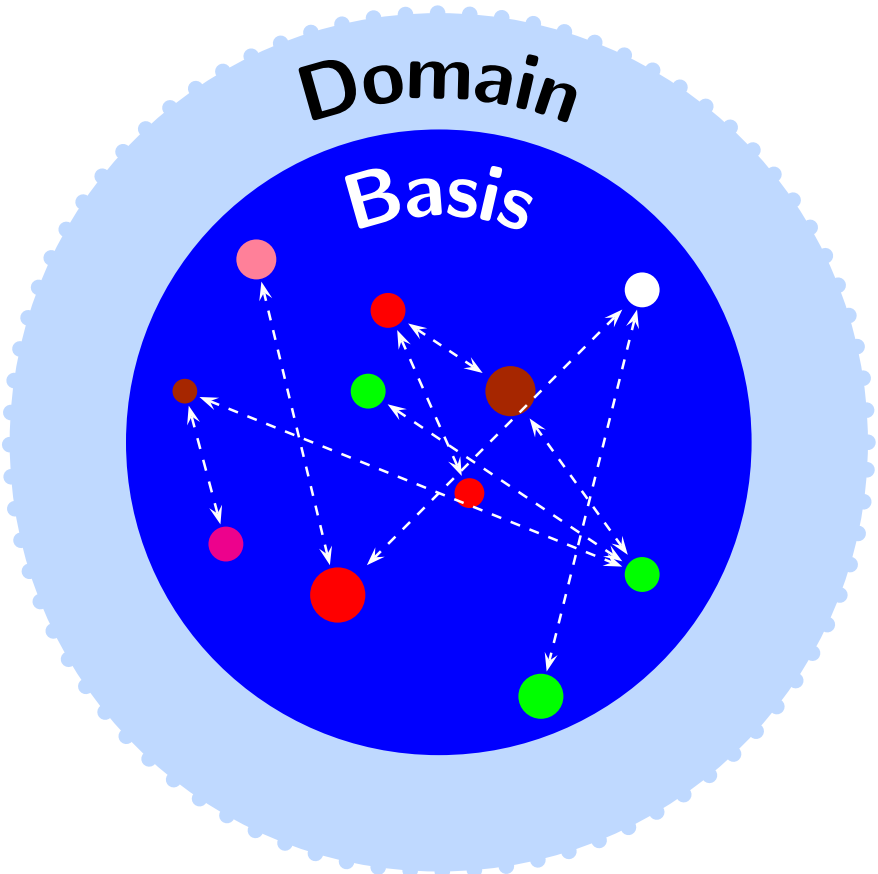

- Basis: Available resources with
  - mature prerequisite ideas/technologies
  - flexible connections
  - free flow of ideas
- Domain: *Adjacent Possible*

# The Basis and the Domain of Good Ideas



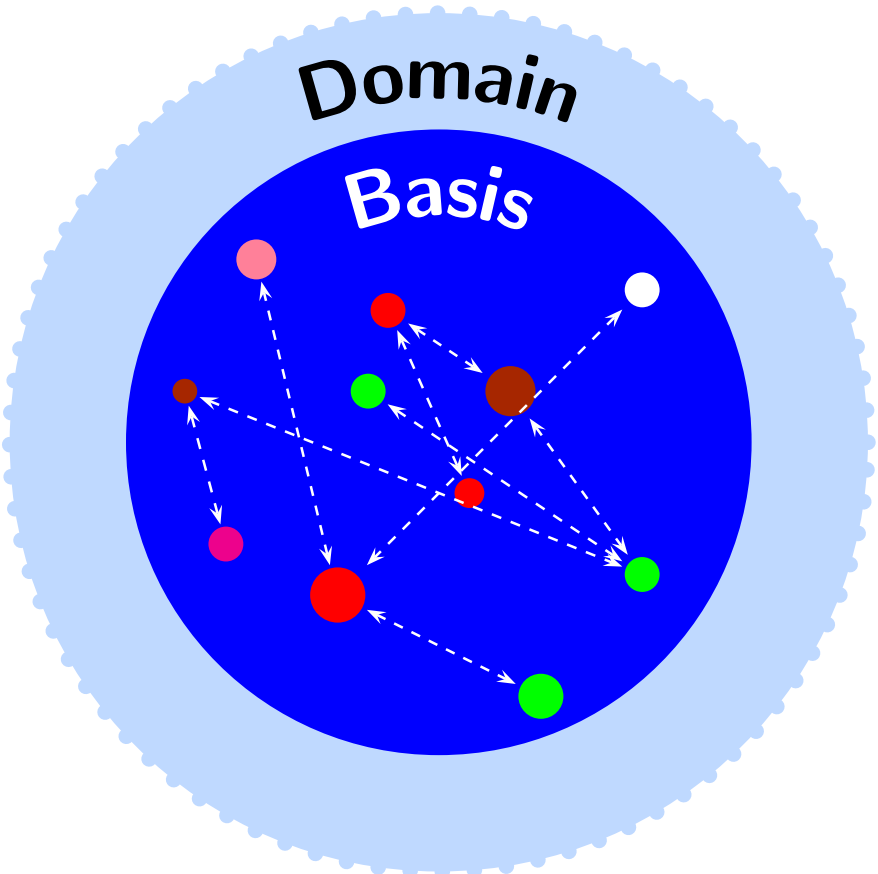

- Basis: Available resources with
  - mature prerequisite ideas/technologies
  - flexible connections
  - free flow of ideas
- Domain: *Adjacent Possible*

# The Basis and the Domain of Good Ideas



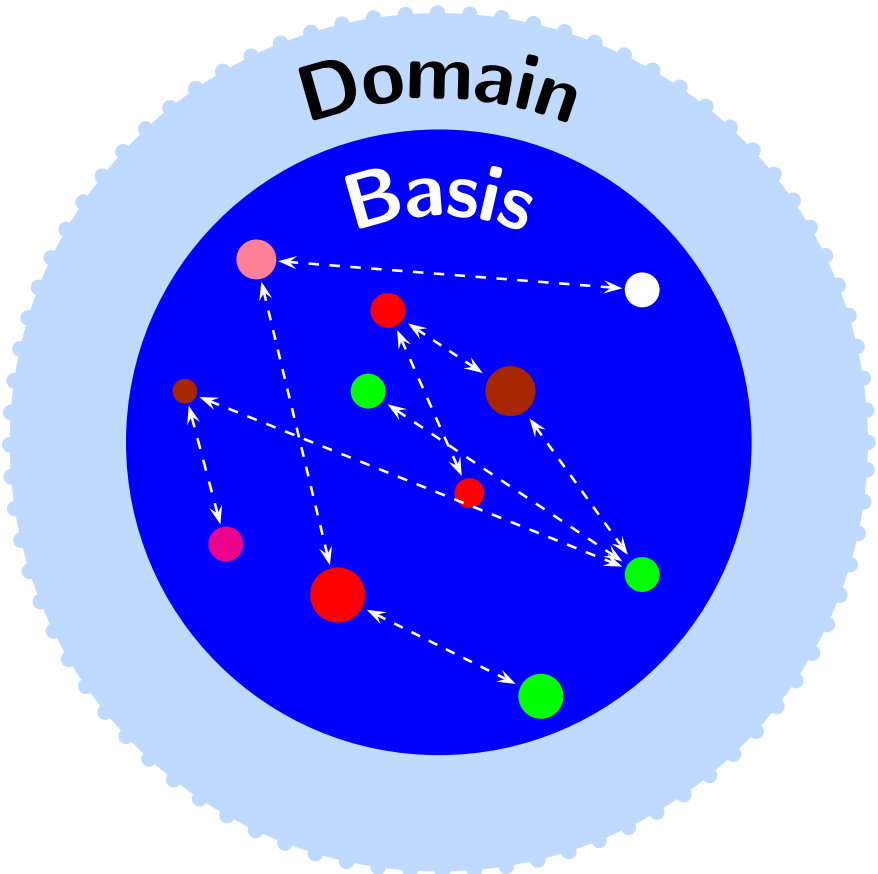

- Basis: Available resources with
  - mature prerequisite ideas/technologies
  - flexible connections
  - free flow of ideas
- Domain: *Adjacent Possible*

# The Basis and the Domain of Good Ideas



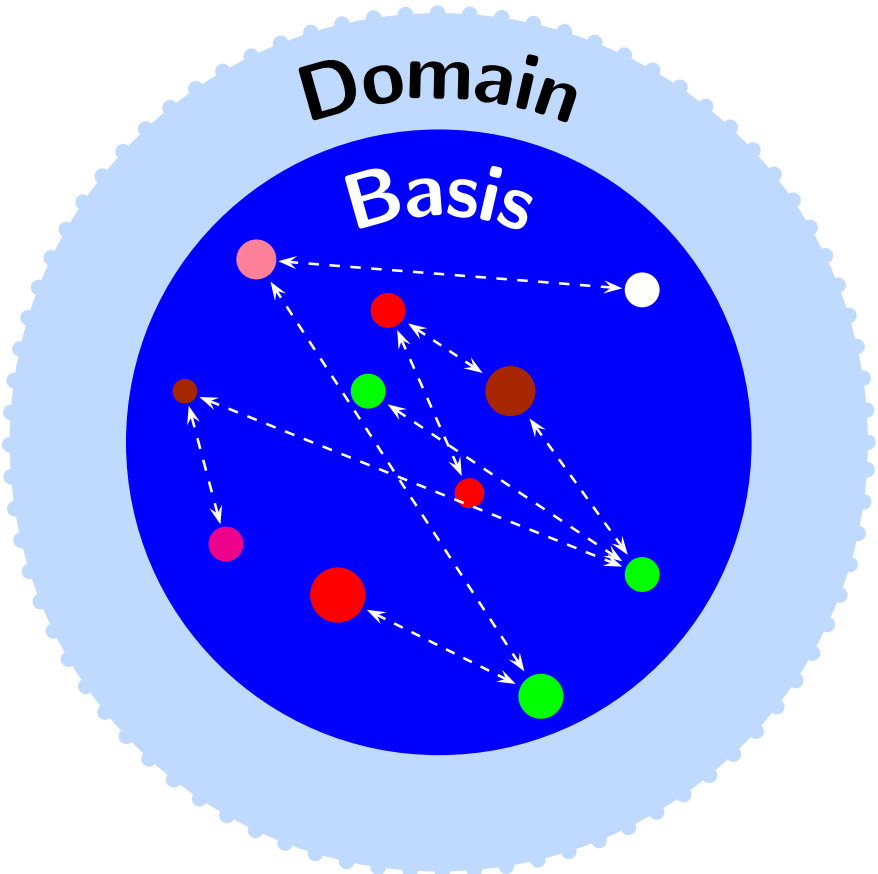

- Basis: Available resources with
  - mature prerequisite ideas/technologies
  - flexible connections
  - free flow of ideas
- Domain: *Adjacent Possible*

# The Basis and the Domain of Good Ideas



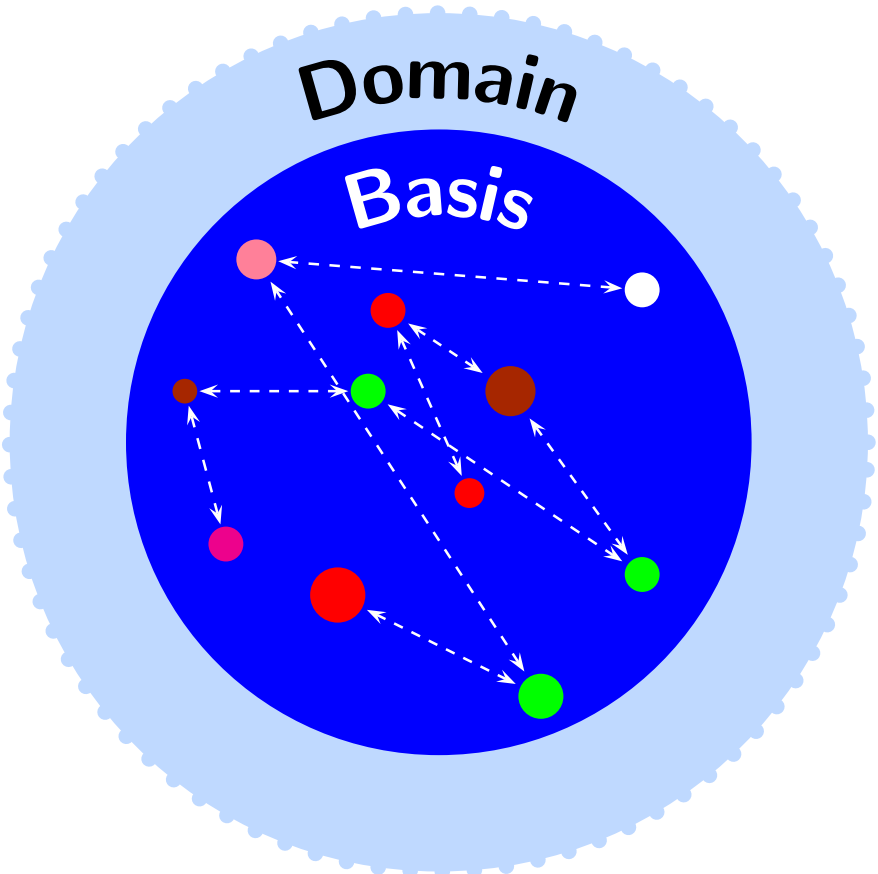

- Basis: Available resources with
  - mature prerequisite ideas/technologies
  - flexible connections
  - free flow of ideas
- Domain: *Adjacent Possible*

# The Basis and the Domain of Good Ideas



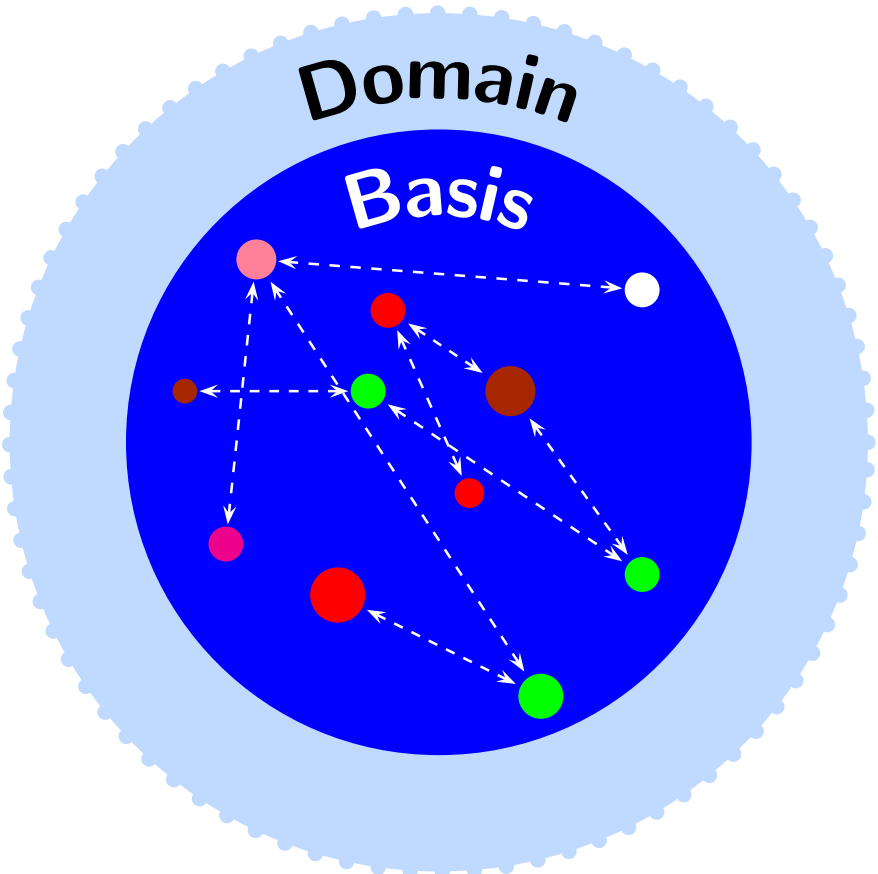

- Basis: Available resources with
  - mature prerequisite ideas/technologies
  - flexible connections
  - free flow of ideas
- Domain: *Adjacent Possible*

# The Basis and the Domain of Good Ideas



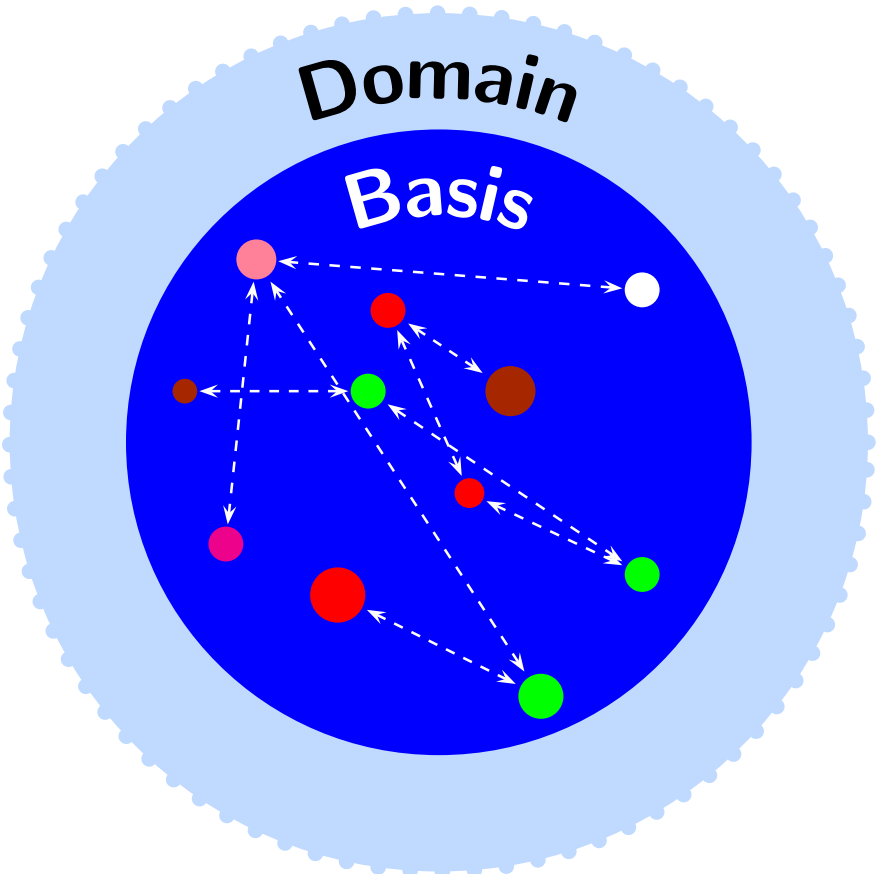

- Basis: Available resources with
  - mature prerequisite ideas/technologies
  - flexible connections
  - free flow of ideas
- Domain: *Adjacent Possible*

# The Basis and the Domain of Good Ideas



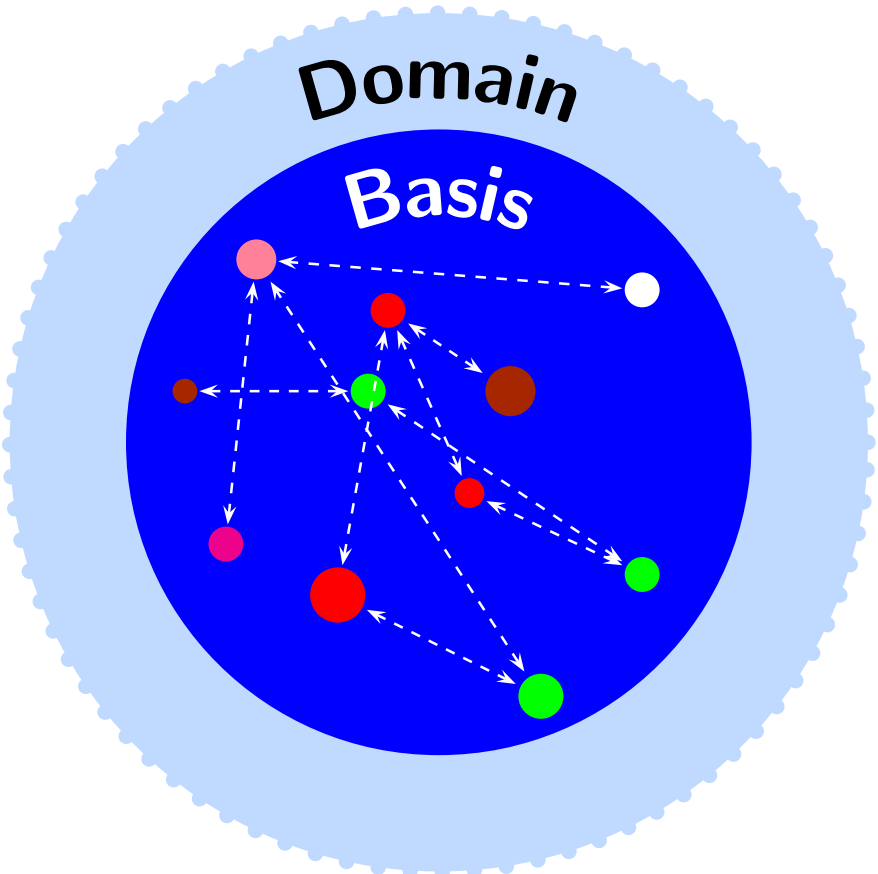

- Basis: Available resources with
  - mature prerequisite ideas/technologies
  - flexible connections
  - free flow of ideas
- Domain: *Adjacent Possible*

# The Basis and the Domain of Good Ideas



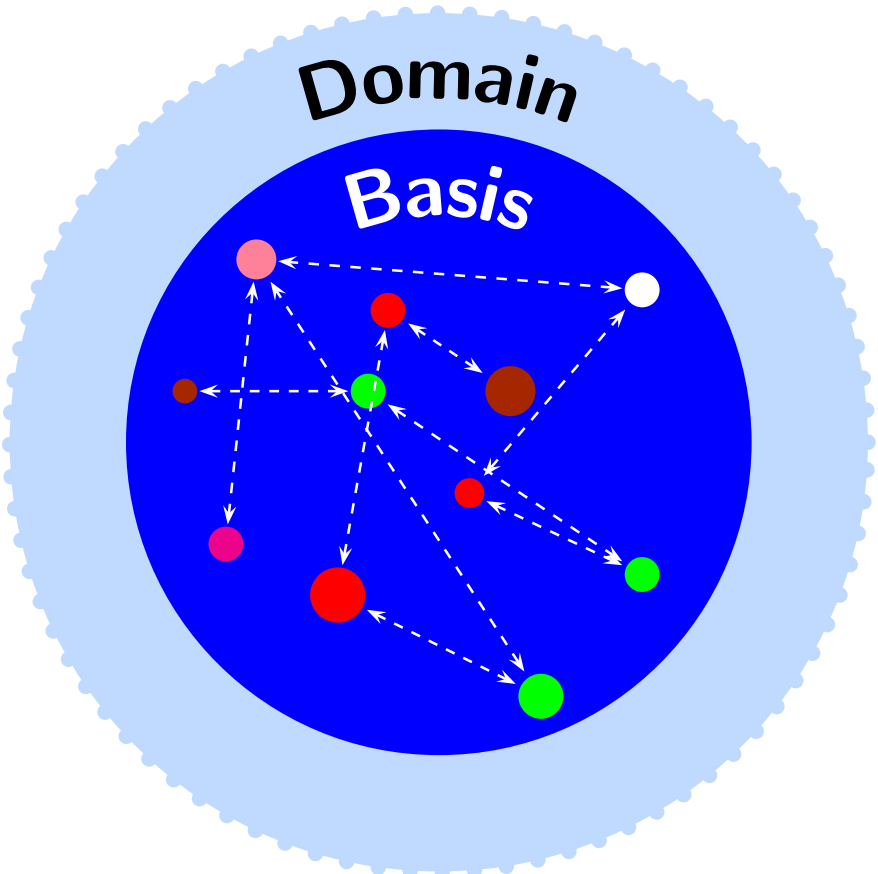

- Basis: Available resources with
  - mature prerequisite ideas/technologies
  - flexible connections
  - free flow of ideas
- Domain: *Adjacent Possible*

# The Basis and the Domain of Good Ideas



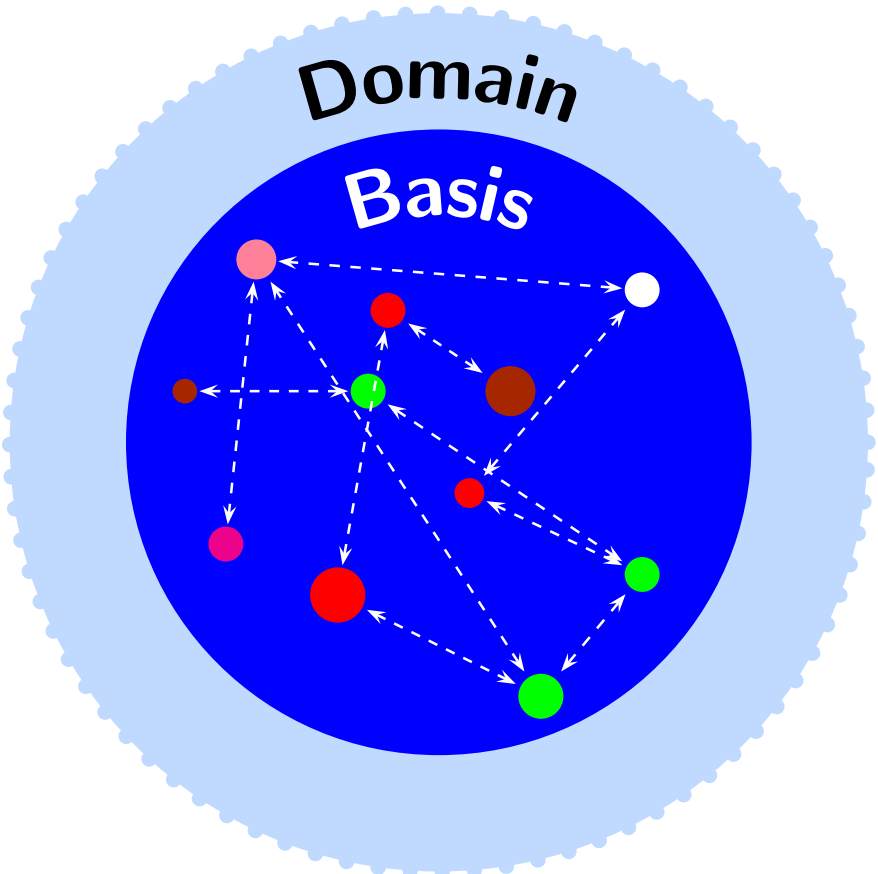

- Basis: Available resources with
  - mature prerequisite ideas/technologies
  - flexible connections
  - free flow of ideas
- Domain: *Adjacent Possible*

