Design & Development

Developing Design Candidates
Select the Best Design (Solution)
Construct a Prototype

Design Process

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