# The Basis and the Domain of Good Ideas



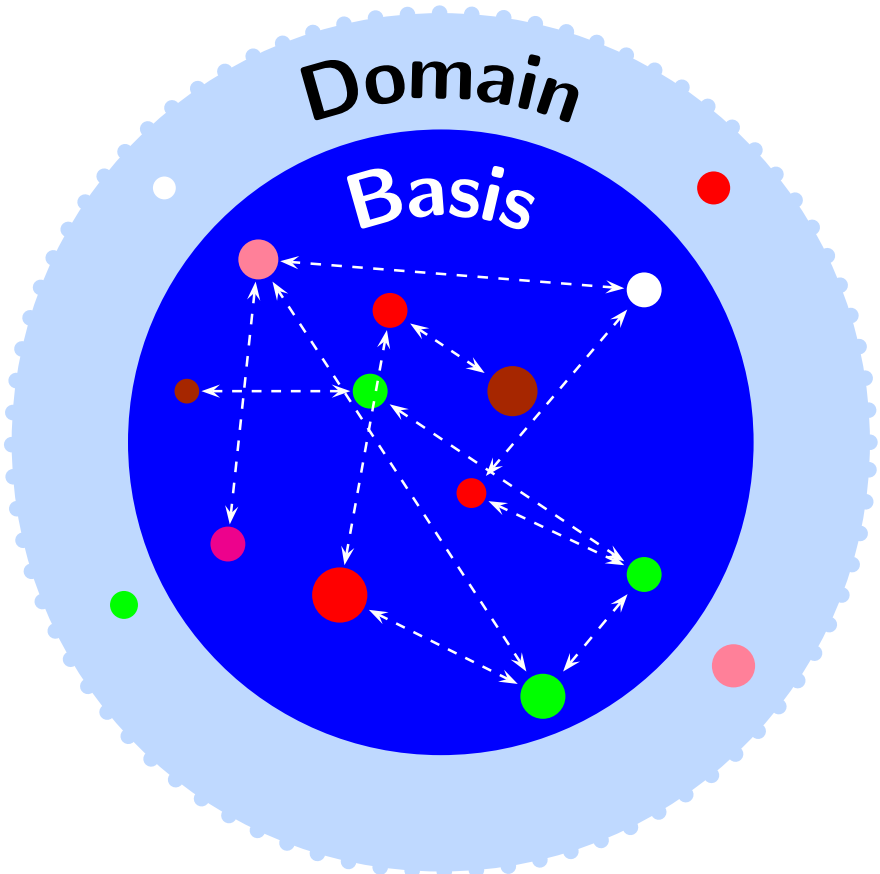

- Basis: Available resources with
  - mature prerequisite ideas/technologies
  - flexible connections
  - free flow of ideas
- Domain: *Adjacent Possible*

# The Basis and the Domain of Good Ideas



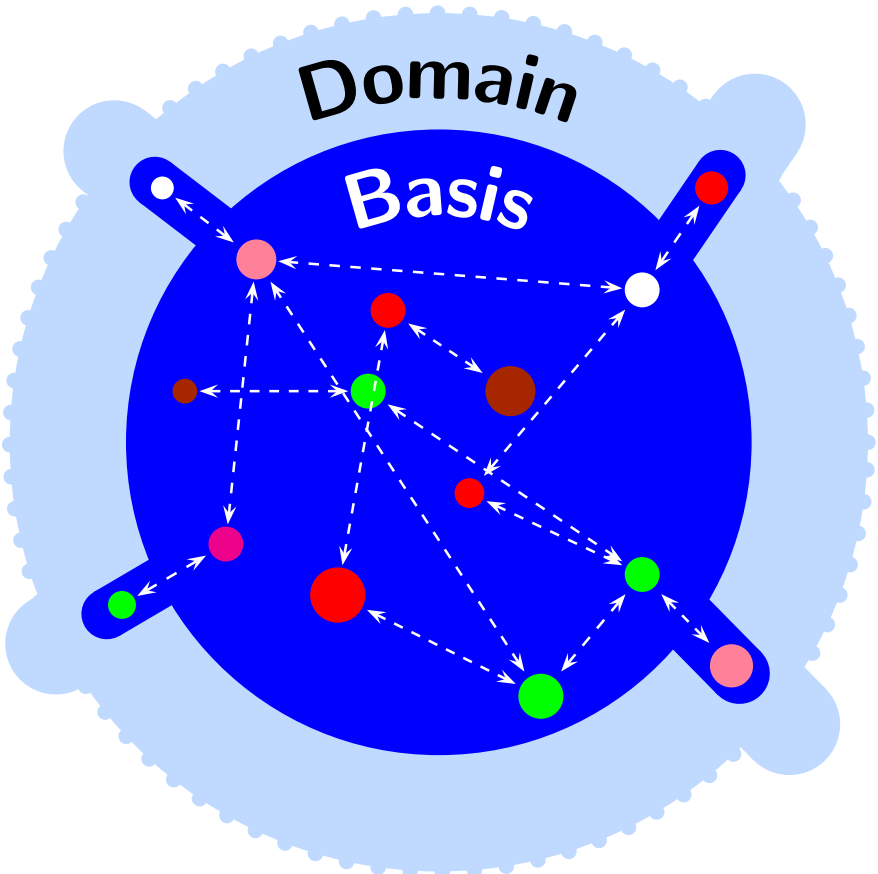

- Basis: Available resources with
  - mature prerequisite ideas/technologies
  - flexible connections
  - free flow of ideas
- Domain: *Adjacent Possible*

# The Basis and the Domain of Good Ideas




- Basis: Available resources with
  - mature prerequisite ideas/technologies
  - flexible connections
  - free flow of ideas
- Domain: *Adjacent Possible*
  - Boundaries define the limit

# The Basis and the Domain of Good Ideas




- Basis: Available resources with
  - mature prerequisite ideas/technologies
  - flexible connections
  - free flow of ideas
- Domain: *Adjacent Possible*
  - Boundaries define the limit
  - Boundaries grow as we explore

# Adjacent Possible

- *First Order Combinations* (Stuart Kaufman, 1995)

# Adjacent Possible

- *First Order Combinations* (Stuart Kaufman, 1995)
- Boundaries grow as we explore them

# Adjacent Possible

- *First Order Combinations* (Stuart Kaufman, 1995)
- Boundaries grow as we explore them
  - Find a new door and open it
  - May lead to a yet another door that needs to be opened

# Adjacent Possible

- *First Order Combinations* (Stuart Kaufman, 1995)
- Boundaries grow as we explore them
  - Find a new door and open it
  - May lead to a yet another door that needs to be opened

*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)



# 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)
- 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



# Creation of FORTRAN as an Example of Adjacent Possible

- Prevailing wisdom circa 1950s : Expressiveness Vs. Efficiency conflict
- Backus's main observations
  - *Economic problem.* Imbalence between the programming costs and computer costs
  - *Technical difficulty.* Inefficiency of translation of an expressive specification
  - *Main obstacle.* Clumsy treatment of program loops and array address calculations



# Creation of FORTRAN as an Example of Adjacent Possible

- Prevailing wisdom circa 1950s : Expressiveness Vs. Efficiency conflict
- Backus's main observations
  - *Economic problem.* Imbalence between the programming costs and computer costs
  - *Technical difficulty.* Inefficiency of translation of an expressive specification
  - *Main obstacle.* Clumsy treatment of program loops and array address calculations
- Backus was the *right person* at the *right time* at the *right place*
  - He had the foresight to recognize that efficient language implementation was well within the *adjacent possible*
  - He was Bernard Shaw's proverbial "unreasonable person"



# Creation of FORTRAN as an Example of Adjacent Possible

- Prevailing wisdom circa 1950s : Expressiveness Vs. Efficiency conflict
- Backus's main observations
  - *Economic problem.* Imbalence between the programming costs and computer costs
  - *Technical difficulty.* Inefficiency of translation of an expressive specification
  - *Main obstacle.* Clumsy treatment of program loops and array address calculations
- Backus was the *right person* at the *right time* at the *right place*
  - He had the foresight to recognize that efficient language implementation was well within the *adjacent possible*
  - He was Bernard Shaw's proverbial "unreasonable person"
- Creation of FORTRAN is a triumph of the genius of AND over the tyranny of OR

# Adaptation

- Using an idea in a completely unrelated context leading to cross fertilization of ideas

# Adaptation

- Using an idea in a completely unrelated context leading to cross fertilization of ideas
- Adaptation Example 1:

  Screw press for wine making used by Gutenberg for printing press

  - Everything else was ready: the movable type face using lead fonts, the ink, the paper,
  - the types however were hand pressed and the process was slow and not suitable for mass production



# Adaptation

- Using an idea in a completely unrelated context leading to cross fertilization of ideas
- Adaptation Example 1:

  Screw press for wine making used by Gutenberg for printing press

  - Everything else was ready: the movable type face using lead fonts, the ink, the paper,
  - the types however were hand pressed and the process was slow and not suitable for mass production
- Adaptation Example 2:

  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)
  - The modern day GPS (Global positioning system)

# 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)
  - The modern day GPS (Global positioning system)

- 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

- Every *Eureka!* moment is preceded by a hunch that has lingered on in the mind for a long time before *mutating* into something useful

# Slow Hunch

- Every *Eureka!* moment is preceded by a hunch that has lingered on in the mind for a long time before *mutating* into something useful
- Evolution of an idea is not a monotonic progress
  - It's more like a blind man walking with a stick
  - Half guesses, some of which are discarded, some are refined further
  - Some times discarded guesses are revisited



# Slow Hunch

- Every *Eureka!* moment is preceded by a hunch that has lingered on in the mind for a long time before *mutating* into something useful
- Evolution of an idea is not a monotonic progress
  - It's more like a blind man walking with a stick
  - Half guesses, some of which are discarded, some are refined further
  - Some times discarded guesses are revisited
- 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)



# 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)

- Dream Example 1:

  Friedrich Kekule's discovery of the molecular structure of Benzene as a prefect ring of carbon with hydrogen items jutting out

  Dreamt of a Greek mythological snake Ouroboros eating its own tail



# 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)

- Dream Example 1:

  Friedrich Kekule's discovery of the molecular structure of Benzene as a prefect ring of carbon with hydrogen items jutting out

  Dreamt of a Greek mythological snake Ouroboros eating its own tail

- Dream Example 2:

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

# Error

- Error often jolts you out of your comfortable assumptions
- Being right keeps you in place, being wrong forces you to explore

# Error

- Error often jolts you out of your comfortable assumptions
- Being right keeps you in place, being wrong forces you to explore
- Error Example 1: Greatbach's pacemaker
  - Original goal was to create a devise to record heart beat
  - A radio like receiver to catch signal's transmitted by heart
  - A wrong resistor connected to oscillator started simulating heart beat

# Error

- Error often jolts you out of your comfortable assumptions
- Being right keeps you in place, being wrong forces you to explore
- Error Example 1: Greatbach's pacemaker
  - Original goal was to create a devise to record heart beat
  - A radio like receiver to catch signal's transmitted by heart
  - A wrong resistor connected to oscillator started simulating heart beat
- 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*

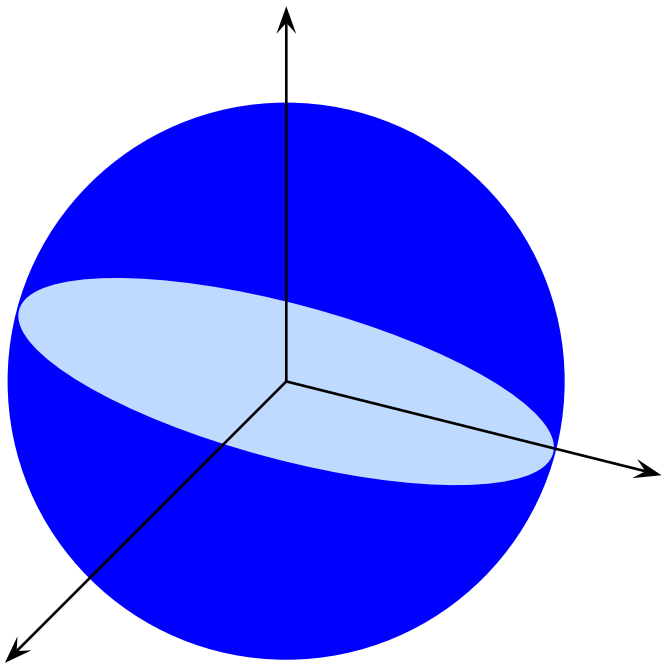
# *The Process of Research*

# The Spirit of Inquiry (1)

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

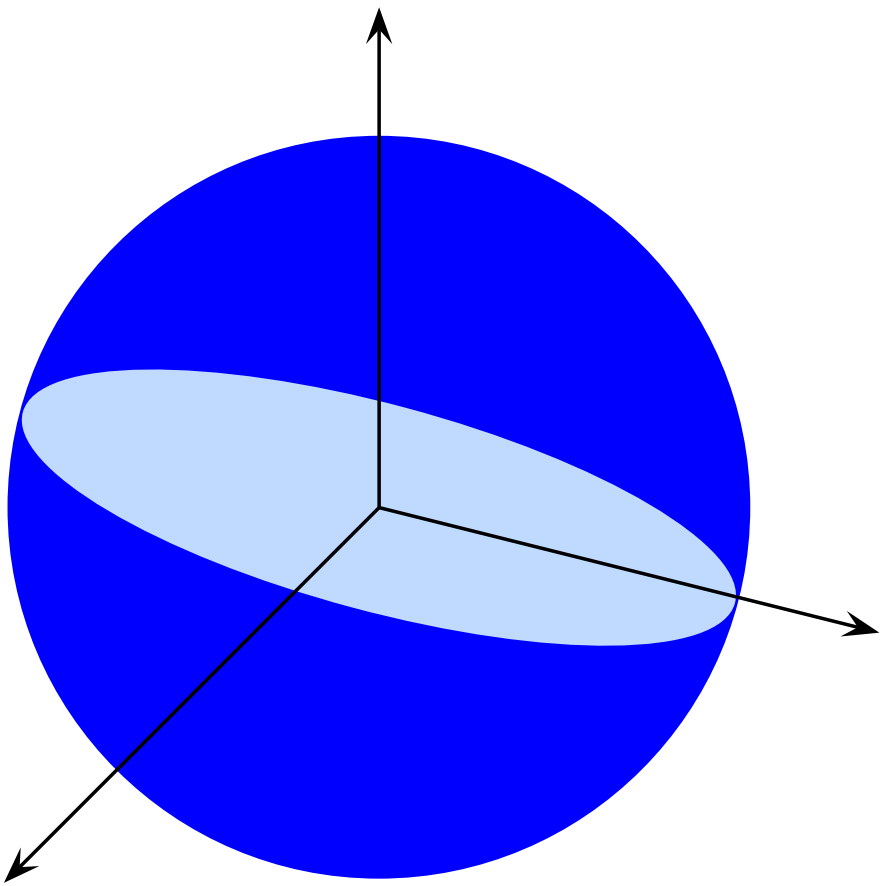
# The Spirit of Inquiry (1)

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



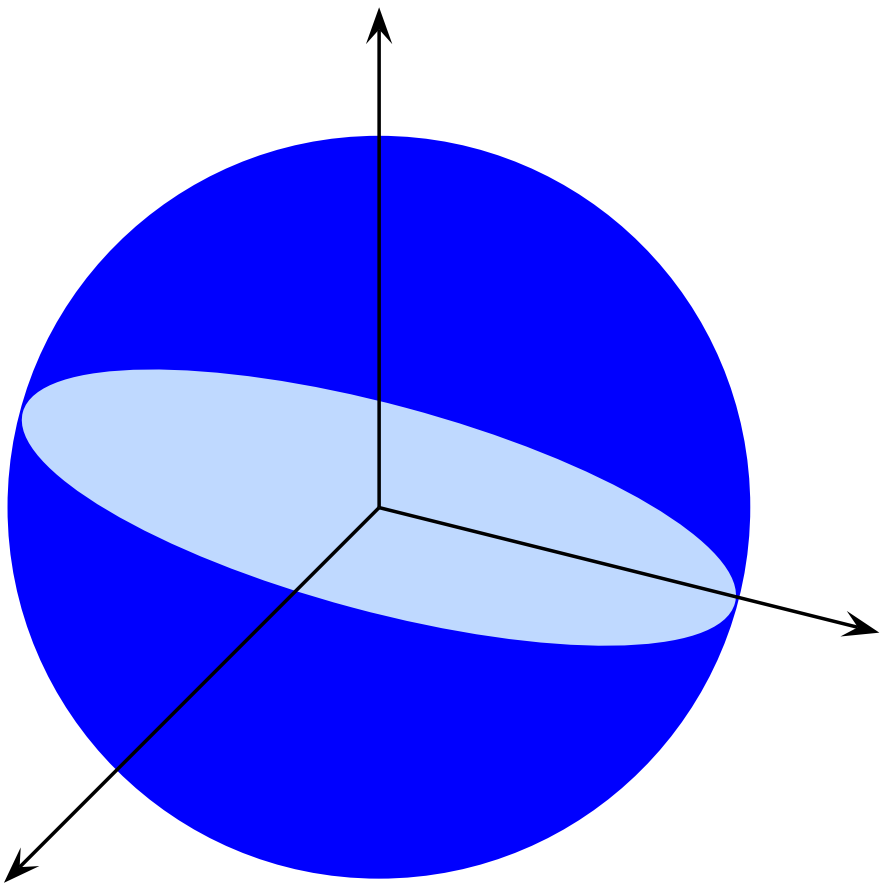
# The Spirit of Inquiry (1)

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



# The Spirit of Inquiry (1)

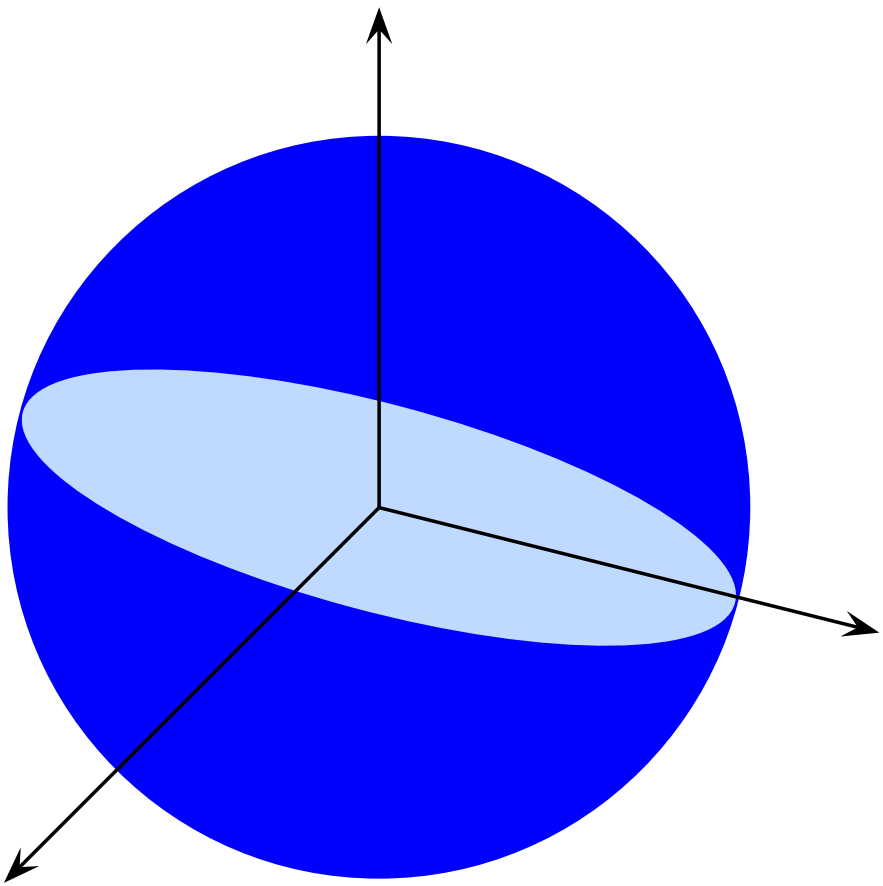
Very few of us know,
how much we have to know,
in order to know,
how little we know



- Relative stupidity Vs. Productive stupidity

# The Spirit of Inquiry (1)

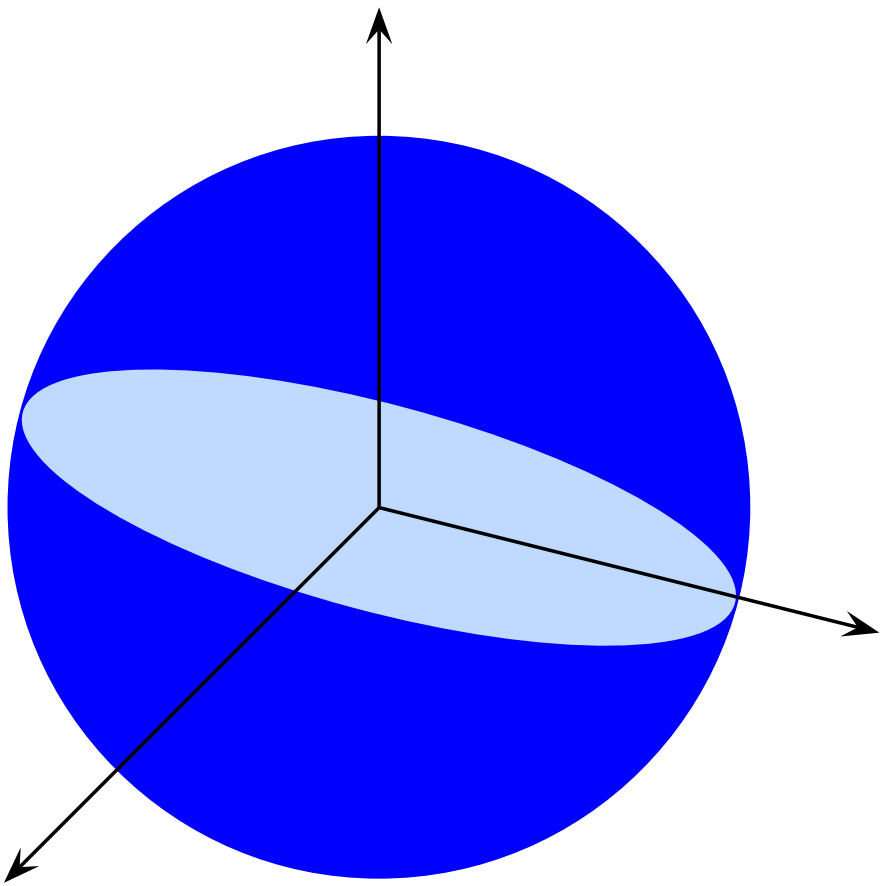
Very few of us know,
how much we have to know,
in order to know,
how little we know



- Relative stupidity Vs. Productive stupidity
- We are taught to feel bad about relative stupidity

# The Spirit of Inquiry (1)

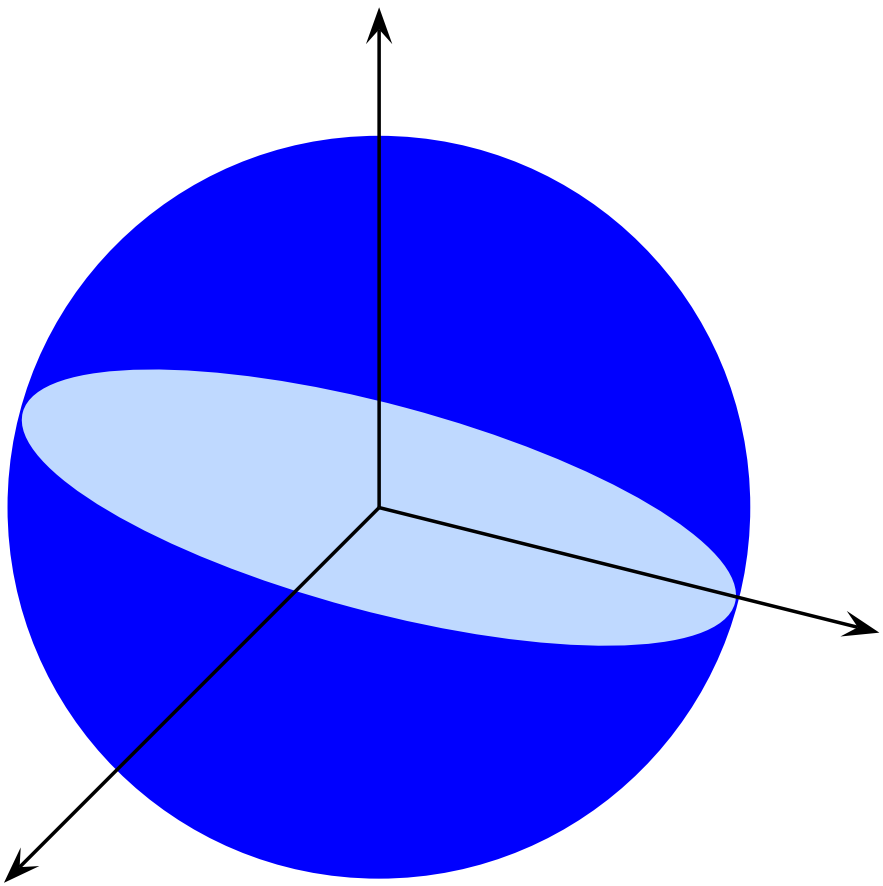
Very few of us know,
how much we have to know,
in order to know,
how little we know



- Relative stupidity Vs. Productive stupidity
- We are taught to feel bad about relative stupidity
- Productive stupidity:

# The Spirit of Inquiry (1)

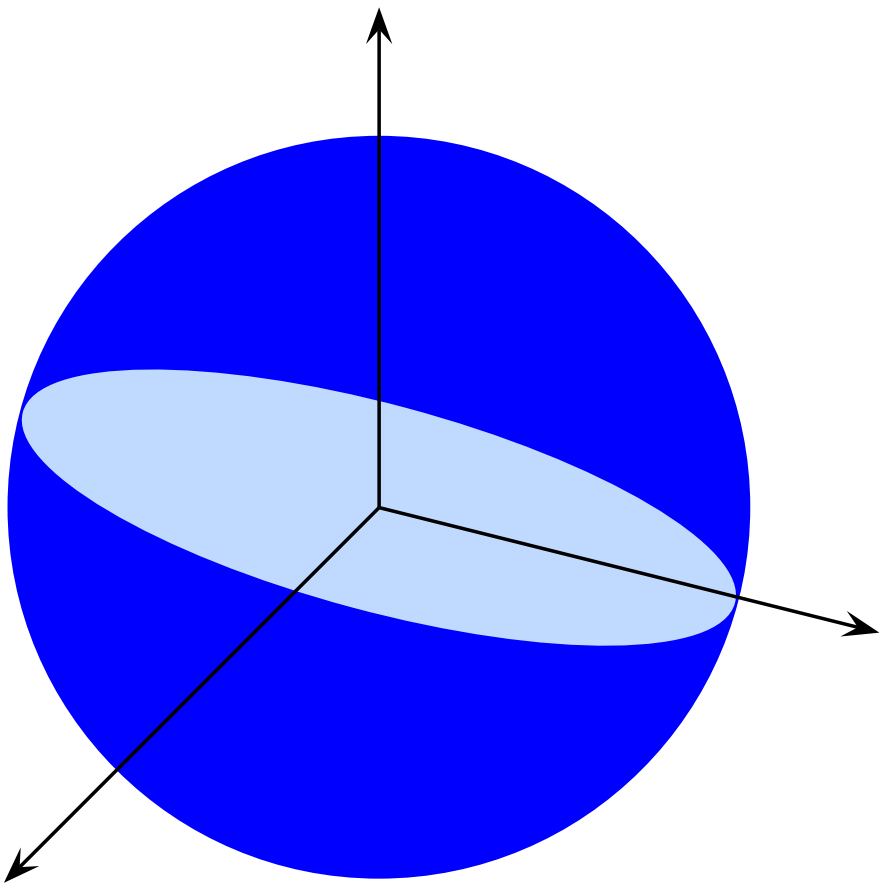
Very few of us know,
how much we have to know,
in order to know,
how little we know



- 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

# The Spirit of Inquiry (1)

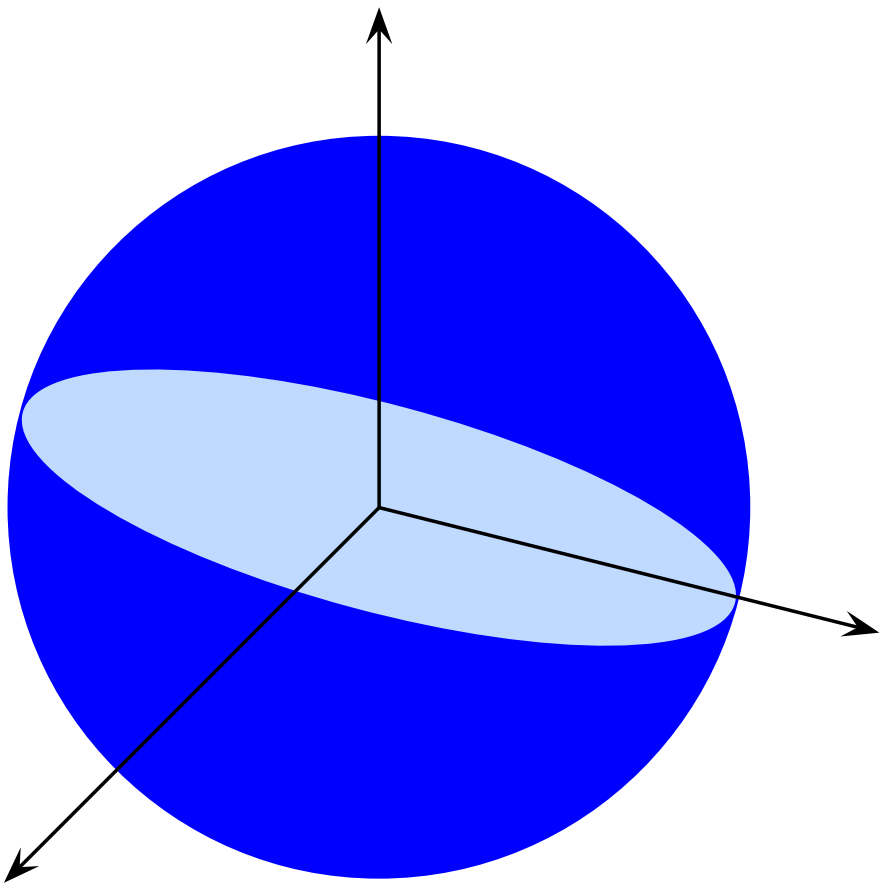
Very few of us know,
how much we have to know,
in order to know,
how little we know



- 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!

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

# The Spirit of Inquiry (2)

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

We end up mixing

- criticism of an idea with criticism of the person 

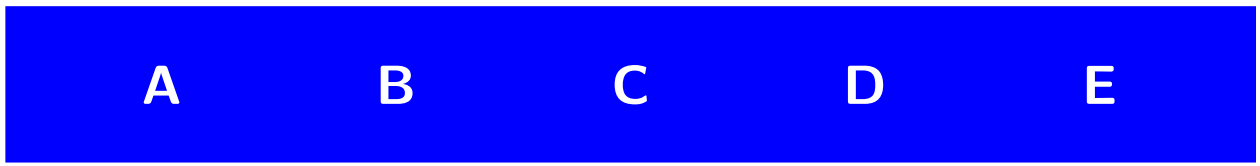
# The Spirit of Inquiry (2)

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

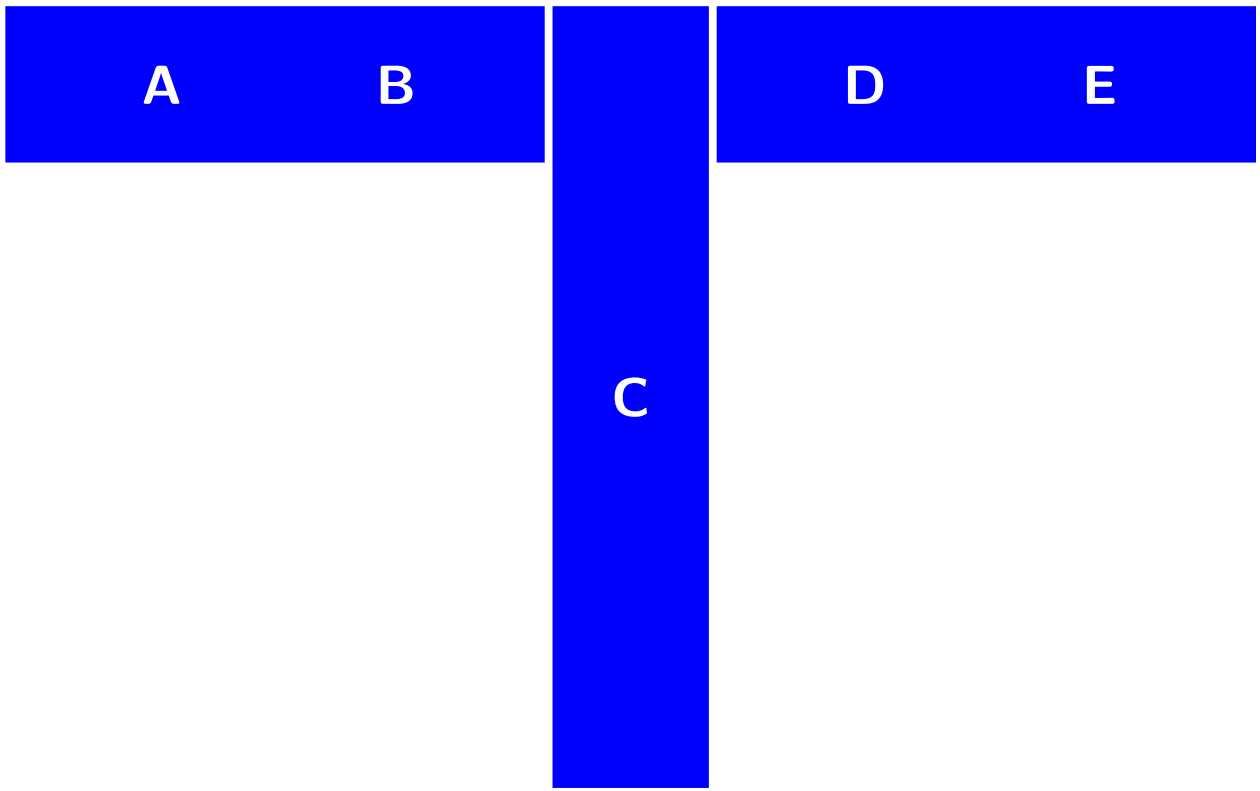
We end up mixing

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

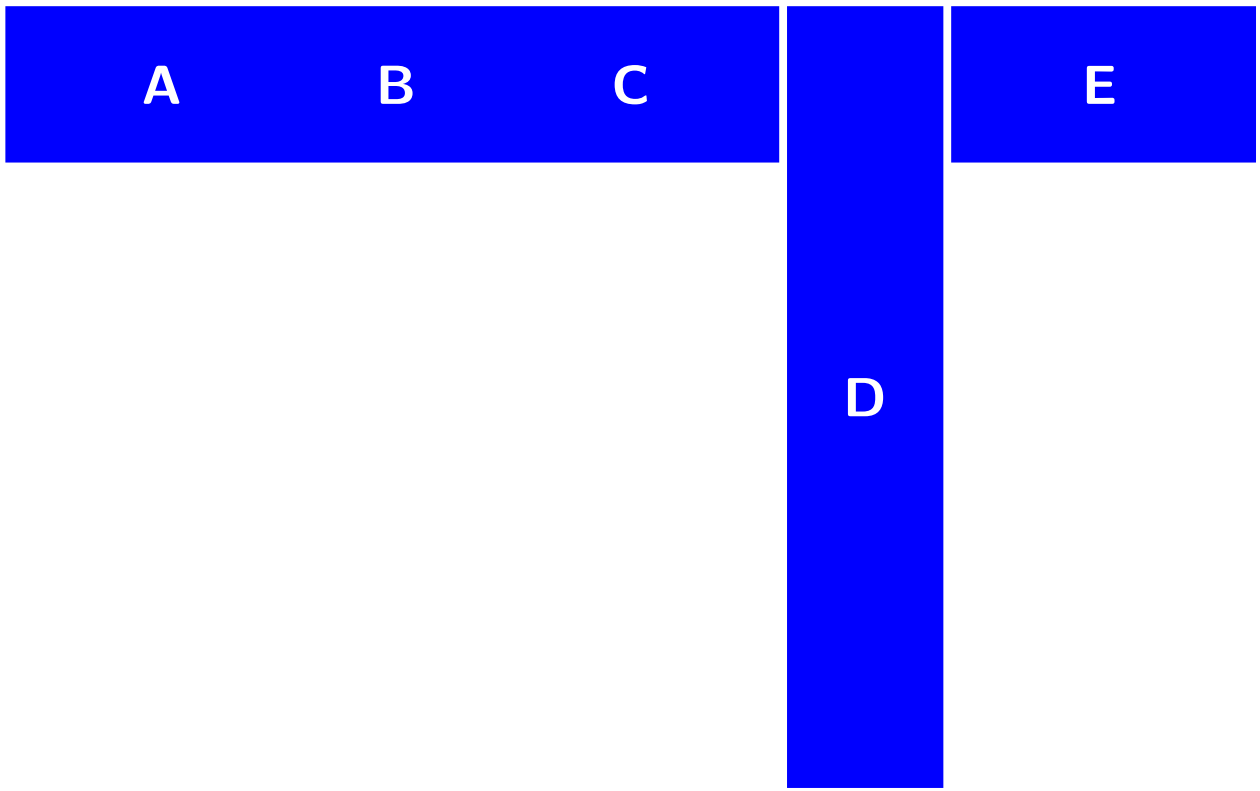
# Breadth Vs. Depth



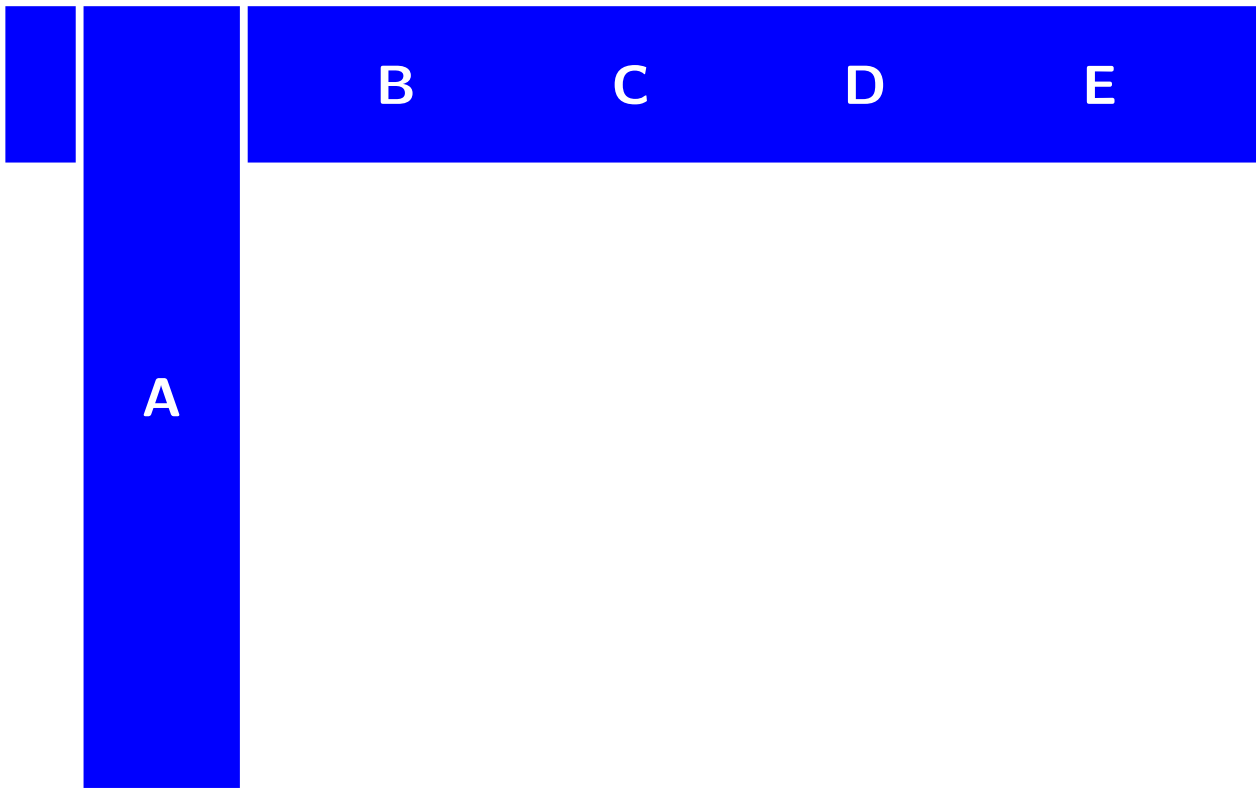
# Breadth Vs. Depth



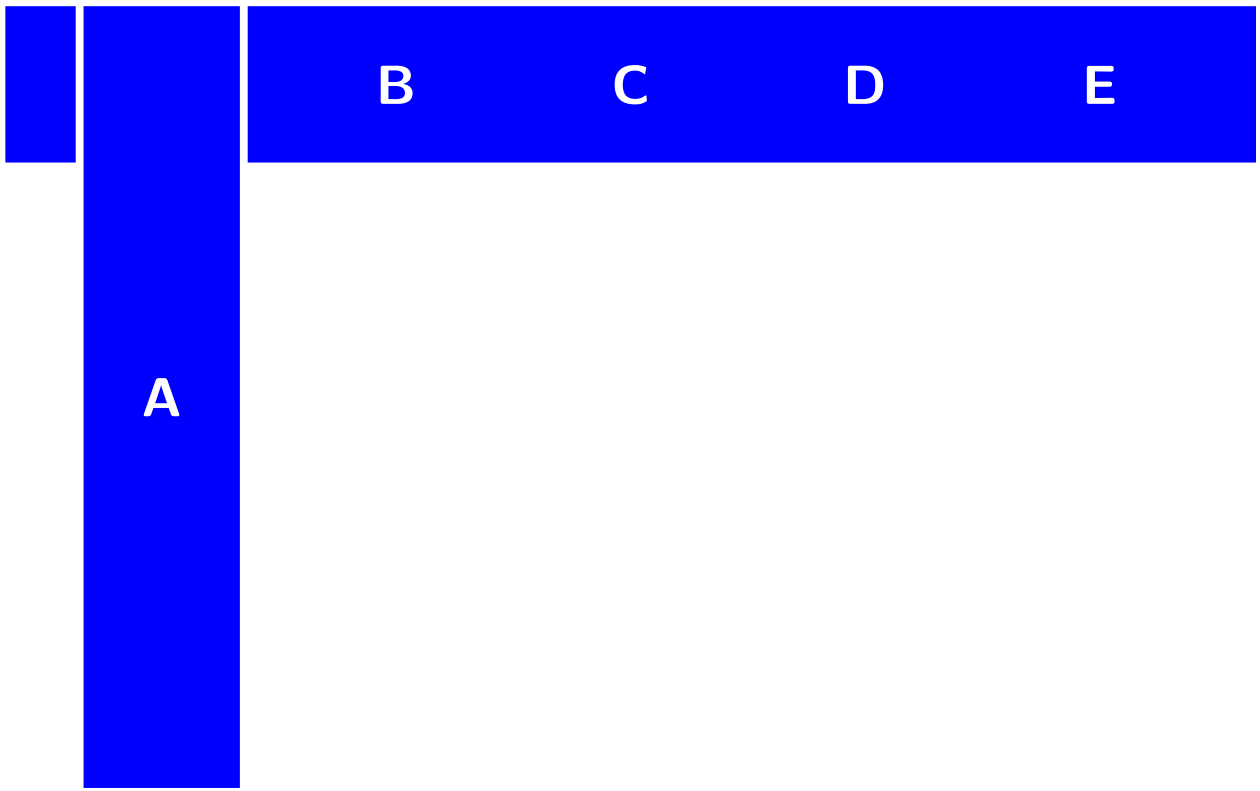
# Breadth Vs. Depth



# Breadth Vs. Depth



# Breadth Vs. Depth

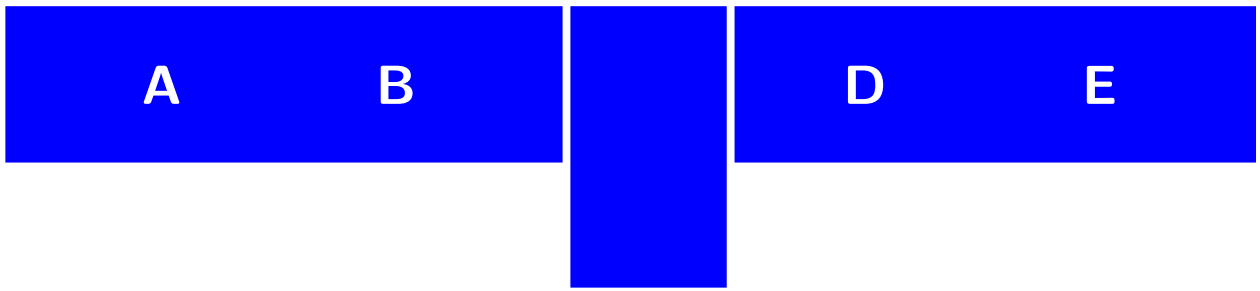



Breadth or Depth?

# Breadth Vs. Depth

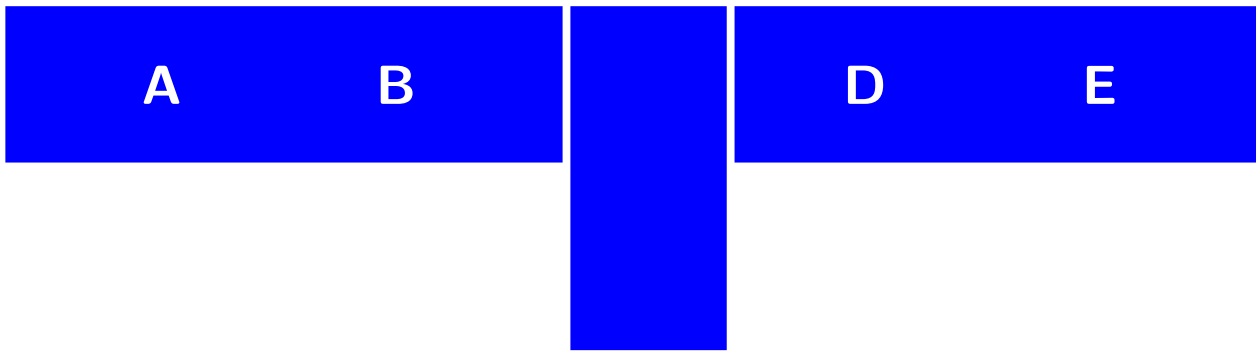

Achieve depth in one area and overall breadth

# Breadth Vs. Depth



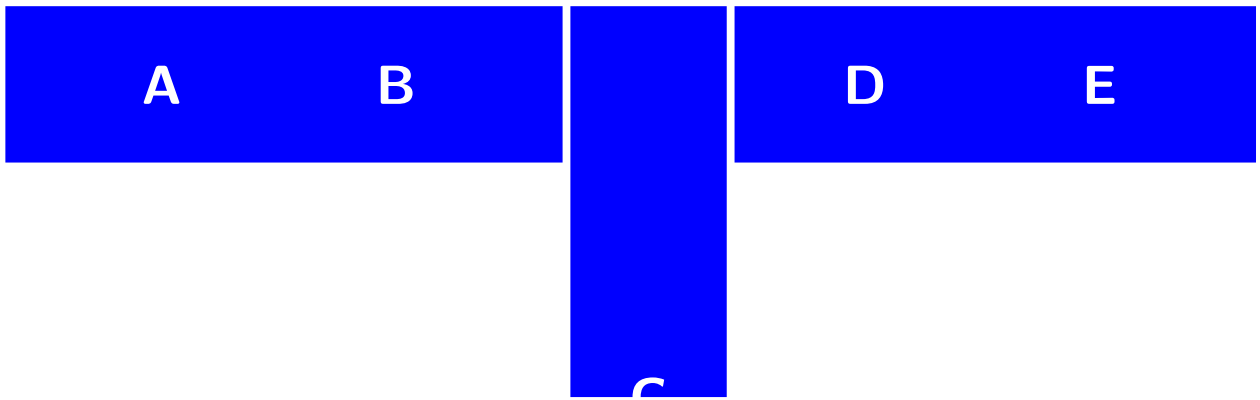

Achieve depth in one area and overall breadth

# Breadth Vs. Depth



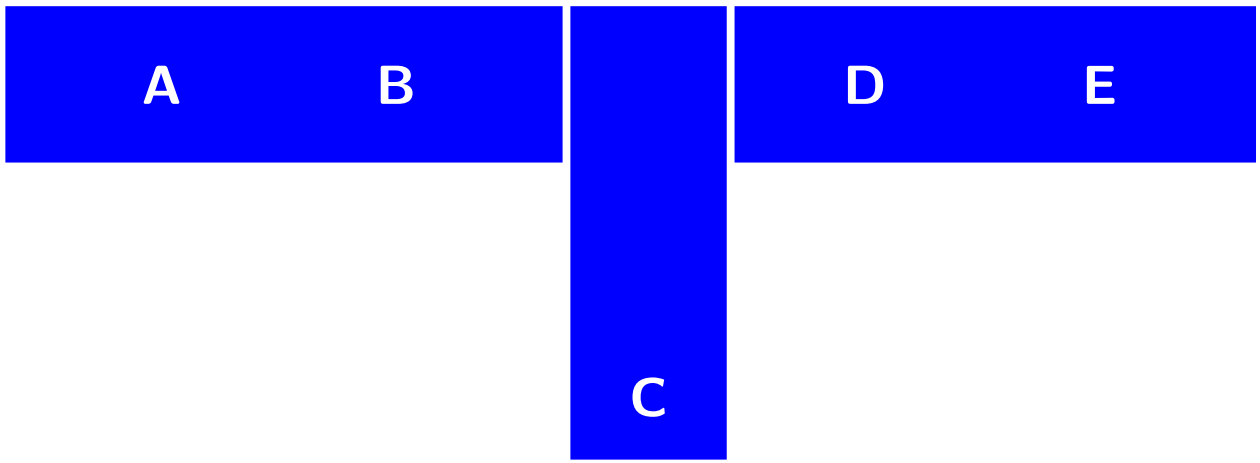

Achieve depth in one area and overall breadth

# Breadth Vs. Depth



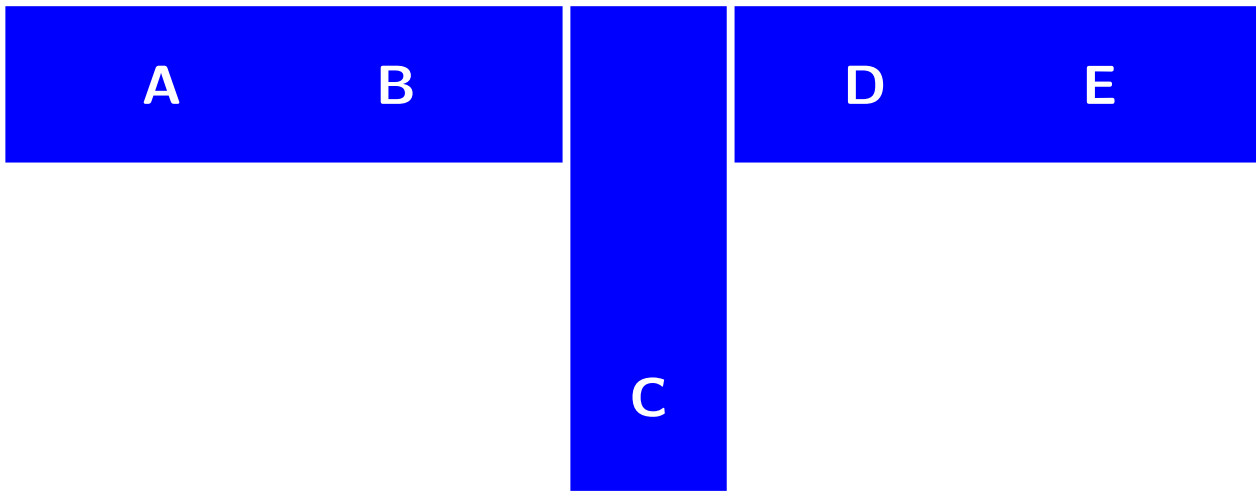

Achieve depth in one area and overall breadth

# Breadth Vs. Depth



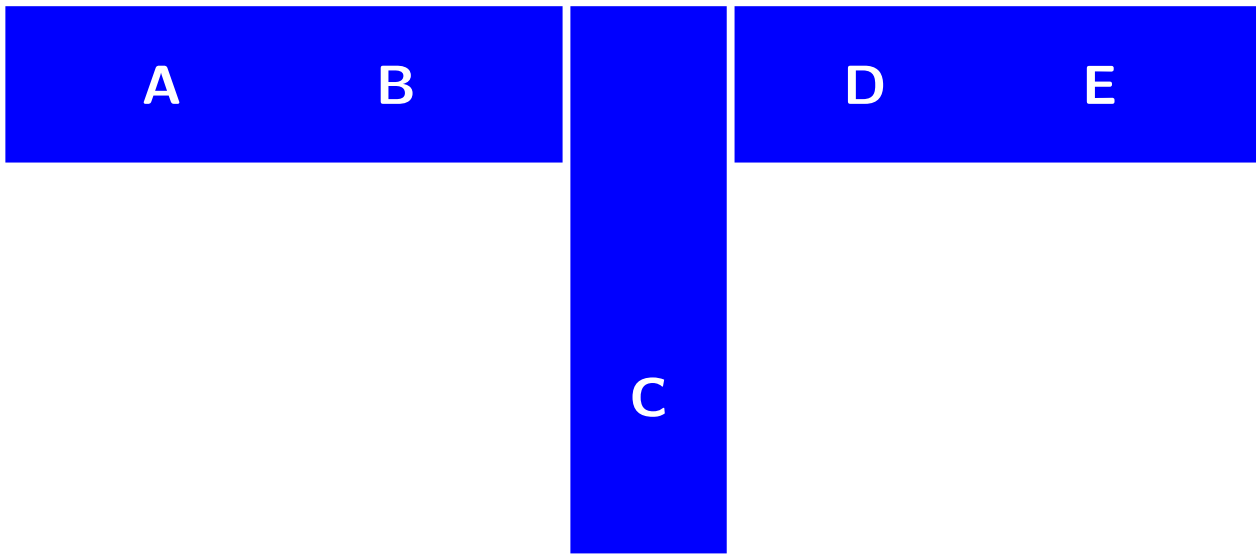

Achieve depth in one area and overall breadth

# Breadth Vs. Depth



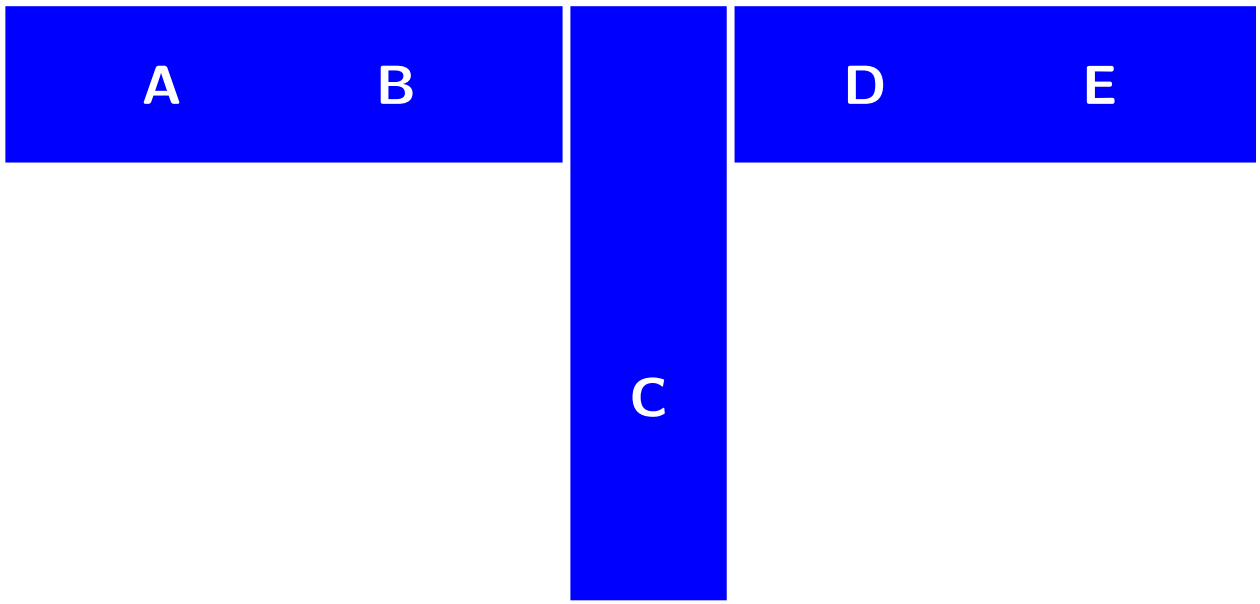

Achieve depth in one area and overall breadth

# Breadth Vs. Depth



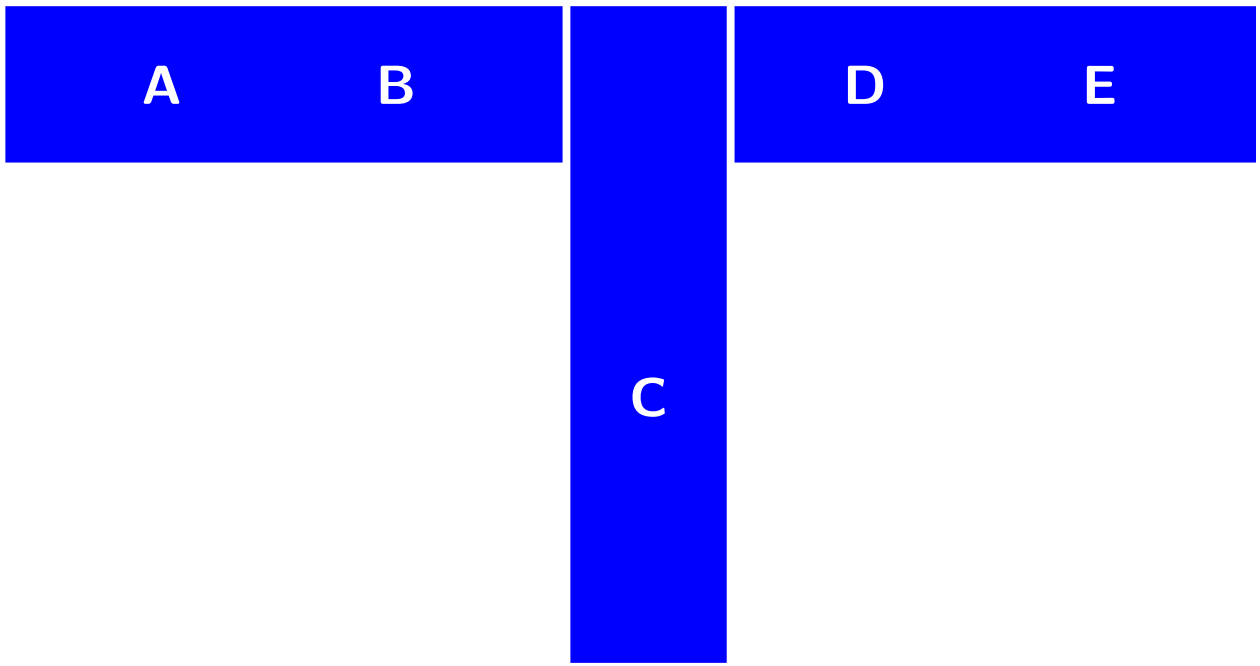

Achieve depth in one area and overall breadth

# Breadth Vs. Depth



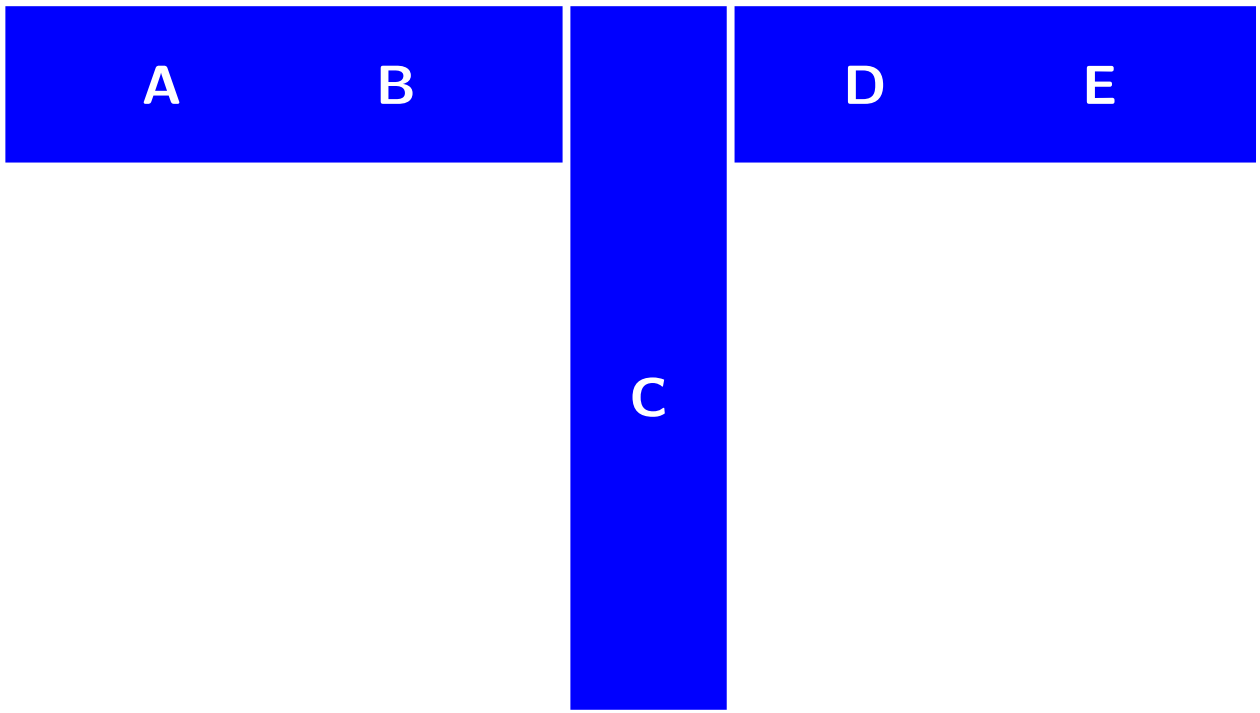

Achieve depth in one area and overall breadth

# Breadth Vs. Depth



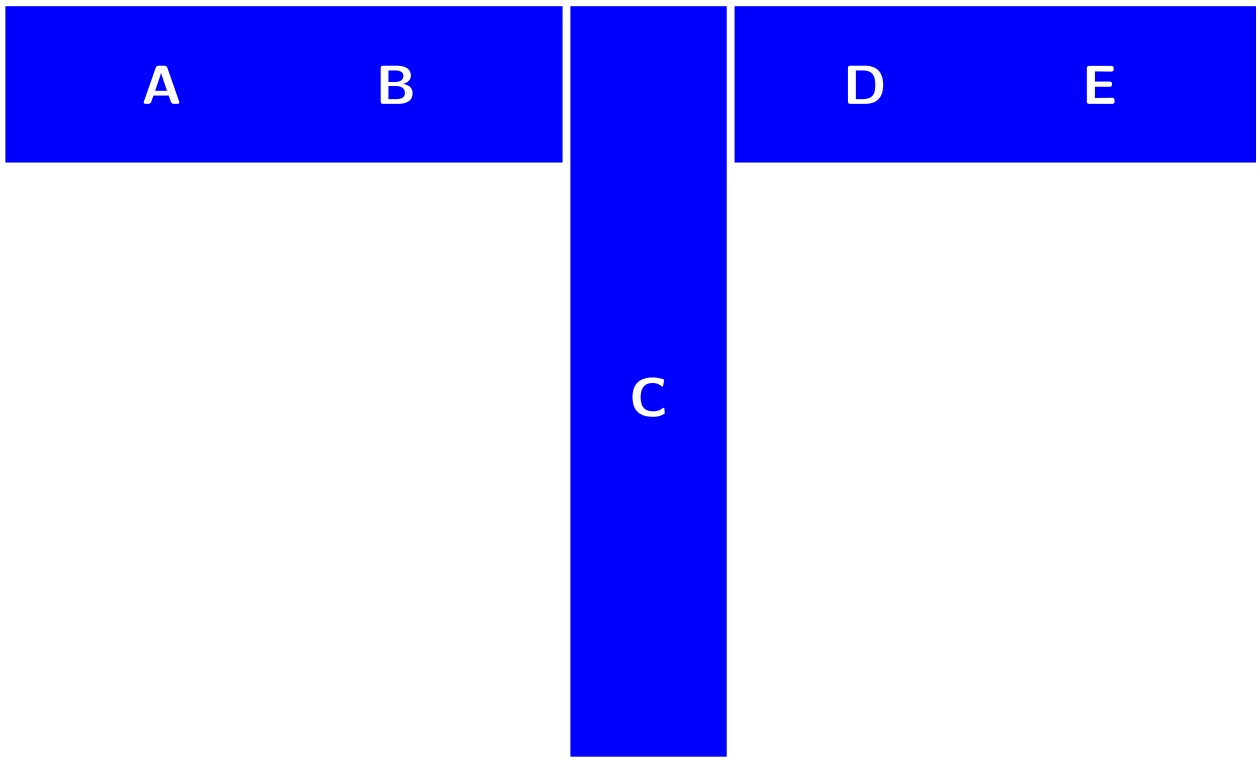

Achieve depth in one area and overall breadth

# Breadth Vs. Depth



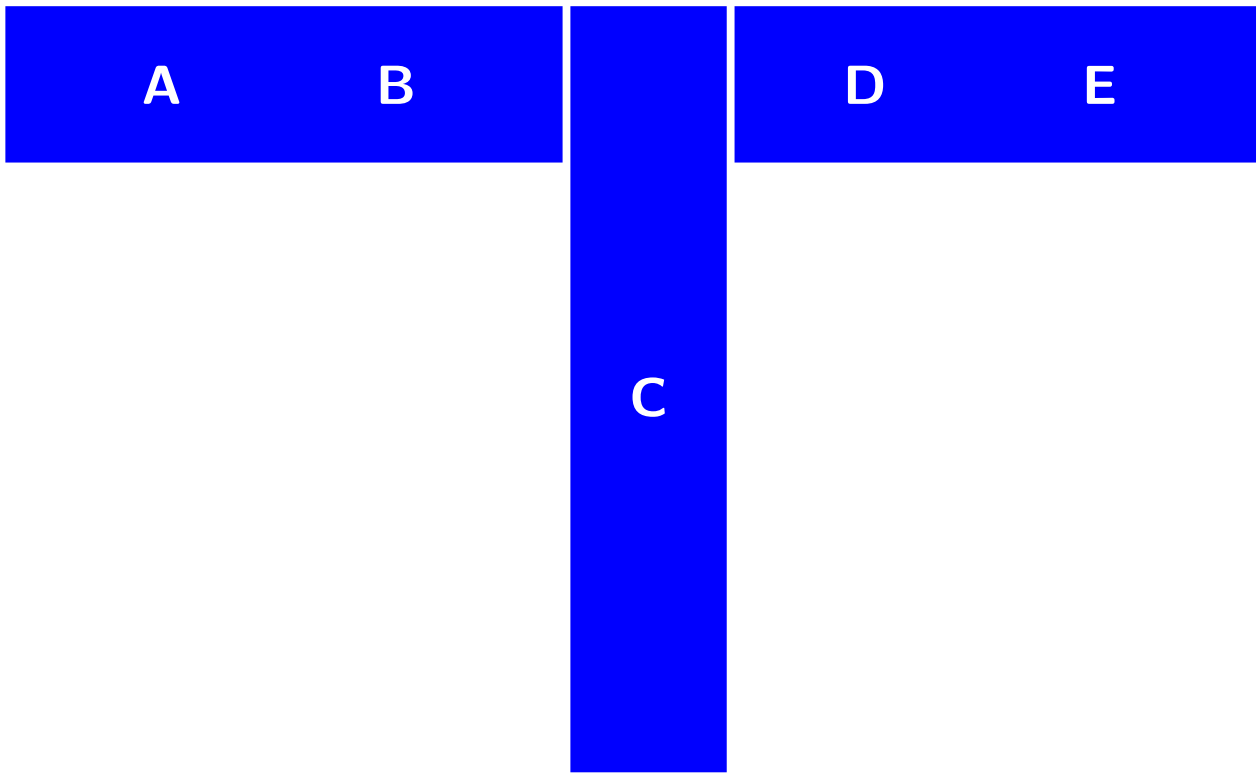

Achieve depth in one area and overall breadth

# Breadth Vs. Depth



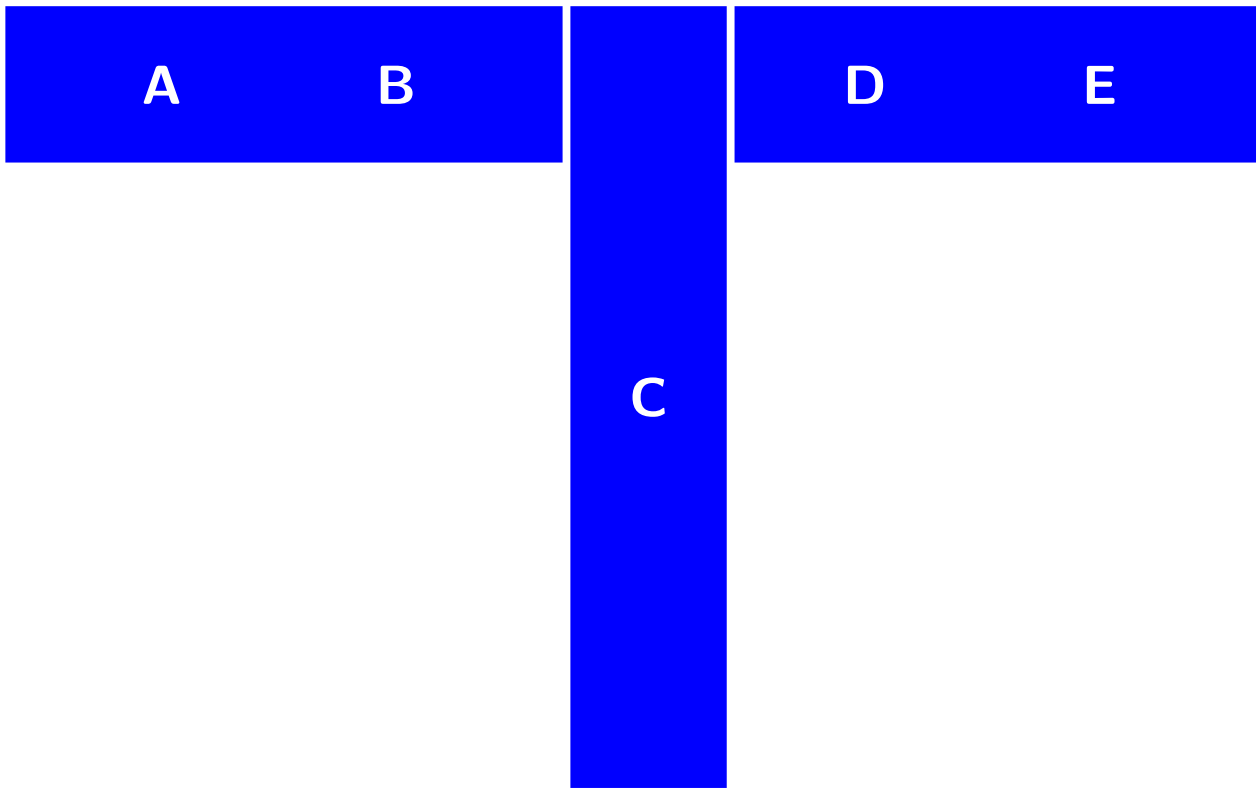

Achieve depth in one area and overall breadth

# Breadth Vs. Depth



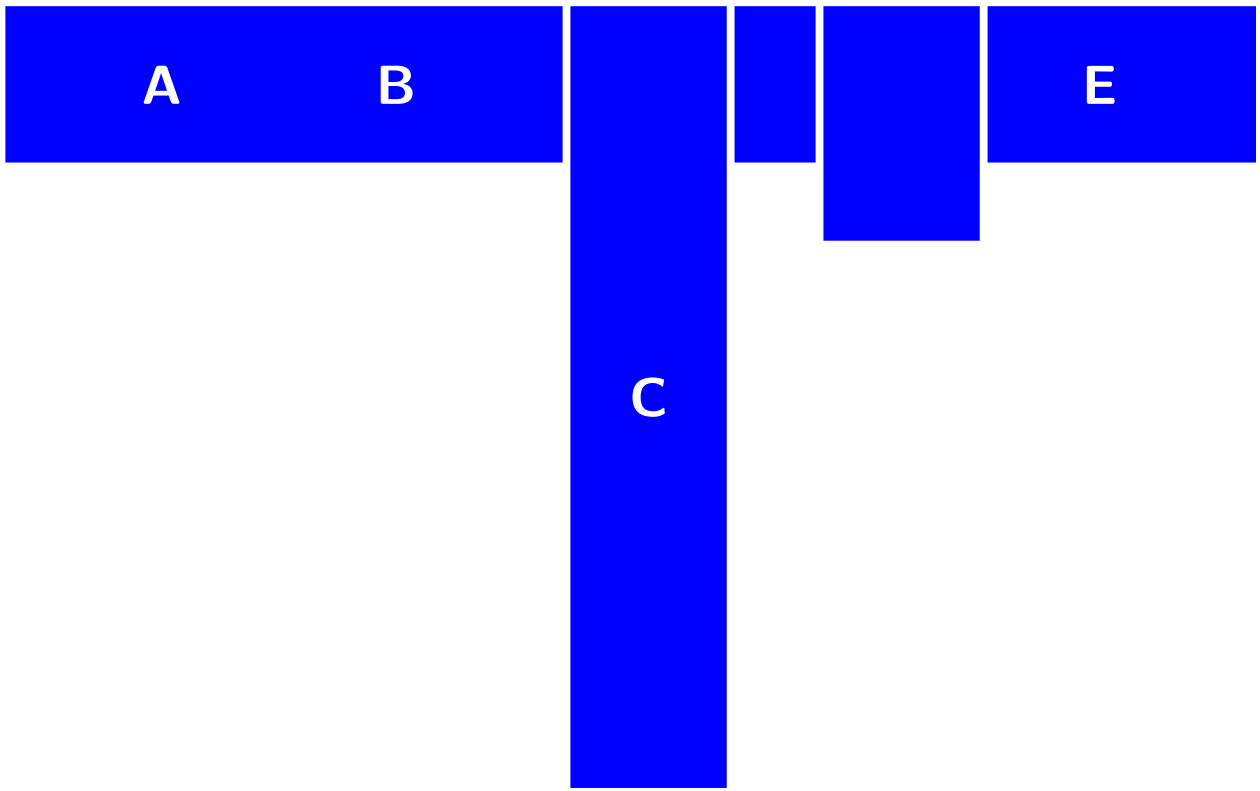

Achieve depth in one area and overall breadth

# Breadth Vs. Depth




Achieve depth in one area and overall breadth

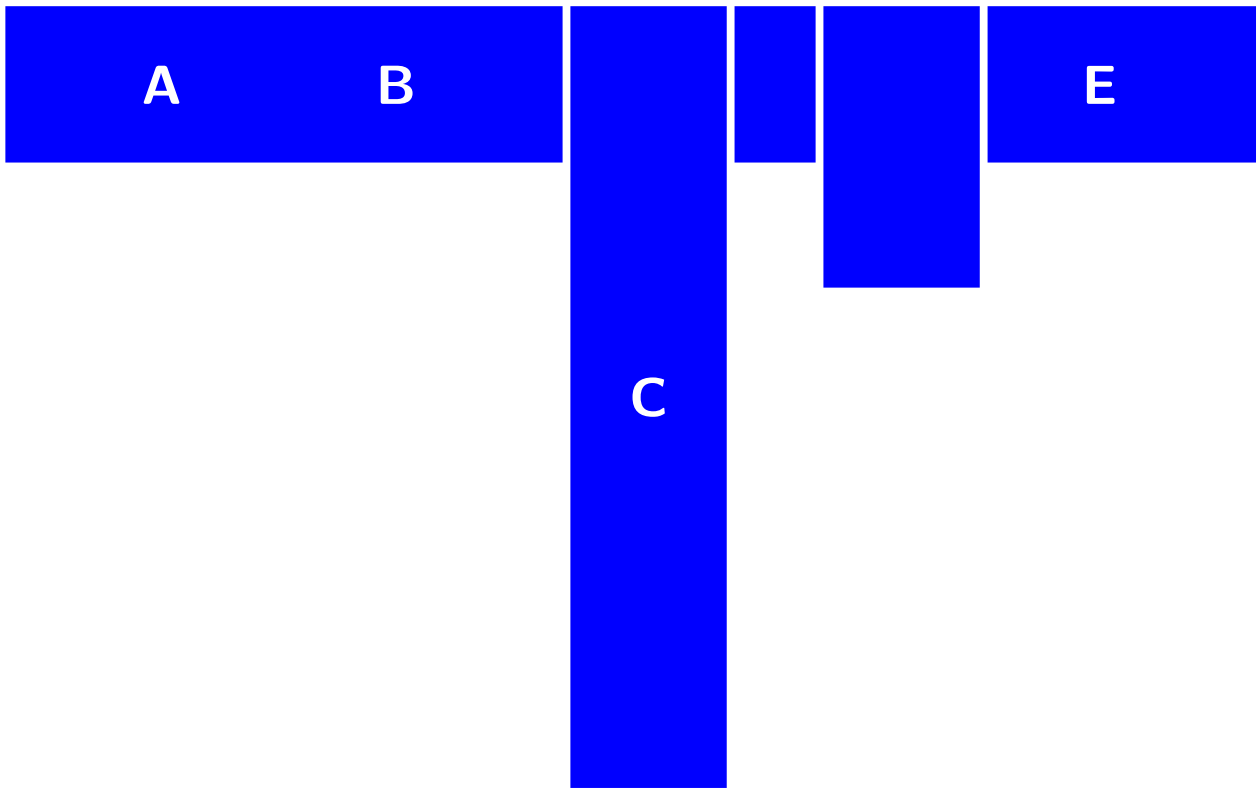
# Breadth Vs. Depth




Achieve depth in one area and overall breadth

Other areas can be understood on need basis relatively quickly

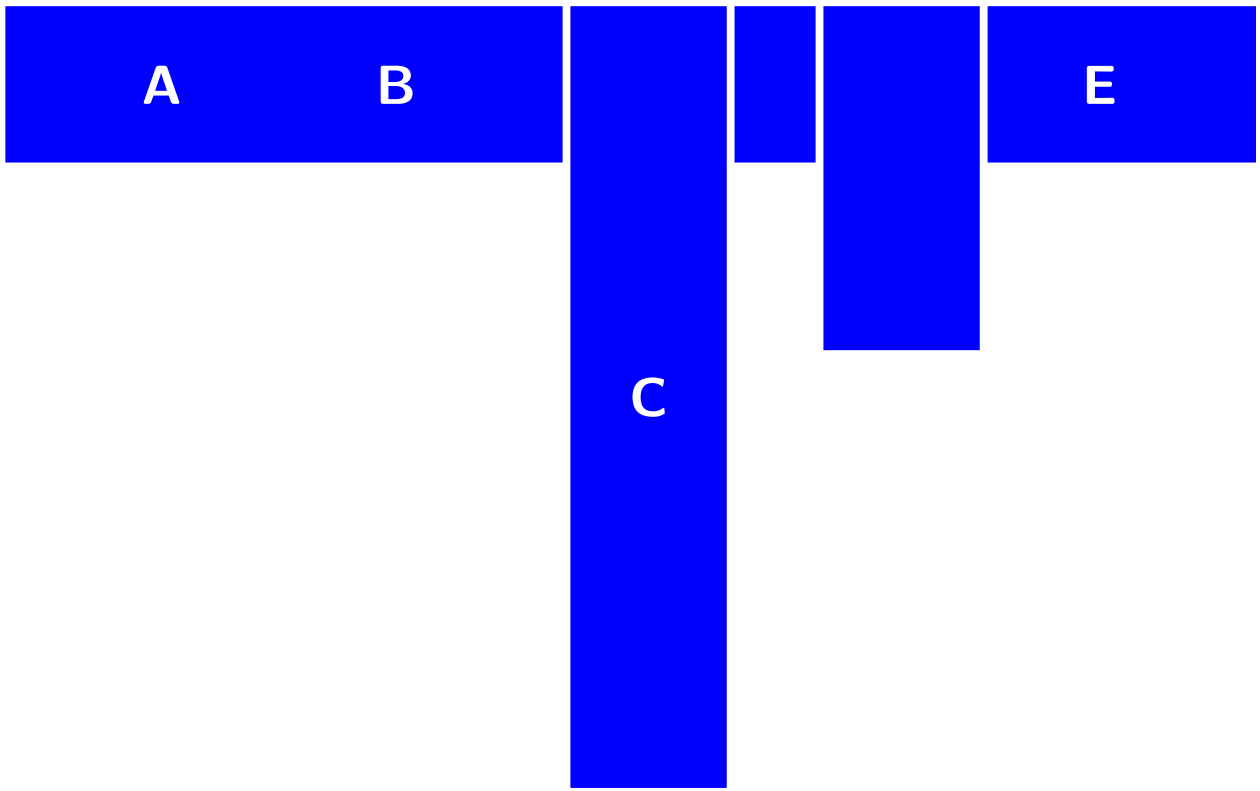
# Breadth Vs. Depth




Achieve depth in one area and overall breadth

Other areas can be understood on need basis relatively quickly

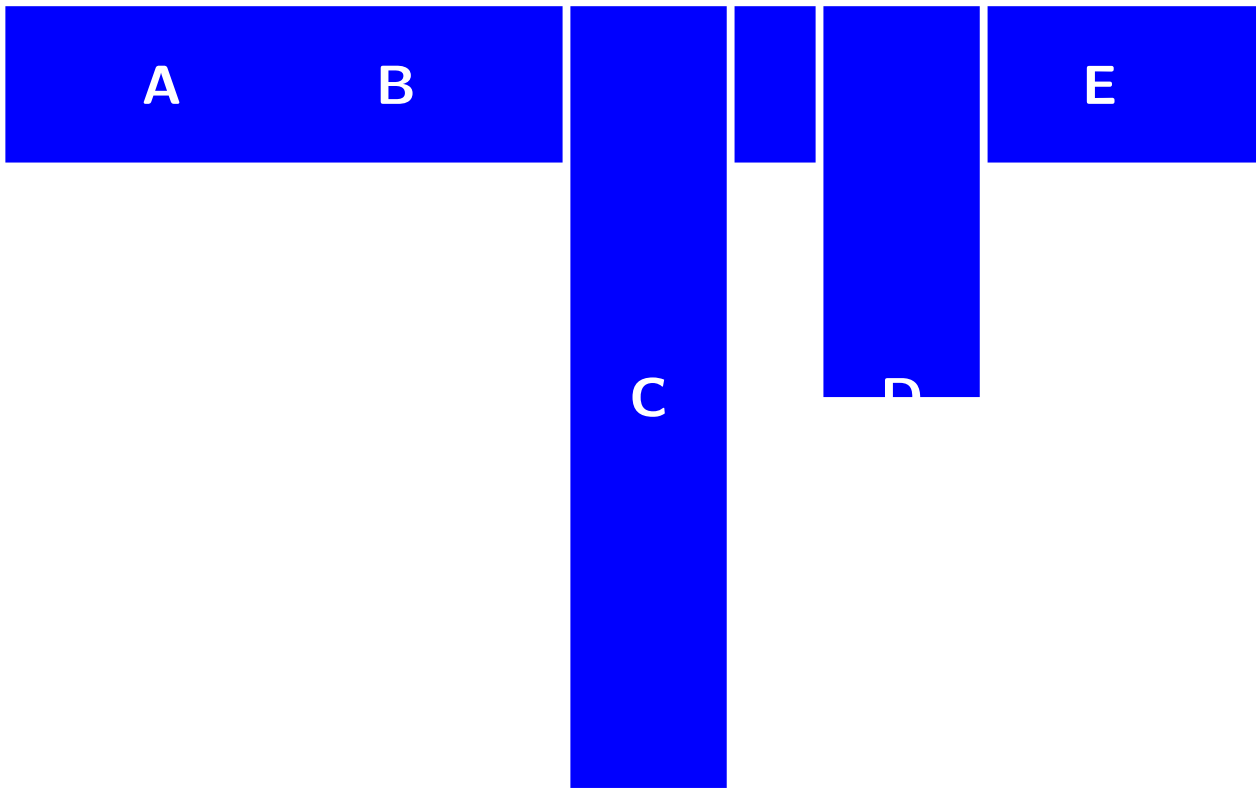
# Breadth Vs. Depth




Achieve depth in one area and overall breadth

Other areas can be understood on need basis relatively quickly

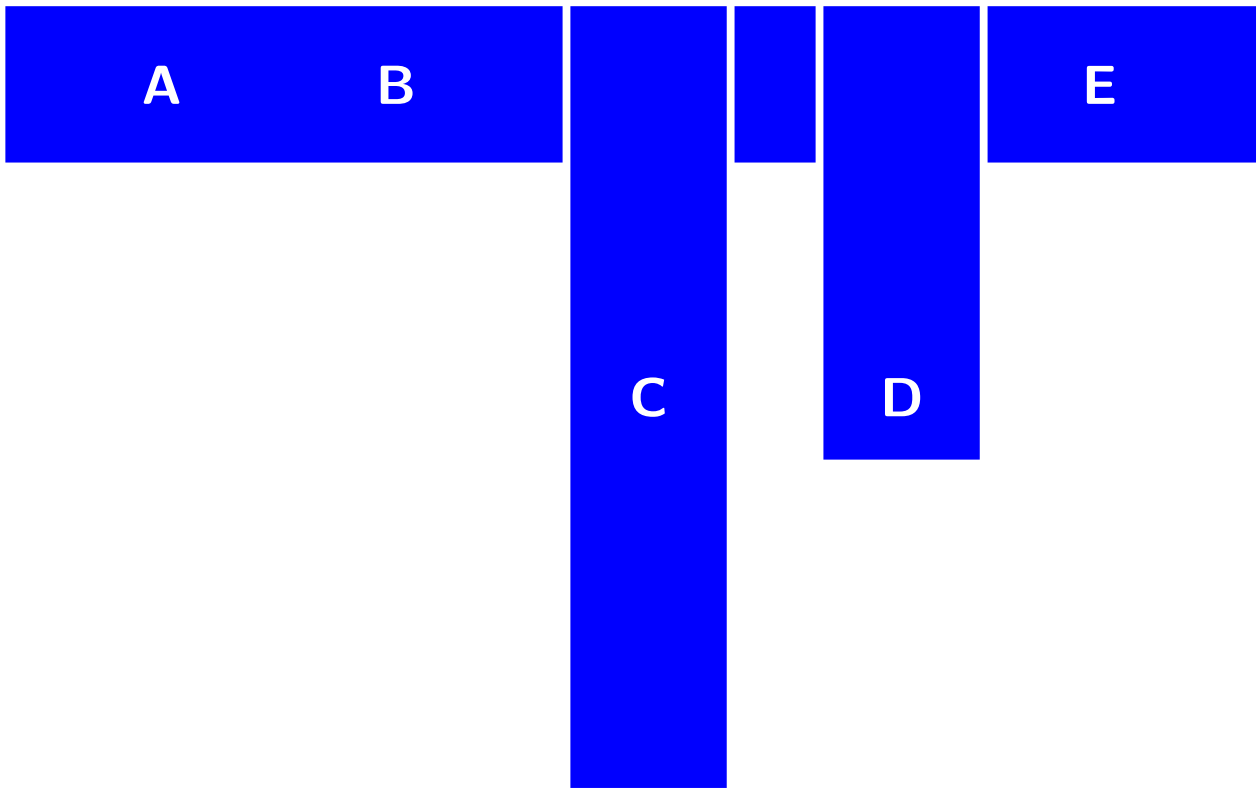
# Breadth Vs. Depth




Achieve depth in one area and overall breadth

Other areas can be understood on need basis relatively quickly

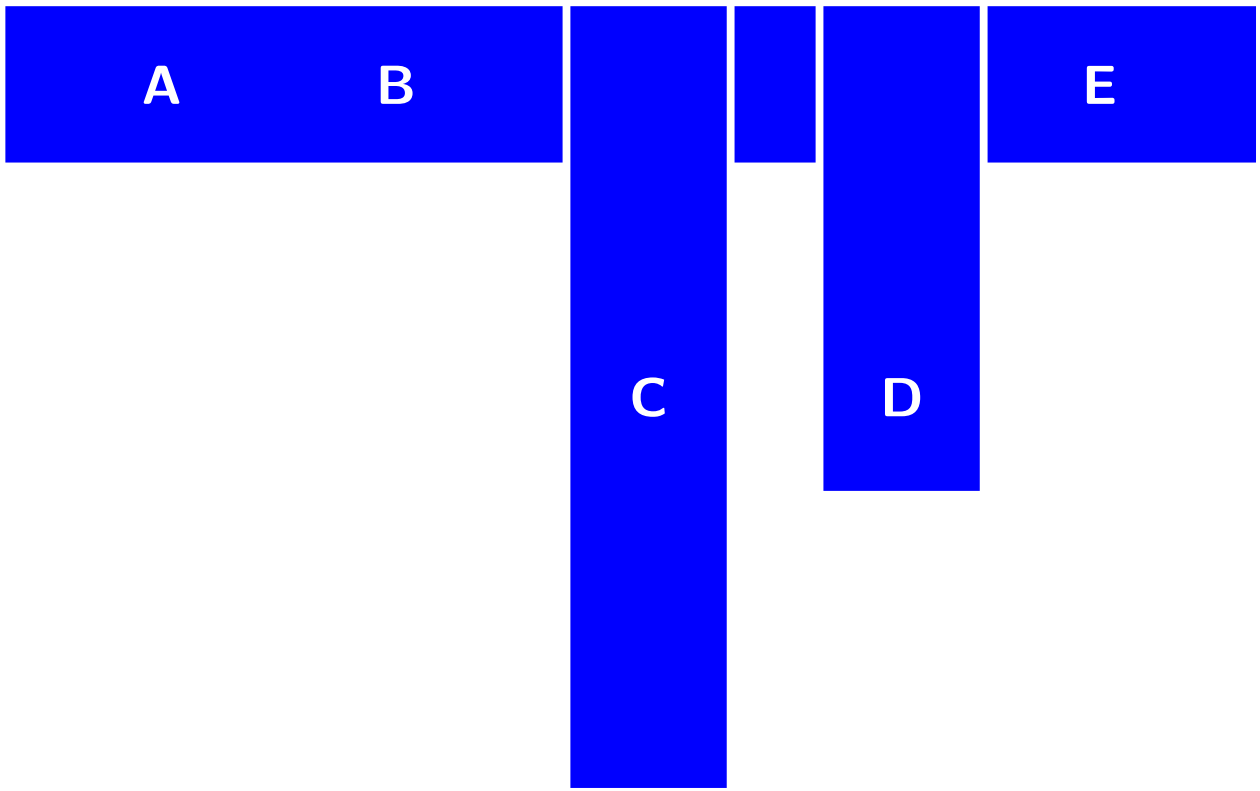
# Breadth Vs. Depth




Achieve depth in one area and overall breadth

Other areas can be understood on need basis relatively quickly

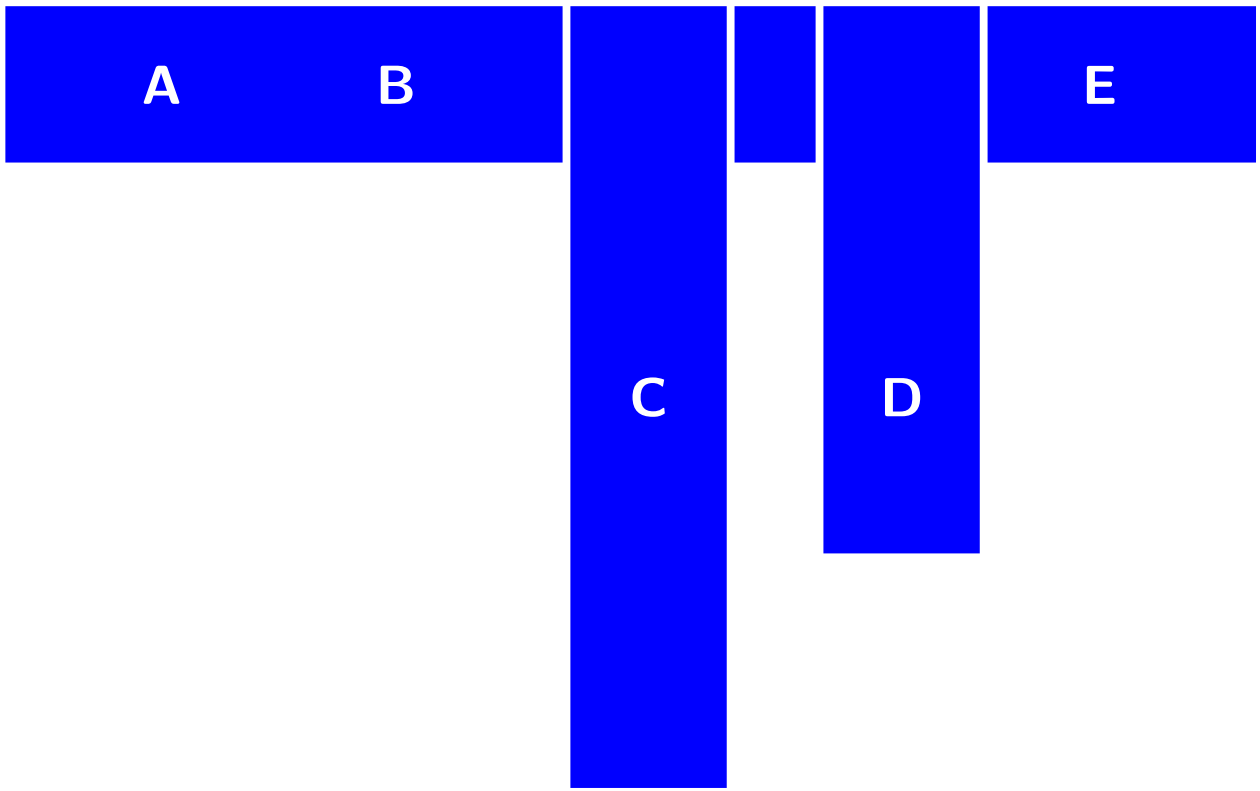
# Breadth Vs. Depth




Achieve depth in one area and overall breadth

Other areas can be understood on need basis relatively quickly

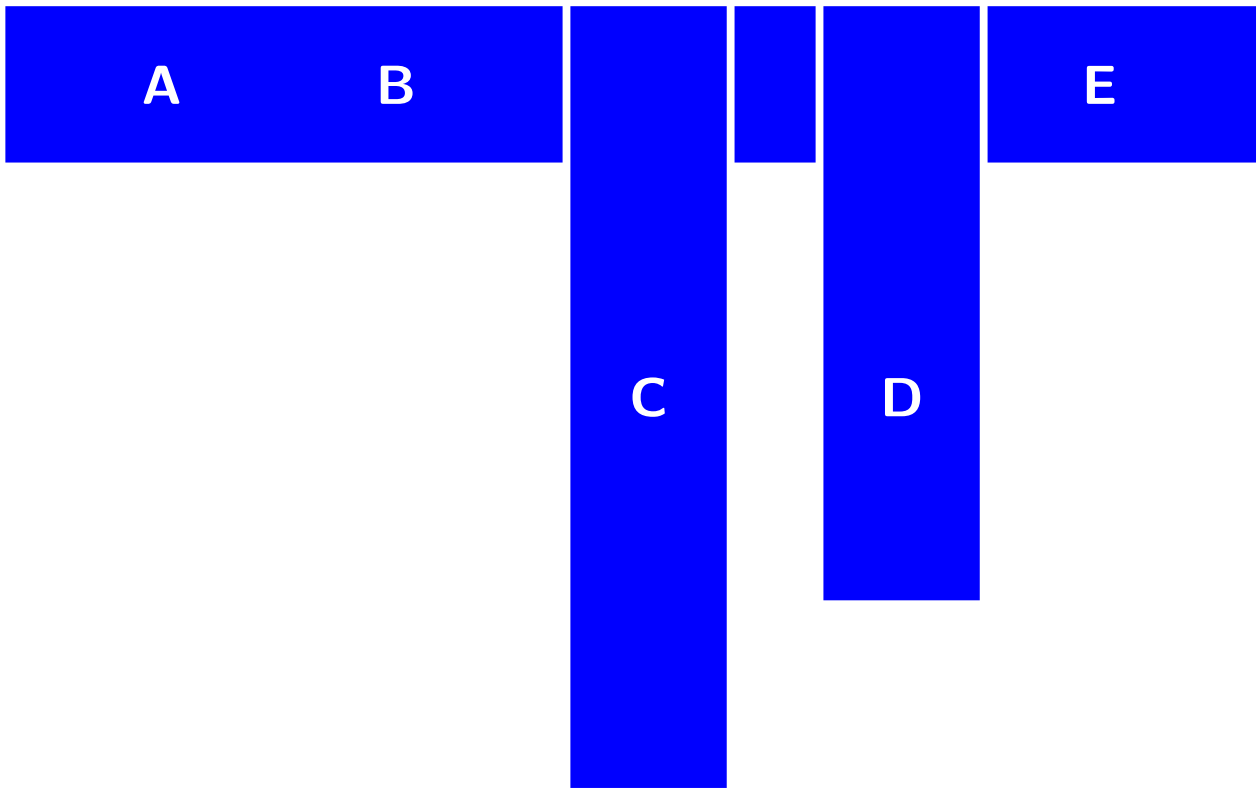
# Breadth Vs. Depth




Achieve depth in one area and overall breadth

Other areas can be understood on need basis relatively quickly

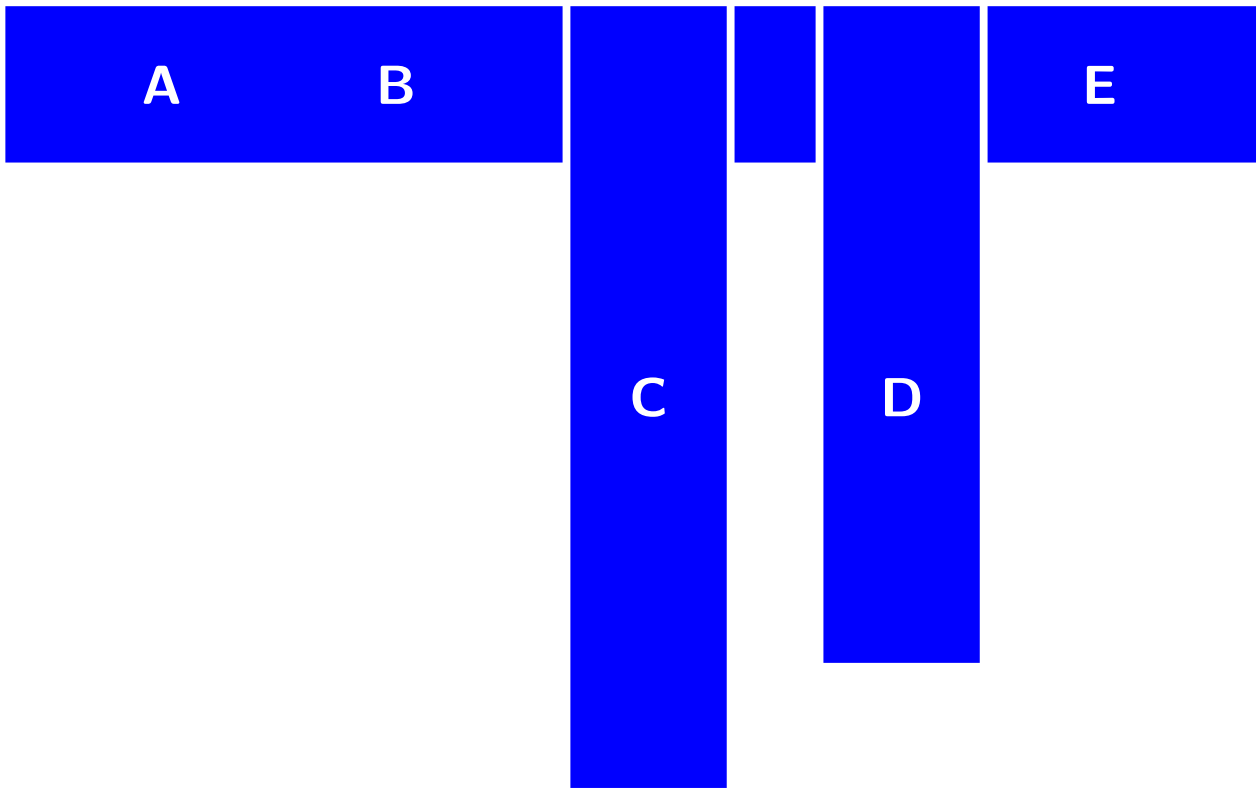
# Breadth Vs. Depth




Achieve depth in one area and overall breadth

Other areas can be understood on need basis relatively quickly

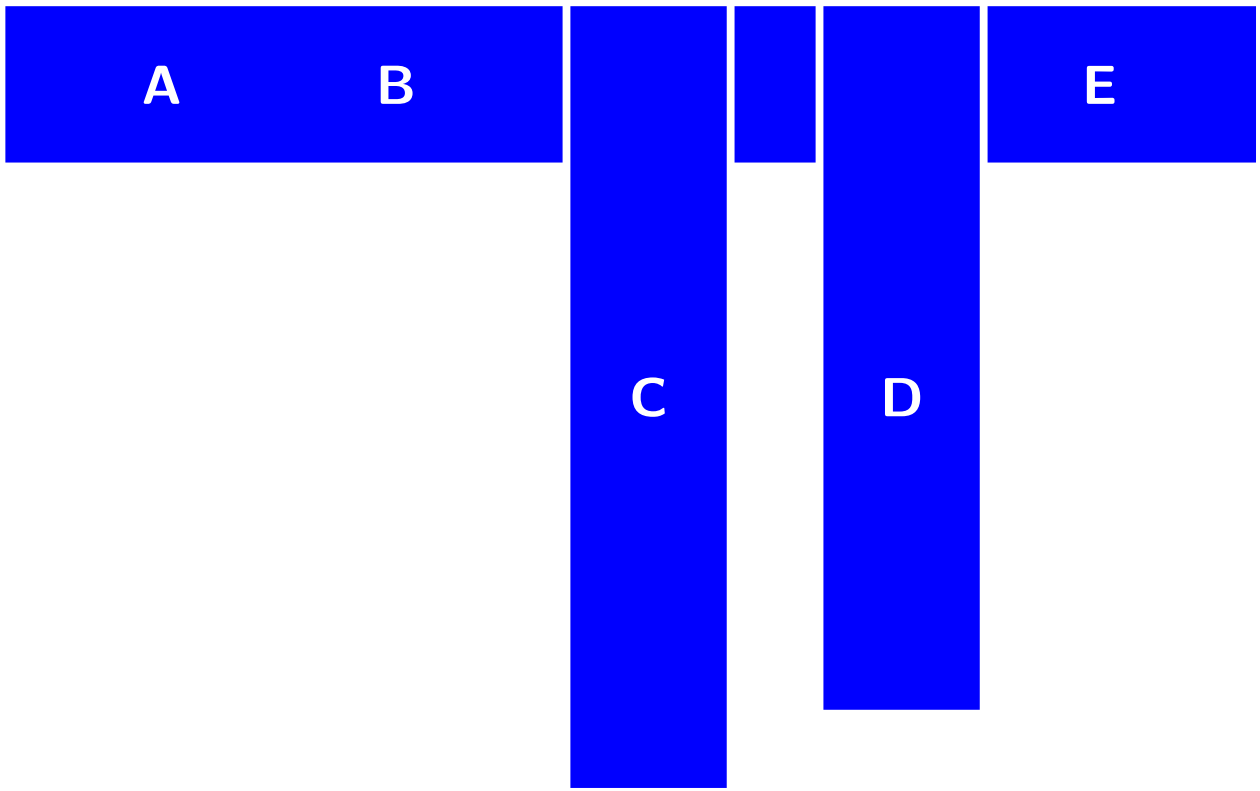
# Breadth Vs. Depth




Achieve depth in one area and overall breadth

Other areas can be understood on need basis relatively quickly

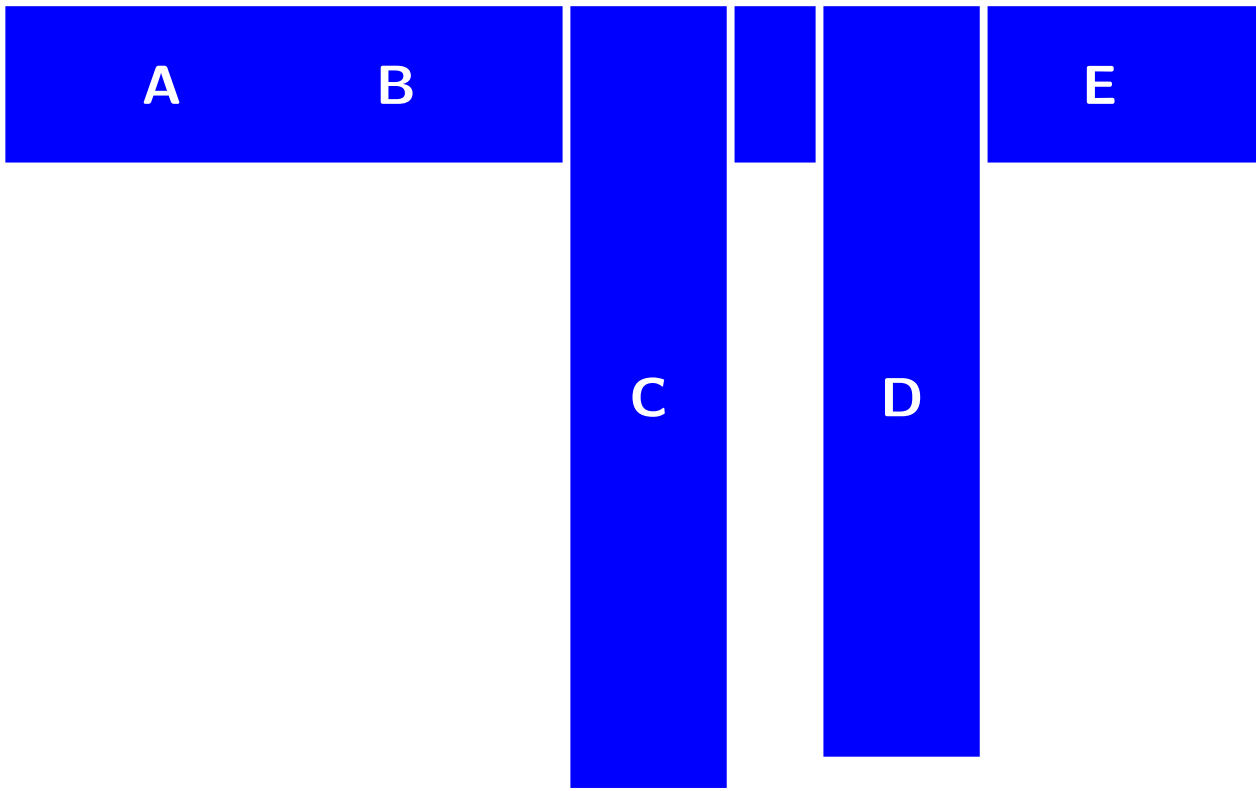
# Breadth Vs. Depth




Achieve depth in one area and overall breadth

Other areas can be understood on need basis relatively quickly

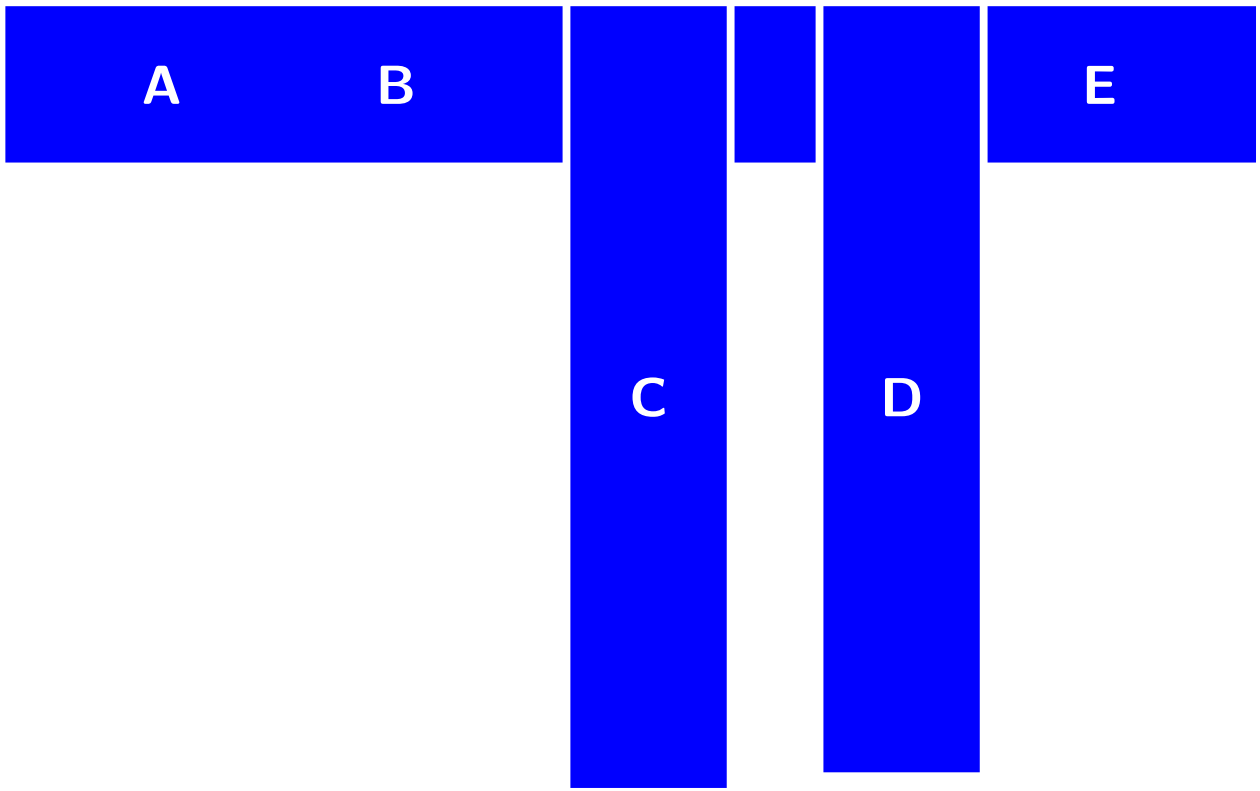
# Breadth Vs. Depth




Achieve depth in one area and overall breadth

Other areas can be understood on need basis relatively quickly

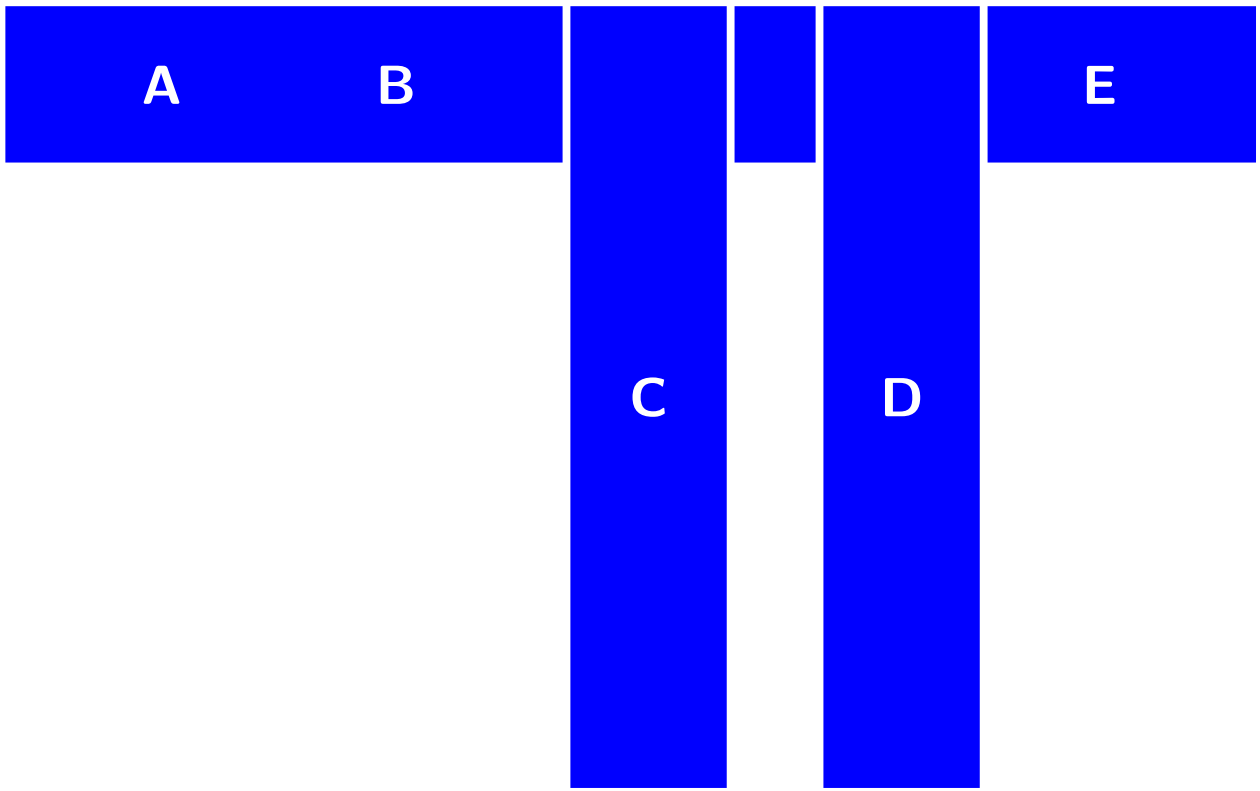
# Breadth Vs. Depth




Achieve depth in one area and overall breadth

Other areas can be understood on need basis relatively quickly

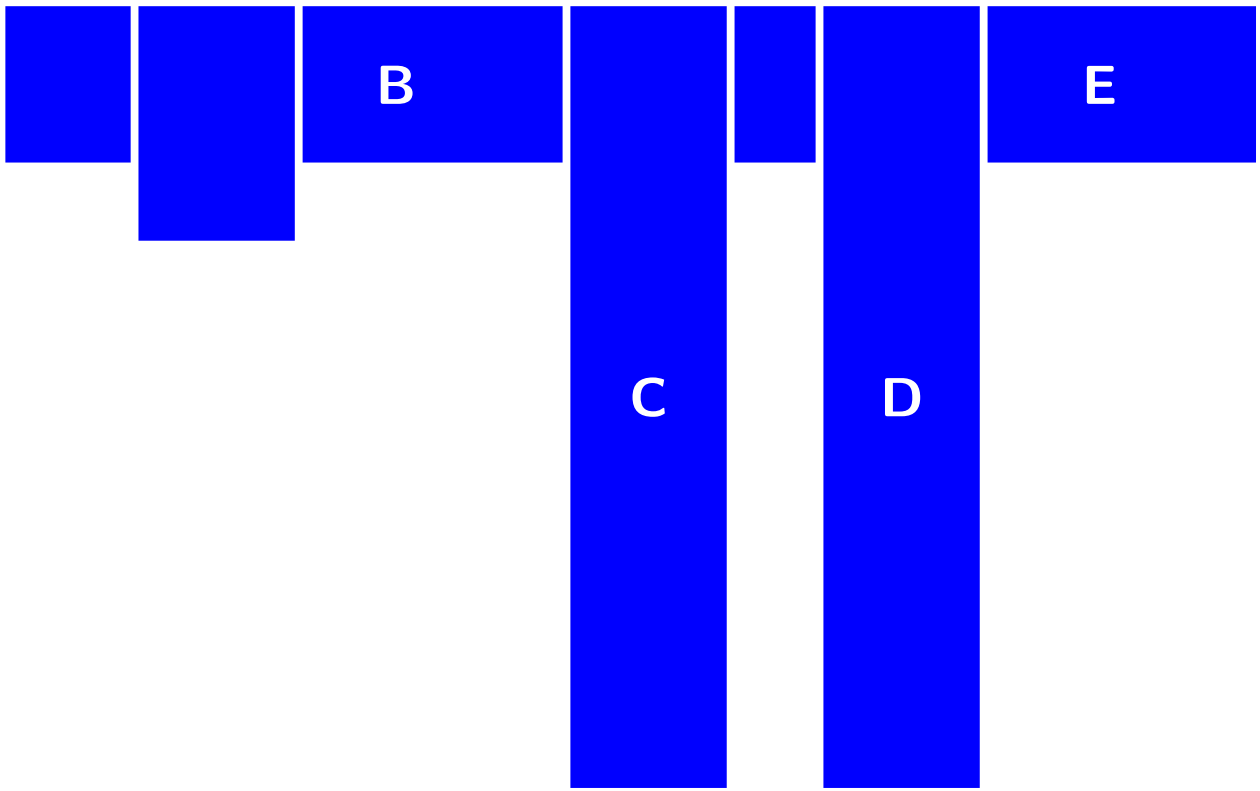
# Breadth Vs. Depth




Achieve depth in one area and overall breadth

Other areas can be understood on need basis relatively quickly

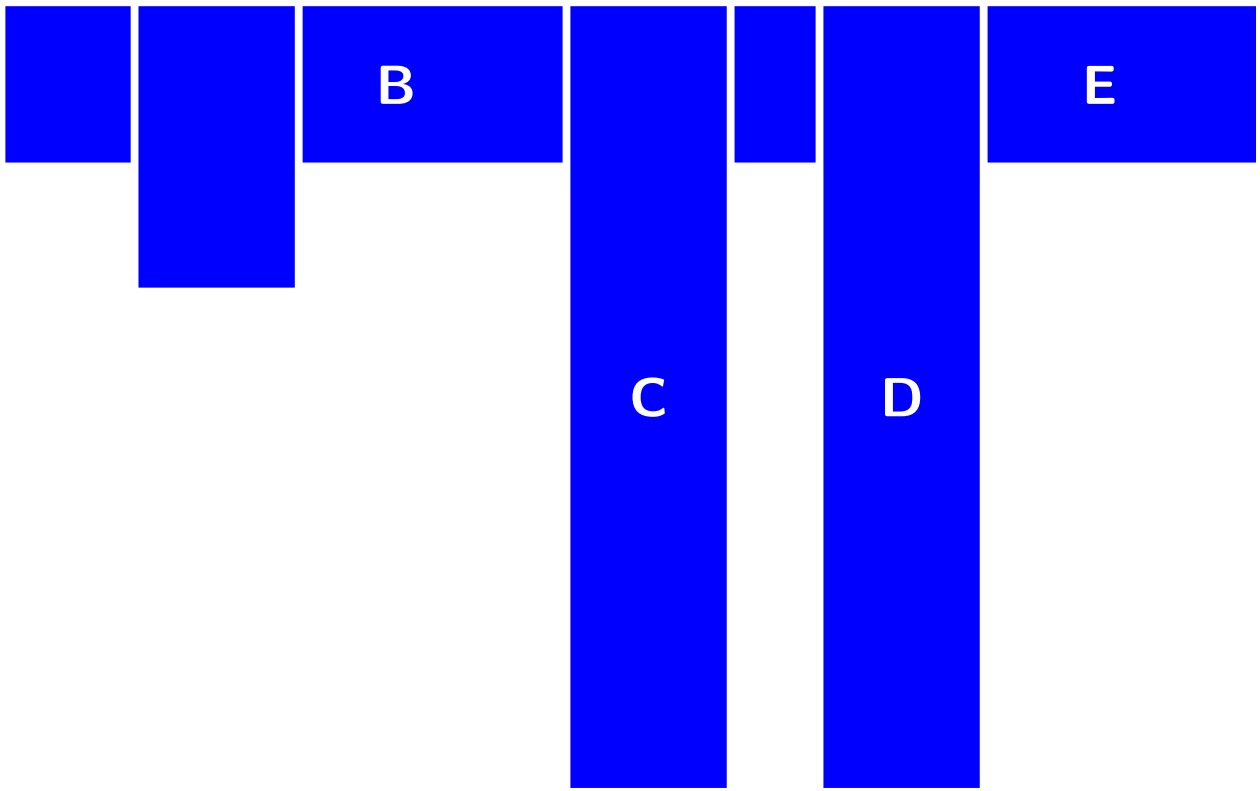
# Breadth Vs. Depth




Achieve depth in one area and overall breadth

Other areas can be understood on need basis relatively quickly

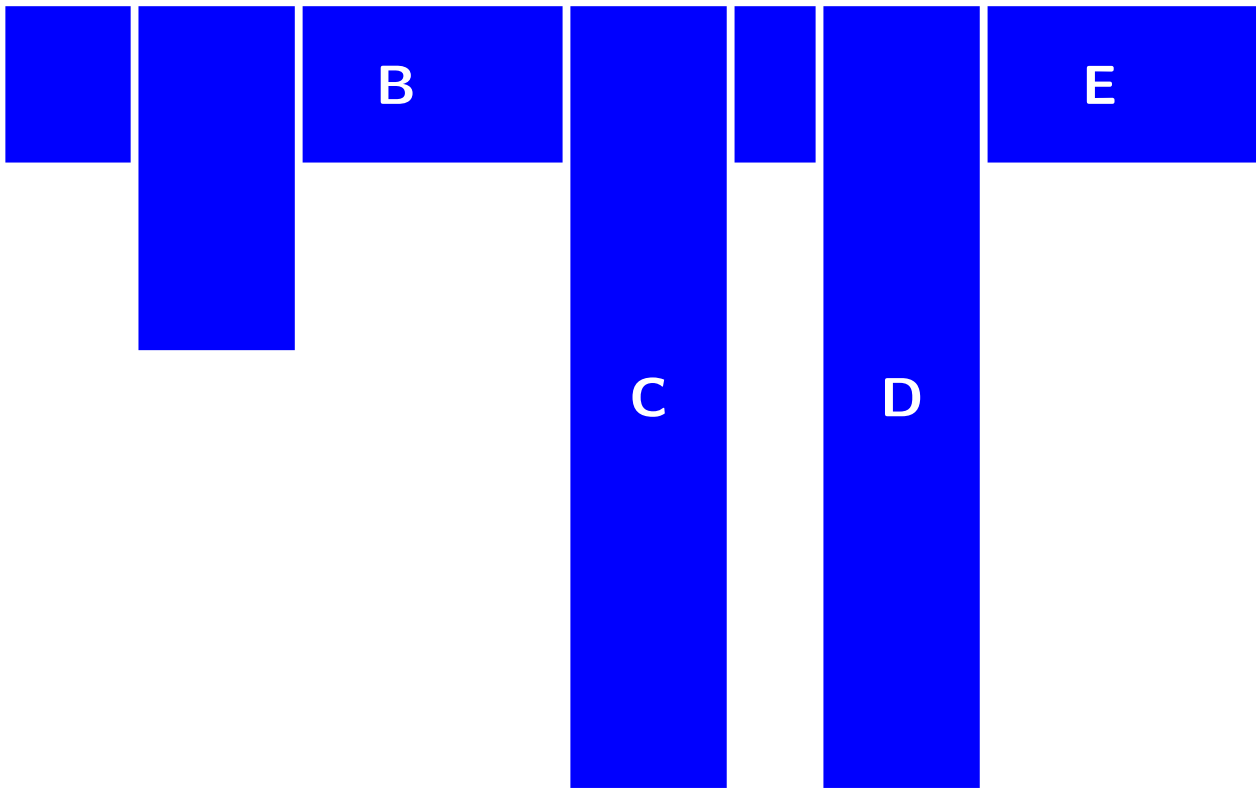
# Breadth Vs. Depth




Achieve depth in one area and overall breadth

Other areas can be understood on need basis relatively quickly

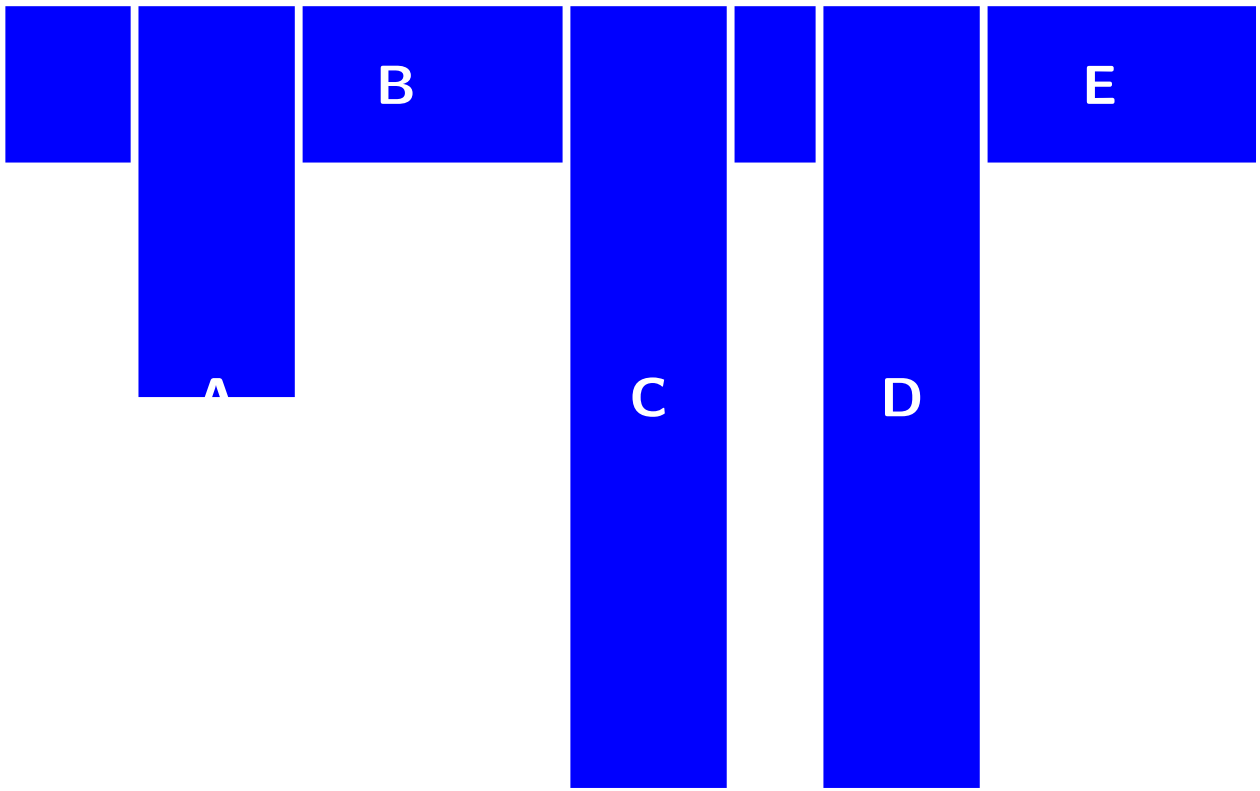
# Breadth Vs. Depth




Achieve depth in one area and overall breadth

Other areas can be understood on need basis relatively quickly

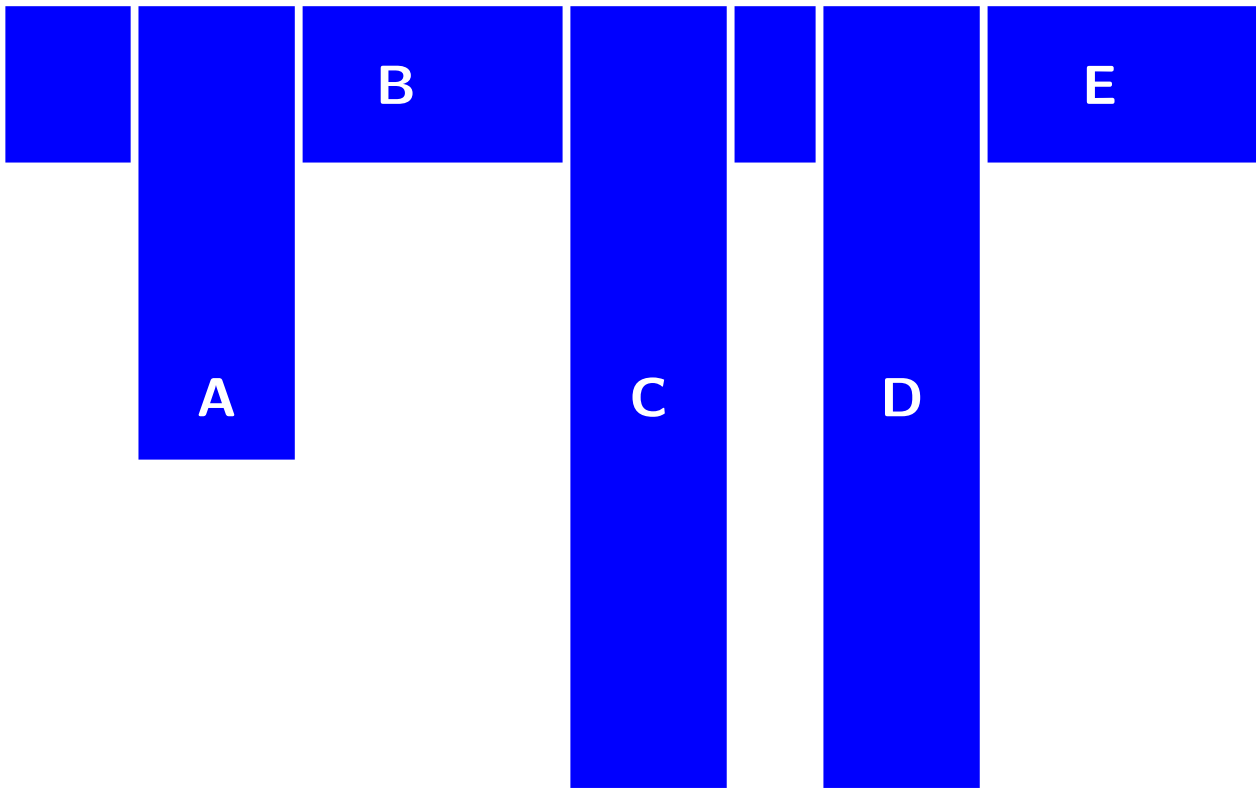
# Breadth Vs. Depth




Achieve depth in one area and overall breadth

Other areas can be understood on need basis relatively quickly

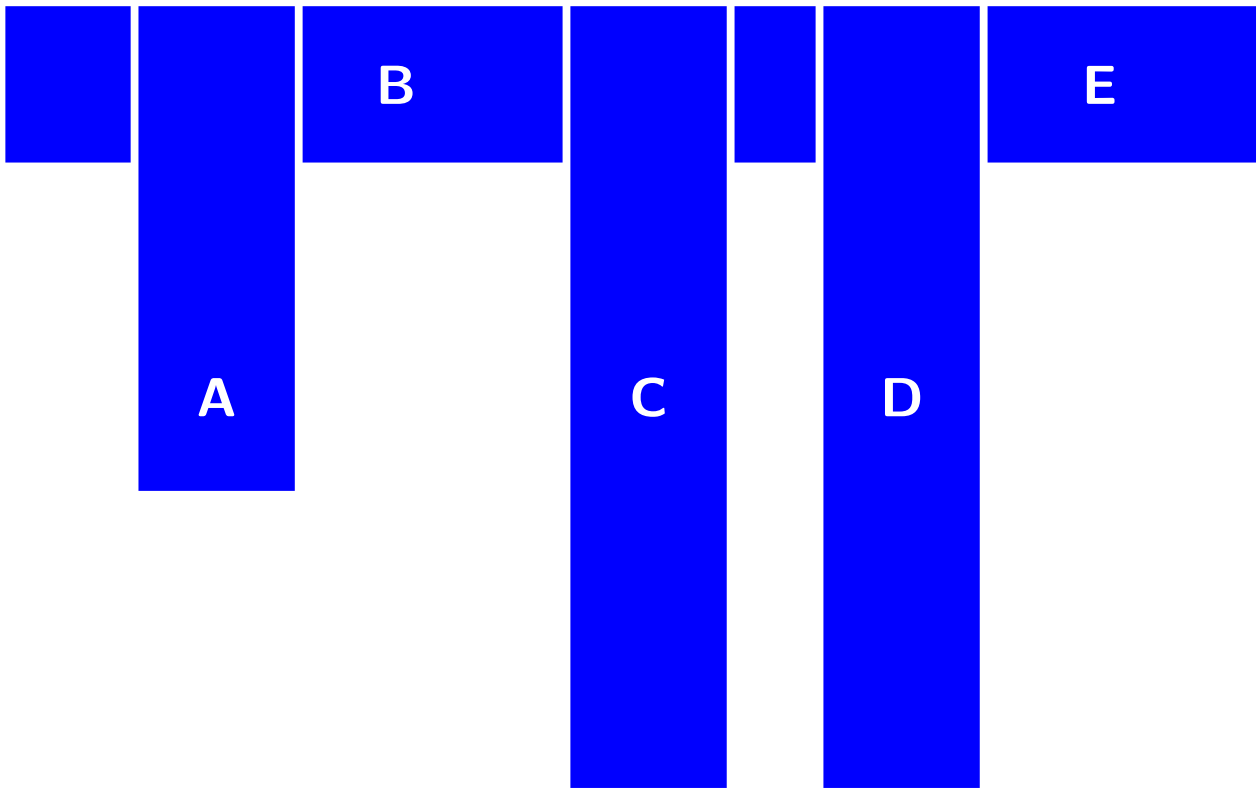
# Breadth Vs. Depth




Achieve depth in one area and overall breadth

Other areas can be understood on need basis relatively quickly

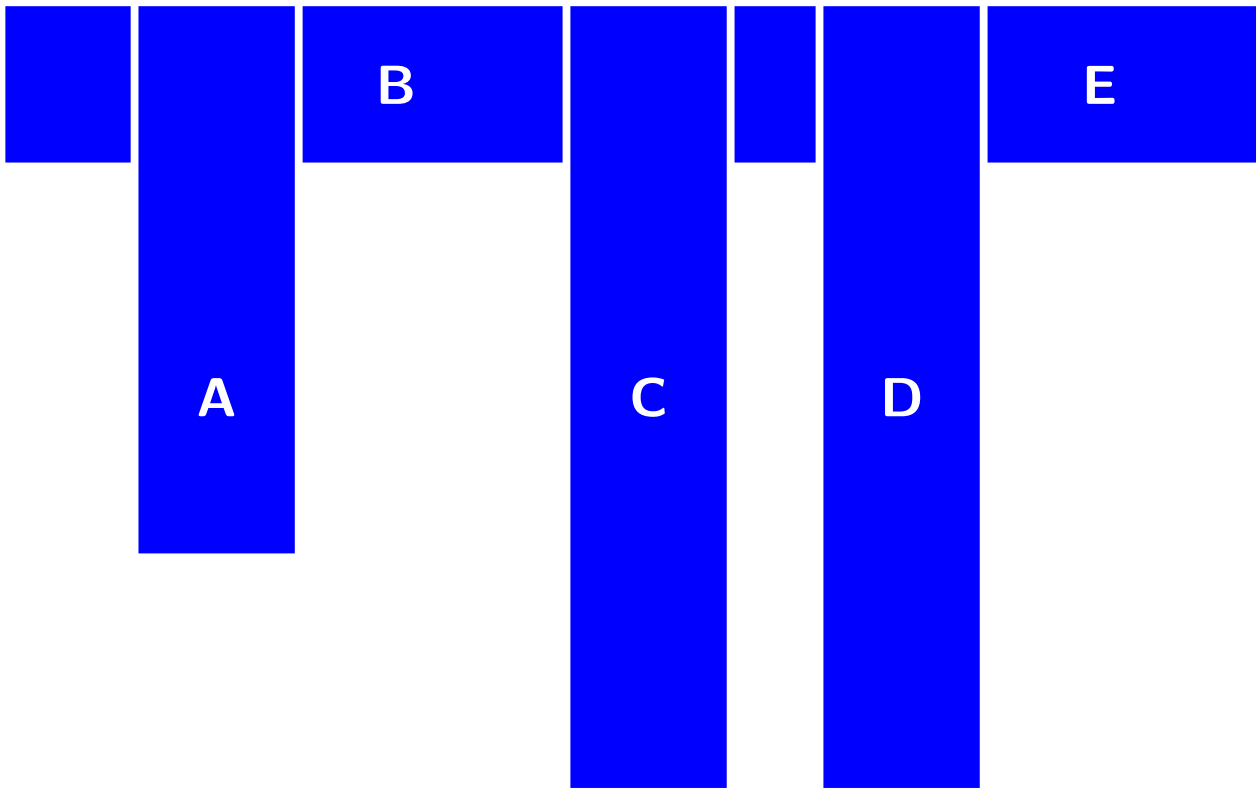
# Breadth Vs. Depth




Achieve depth in one area and overall breadth

Other areas can be understood on need basis relatively quickly

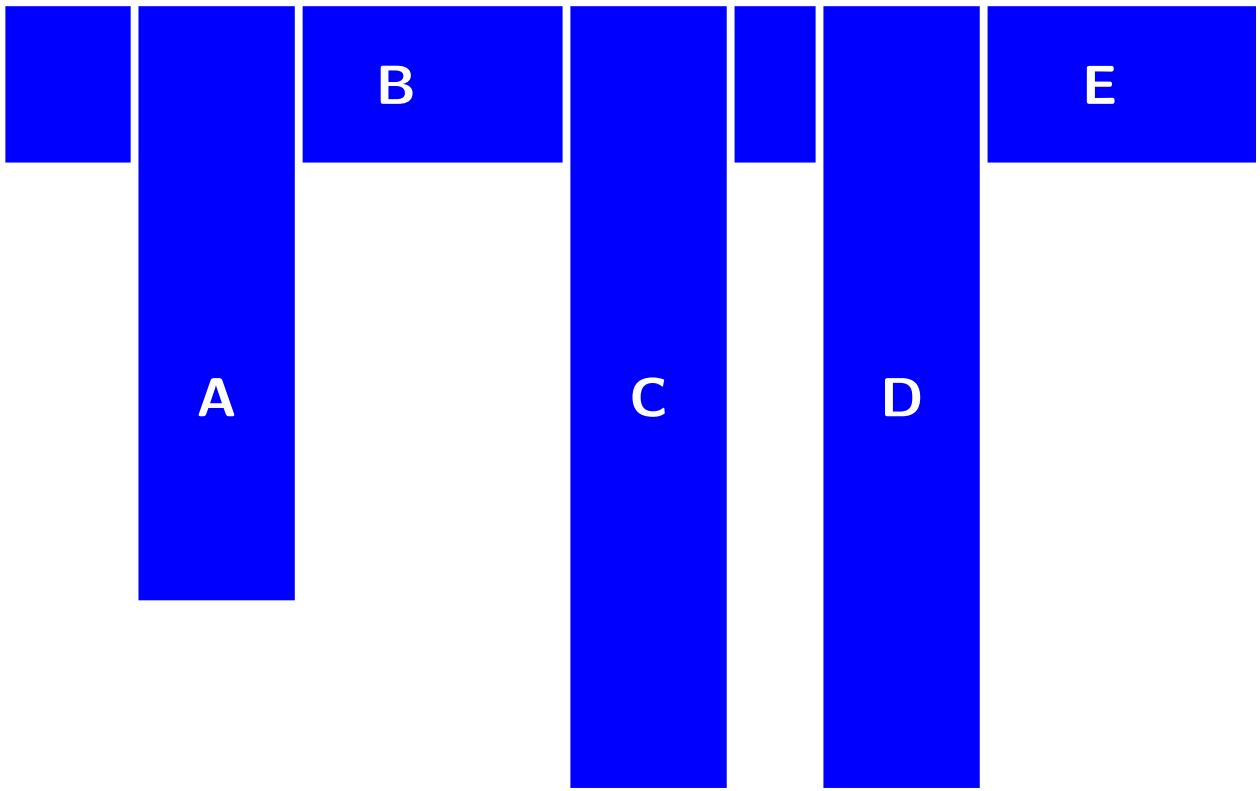
# Breadth Vs. Depth




Achieve depth in one area and overall breadth

Other areas can be understood on need basis relatively quickly

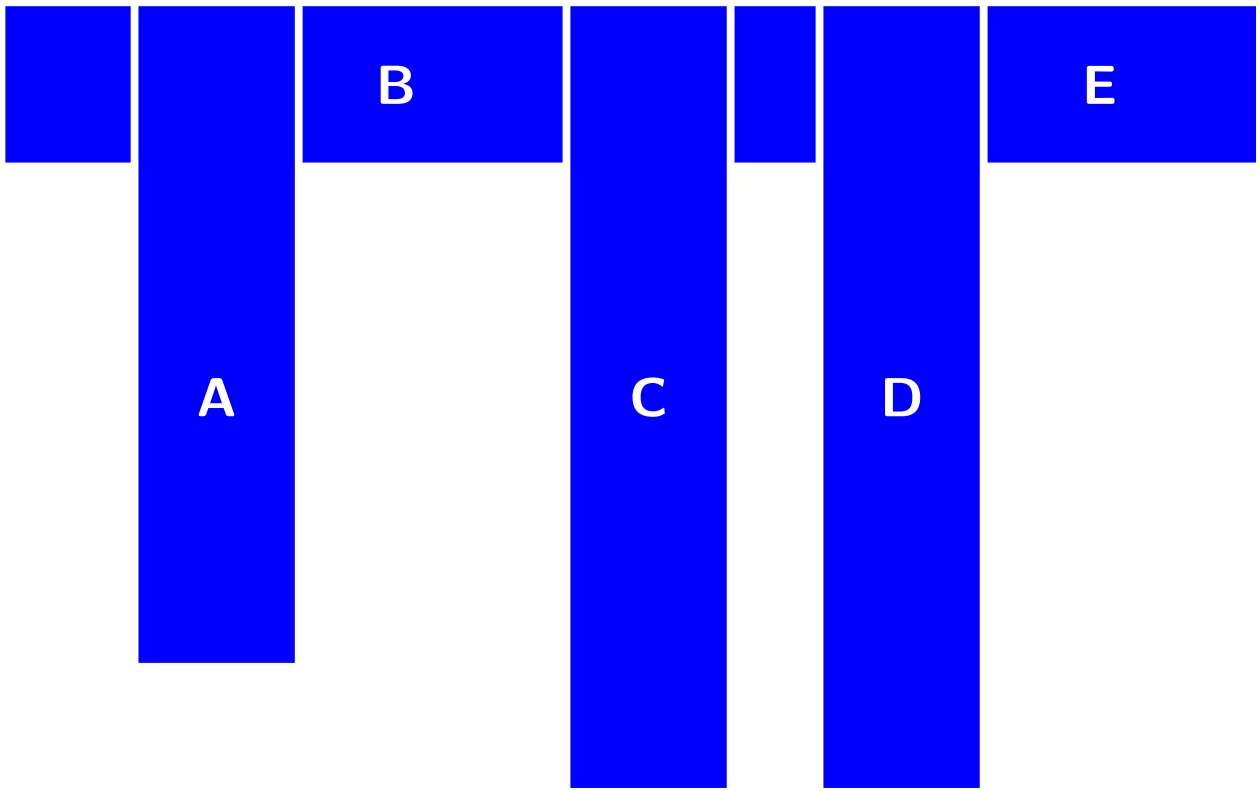
# Breadth Vs. Depth




Achieve depth in one area and overall breadth

Other areas can be understood on need basis relatively quickly

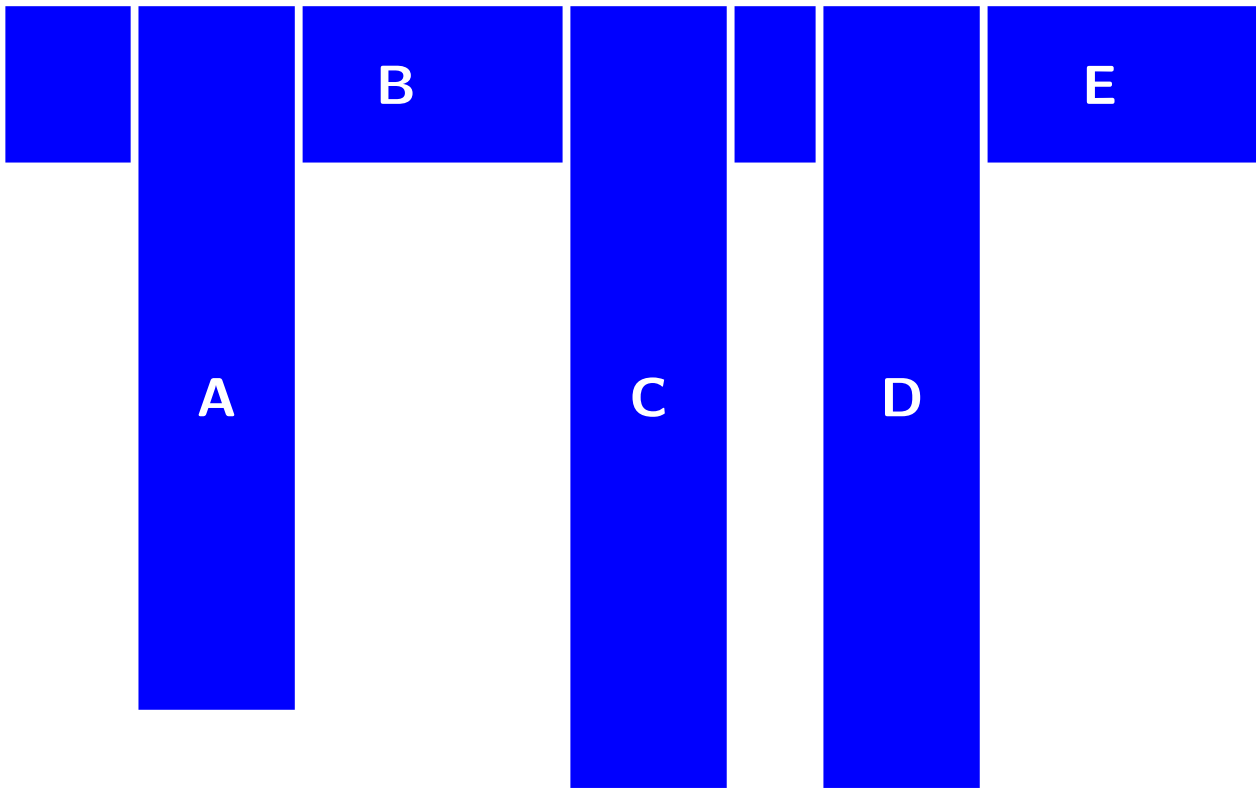
# Breadth Vs. Depth




Achieve depth in one area and overall breadth

Other areas can be understood on need basis relatively quickly

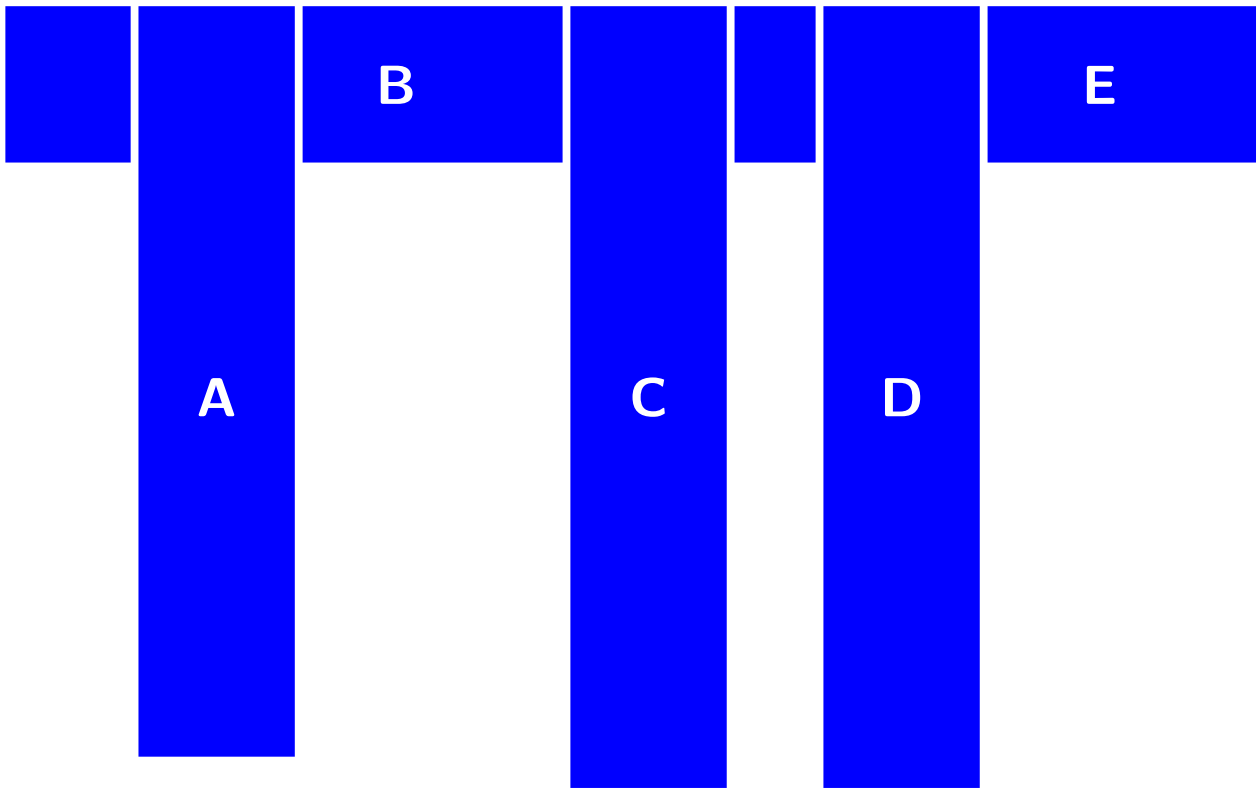
# Breadth Vs. Depth




Achieve depth in one area and overall breadth

Other areas can be understood on need basis relatively quickly

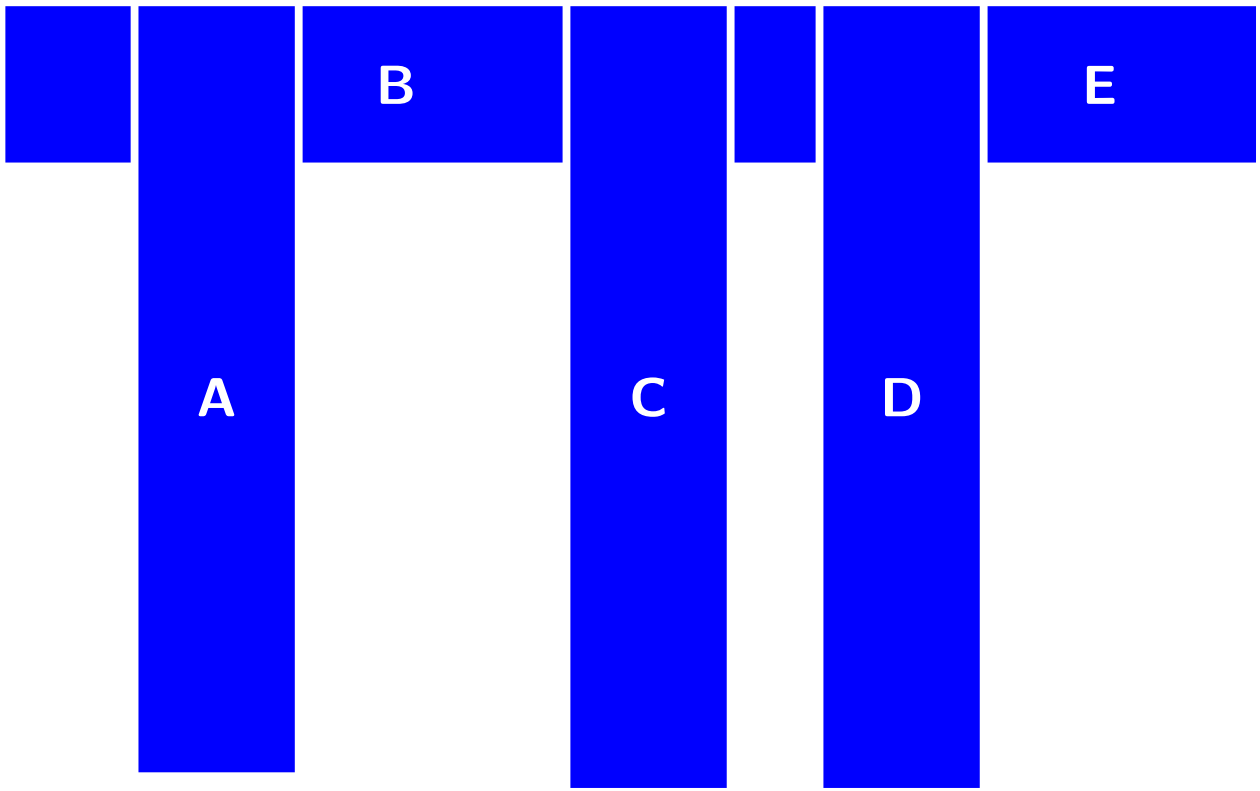
# Breadth Vs. Depth




Achieve depth in one area and overall breadth

Other areas can be understood on need basis relatively quickly

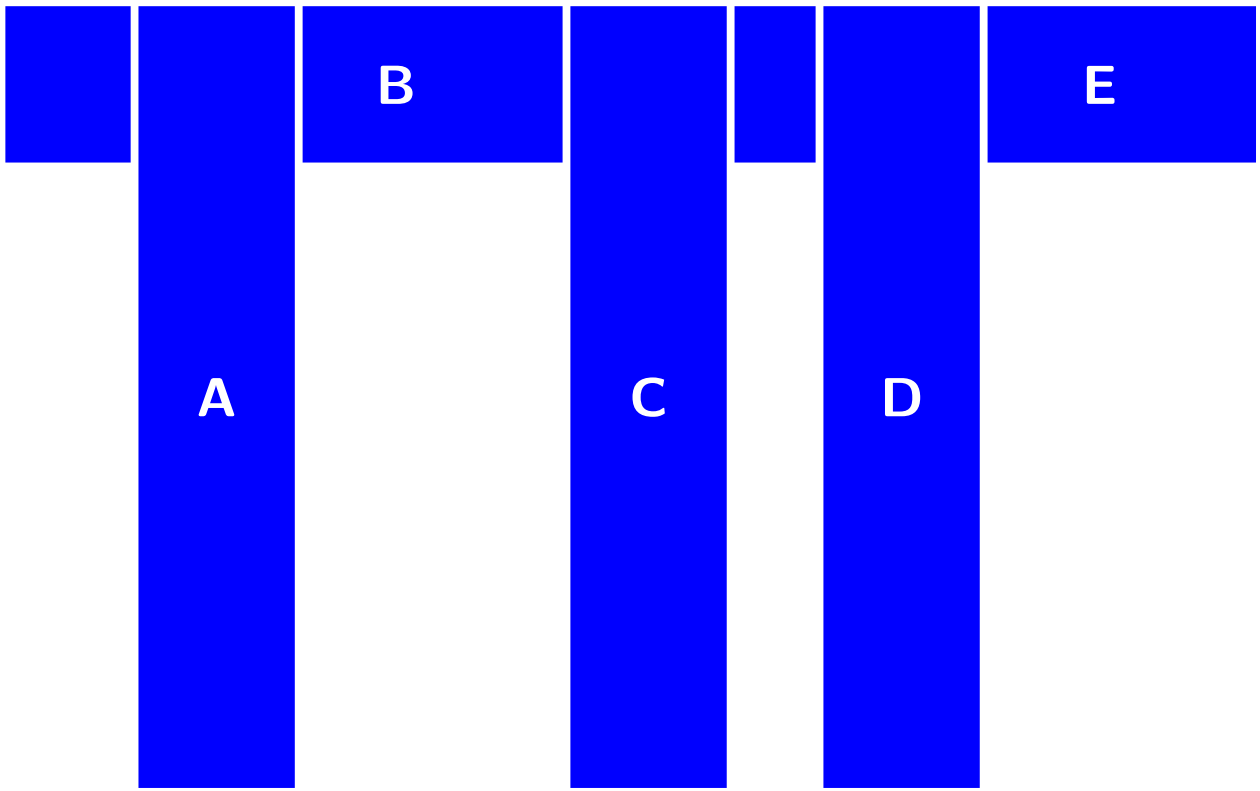
# Breadth Vs. Depth




Achieve depth in one area and overall breadth

Other areas can be understood on need basis relatively quickly

# Breadth Vs. Depth




Achieve depth in one area and overall breadth

Other areas can be understood on need basis relatively quickly

# Ability to Abstract and Modularize

- Different levels of abstraction and different granularities of modularization

  Example : Describing a car to

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

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



# From Confusion to Conviction

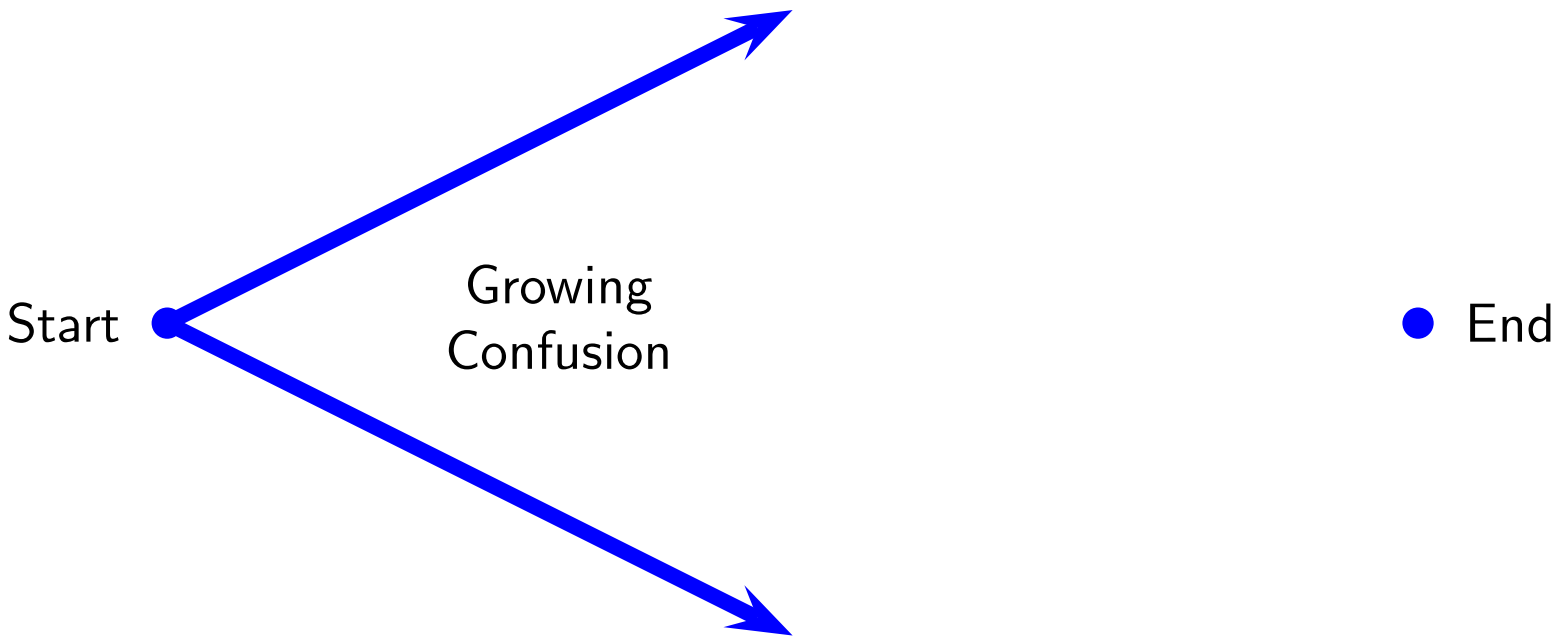
Start ● ● End

# From Confusion to Conviction

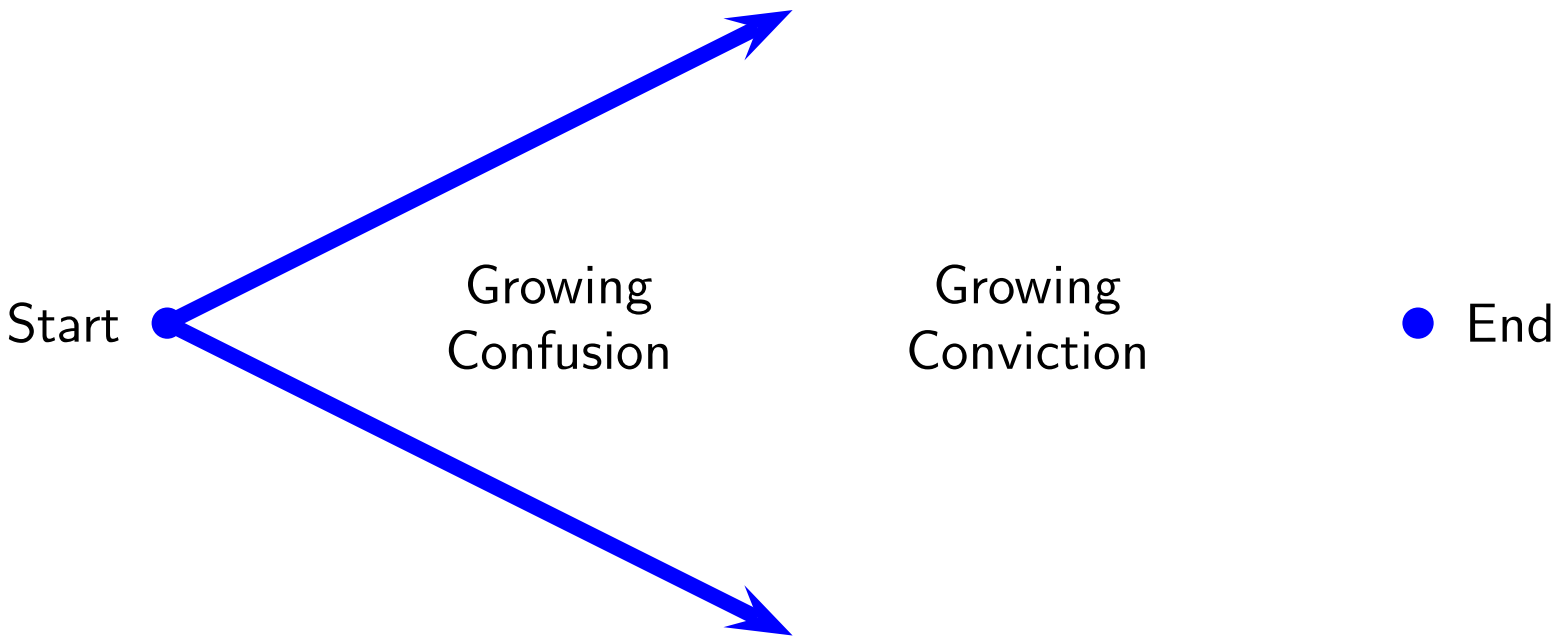
Start ● Growing Confusion ● End



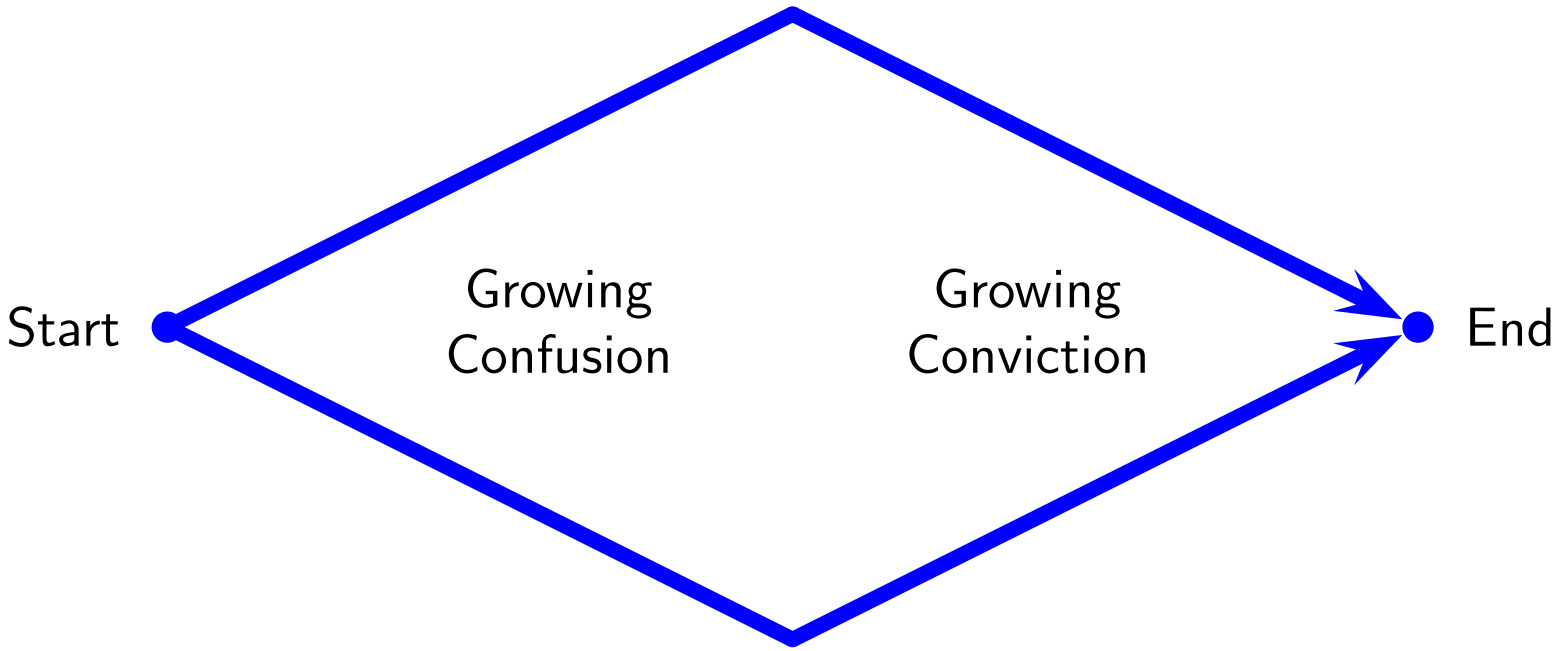
# From Confusion to Conviction



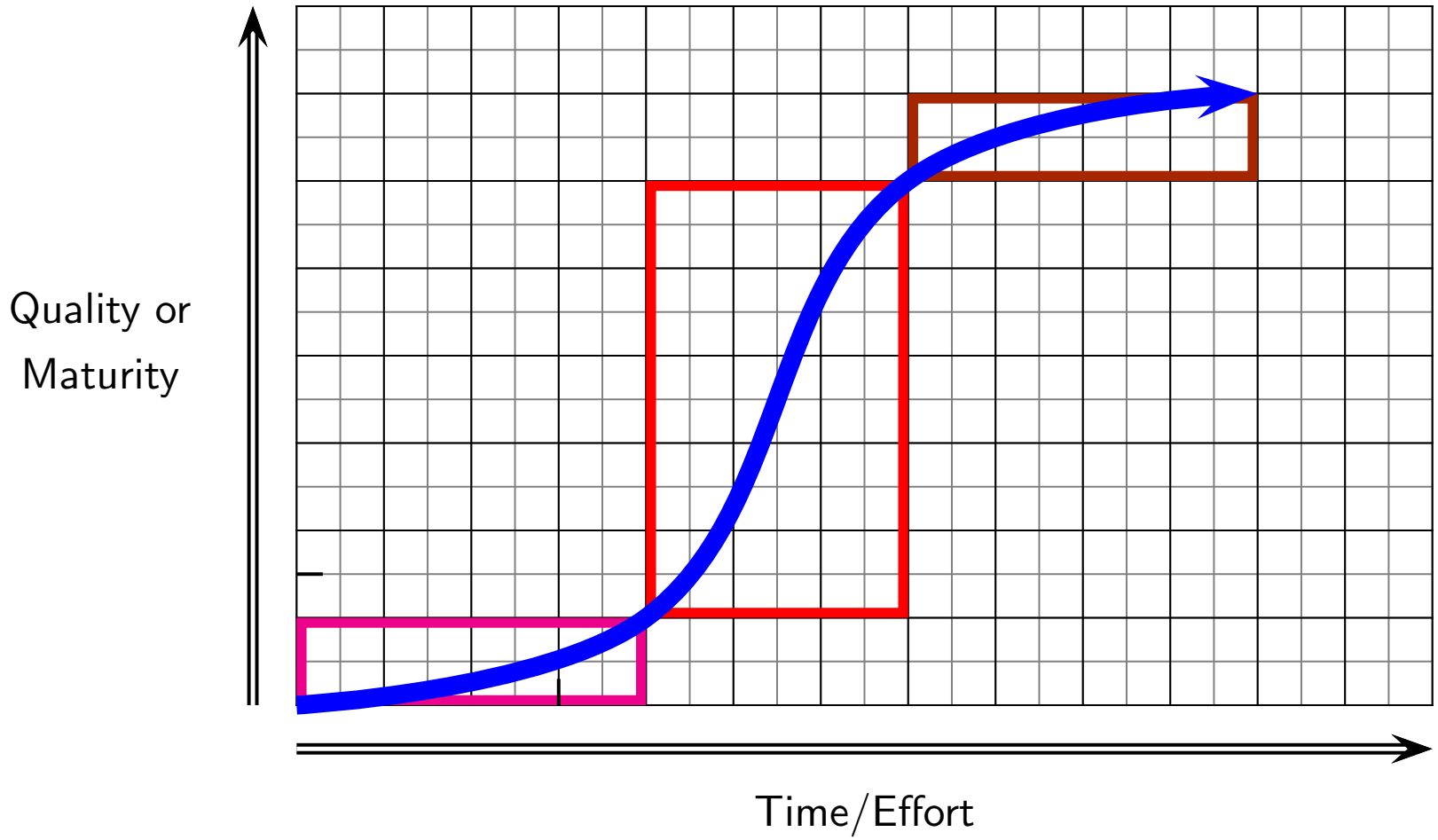
# From Confusion to Conviction



# From Confusion to Conviction



# 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



# 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
- Industry
  - Needs to combine results of many idea driven research efforts

# 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
- Industry
  - Needs to combine results of many idea driven research efforts
  - Faces the challenge of deployment much more significantly



# 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
- Industry
  - Needs to combine results of many idea driven research efforts
  - Faces the challenge of deployment much more significantly
  - Focus on an independent idea may be an unaffordable luxury



# 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
- Industry
  - Needs to combine results of many idea driven research efforts
  - Faces the challenge of deployment much more significantly
  - Focus on an independent idea may be an unaffordable luxury
- Research in academia
  - Typically not bound by a particular product



# 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
- Industry
  - Needs to combine results of many idea driven research efforts
  - Faces the challenge of deployment much more significantly
  - Focus on an independent idea may be an unaffordable luxury
- Research in academia
  - Typically not bound by a particular product
  - Can afford to focus on ideas exclusively



# 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
- Industry
  - Needs to combine results of many idea driven research efforts
  - Faces the challenge of deployment much more significantly
  - Focus on an independent idea may be an unaffordable luxury
- Research in academia
  - Typically not bound by a particular product
  - Can afford to focus on ideas exclusively
  - Can have longer gestation periods



# 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
- Industry
  - Needs to combine results of many idea driven research efforts
  - Faces the challenge of deployment much more significantly
  - Focus on an independent idea may be an unaffordable luxury
- Research in academia
  - Typically not bound by a particular product
  - Can afford to focus on ideas exclusively
  - Can have longer gestation periods

  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 that those who have great skill and dabble in it, who work during the day and go home and do other things and come back and work the next day. They don't have the deep commitment that is apparently necessary for really first-class work. "

# On the Role of Commitment and Creativity in Research

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

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

# Committment, Hard Work, and Preparation Enhance Creativity

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

# What Does it Take to Be a Researcher?

- What we all may already possess

  Motivation, Curiosity, Creativity, Perseverance, Good Grasp

# What Does it Take to Be a Researcher?

- What we all may already possess

  Motivation, Curiosity, Creativity, Perseverance, Good Grasp

- What we may have to acquire with effort

# What Does it Take to Be a Researcher?

- What we all may already possess

  Motivation, Curiosity, Creativity, Perseverance, Good Grasp

- What we may have to acquire with effort

  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?

# Why Do People Do Research?

Why do mountaineers climb mountains?

# Why Do People Do Research?

Why do mountaineers climb mountains?

- Money? Fame? Power? Security?

# Why Do People Do Research?

Why do mountaineers climb mountains?

- Money? Fame? Power? Security?

  Reply by a mountaineer: Because mountains exist

# Why Do People Do Research?

Why do mountaineers climb mountains?

- Money? Fame? Power? Security?
  Reply by a mountaineer: Because mountains exist
- Test of mental and physical endurance

# Why Do People Do Research?

Why do mountaineers climb mountains?

- Money? Fame? Power? Security?
  Reply by a mountaineer: Because mountains exist
- Test of mental and physical endurance
- The real reward?

# Why Do People Do Research?

Why do mountaineers climb mountains?

- Money? Fame? Power? Security?
  Reply by a mountaineer: Because mountains exist
- Test of mental and physical endurance
- The real reward?
  An unforgettable experience of nature in its purest form

# Why Do People Do Research?

- Research is a test of intellectual agility and endurance
- The reward?

# Why Do People Do Research?

- Research is a test of intellectual agility and endurance
- The reward?

  An experience of the beauty of knowledge in its purest form

# Why Do People Do Research?

- Research is a test of intellectual agility and endurance
- The reward?

  An experience of the beauty of knowledge in its purest form

Research takes us to a different state of mind!



# How is Research Different from Problem Solving?

- Solving intellectually challenging problems

# How is Research Different from Problem Solving?

- Solving intellectually challenging problems
  - Also requires creativity, perseverance, intellectual endurance etc.
  - Also creates a good learning experience

# How is Research Different from Problem Solving?

- Solving intellectually challenging problems
  - Also requires creativity, perseverance, intellectual endurance etc.
  - Also creates a good learning experience
- However, the questions addressed may not be new

  (May be new to the person but not to some others)

# How is Research Different from Problem Solving?

- Solving intellectually challenging problems
  - Also requires creativity, perseverance, intellectual endurance etc.
  - Also creates a good learning experience
- However, the questions addressed may not be new

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

  (Or have not been addressed adequately before)

# The Ten Commandments of Creativity in Research

1. Adapt. Seek extension of an earlier known solution



# The Ten Commandments of Creativity in Research

1. Adapt. Seek extension of an earlier known solution
2. If you have a solution, find a problem

# The Ten Commandments of Creativity in Research

1. Adapt. Seek extension of an earlier known solution
2. If you have a solution, find a problem
3. Let slow hunch simmer in your mind

# The Ten Commandments of Creativity in Research

1. Adapt. Seek extension of an earlier known solution
2. If you have a solution, find a problem
3. Let slow hunch simmer in your mind
4. Find out the right questions to ask

# The Ten Commandments of Creativity in Research

1. Adapt. Seek extension of an earlier known solution
2. If you have a solution, find a problem
3. Let slow hunch simmer in your mind
4. Find out the right questions to ask
5. Seek generality by removing specificities

# The Ten Commandments of Creativity in Research

1. Adapt. Seek extension of an earlier known solution
2. If you have a solution, find a problem
3. Let slow hunch simmer in your mind
4. Find out the right questions to ask
5. Seek generality by removing specificities
6. Seek symmetry by testing for duality



# The Ten Commandments of Creativity in Research

1. Adapt. Seek extension of an earlier known solution
2. If you have a solution, find a problem
3. Let slow hunch simmer in your mind
4. Find out the right questions to ask
5. Seek generality by removing specificities
6. Seek symmetry by testing for duality
7. Distill the essence by distinguishing the relevant from the irrelevant



# The Ten Commandments of Creativity in Research

1. Adapt. Seek extension of an earlier known solution
2. If you have a solution, find a problem
3. Let slow hunch simmer in your mind
4. Find out the right questions to ask
5. Seek generality by removing specificities
6. Seek symmetry by testing for duality
7. Distill the essence by distinguishing the relevant from the irrelevant
8. Learn to believe and doubt your ideas at the same time

# The Ten Commandments of Creativity in Research

1. Adapt. Seek extension of an earlier known solution
2. If you have a solution, find a problem
3. Let slow hunch simmer in your mind
4. Find out the right questions to ask
5. Seek generality by removing specificities
6. Seek symmetry by testing for duality
7. Distill the essence by distinguishing the relevant from the irrelevant
8. Learn to believe and doubt your ideas at the same time
9. Build levels of abstractions and migrate between them

# The Ten Commandments of Creativity in Research

1. Adapt. Seek extension of an earlier known solution
2. If you have a solution, find a problem
3. Let slow hunch simmer in your mind
4. Find out the right questions to ask
5. Seek generality by removing specificities
6. Seek symmetry by testing for duality
7. Distill the essence by distinguishing the relevant from the irrelevant
8. Learn to believe and doubt your ideas at the same time
9. Build levels of abstractions and migrate between them
10. Mix deep thinking with routine mechanical work

# The Ten Commandments of Success in Research

1. Work on important problems
2. Work on multiple problems
3. For each problem, identify where you are on the S curve
4. Seek beauty in everything you do
5. Get emotionally involved
   (with the process, not with the results)
6. Remain committed
7. Work hard, work continuously
8. Consolidate your understanding
9. Don't depend on luck
10. Handle uncertainty and disappointments

# The Ten Commandments of Success in Research

1. Work on important problems
2. Work on multiple problems
3. For each problem, identify where you are on the S curve
4. Seek beauty in everything you do
5. Get emotionally involved
   (with the process, not with the results)
6. Remain committed
7. Work hard, work continuously
8. Consolidate your understanding
9. Don't depend on luck
10. Handle uncertainty and disappointments

Also applicable to

- A practising engineer
- A student
- A teacher

. . . all intellectual pursuits!

# Last But Not the Least

*Thank You!*

# Last But Not the Least

*Thank You!*

Contacting me :

- uday@cse.iitb.ac.in
- http://www.cse.iitb.ac.in/~uday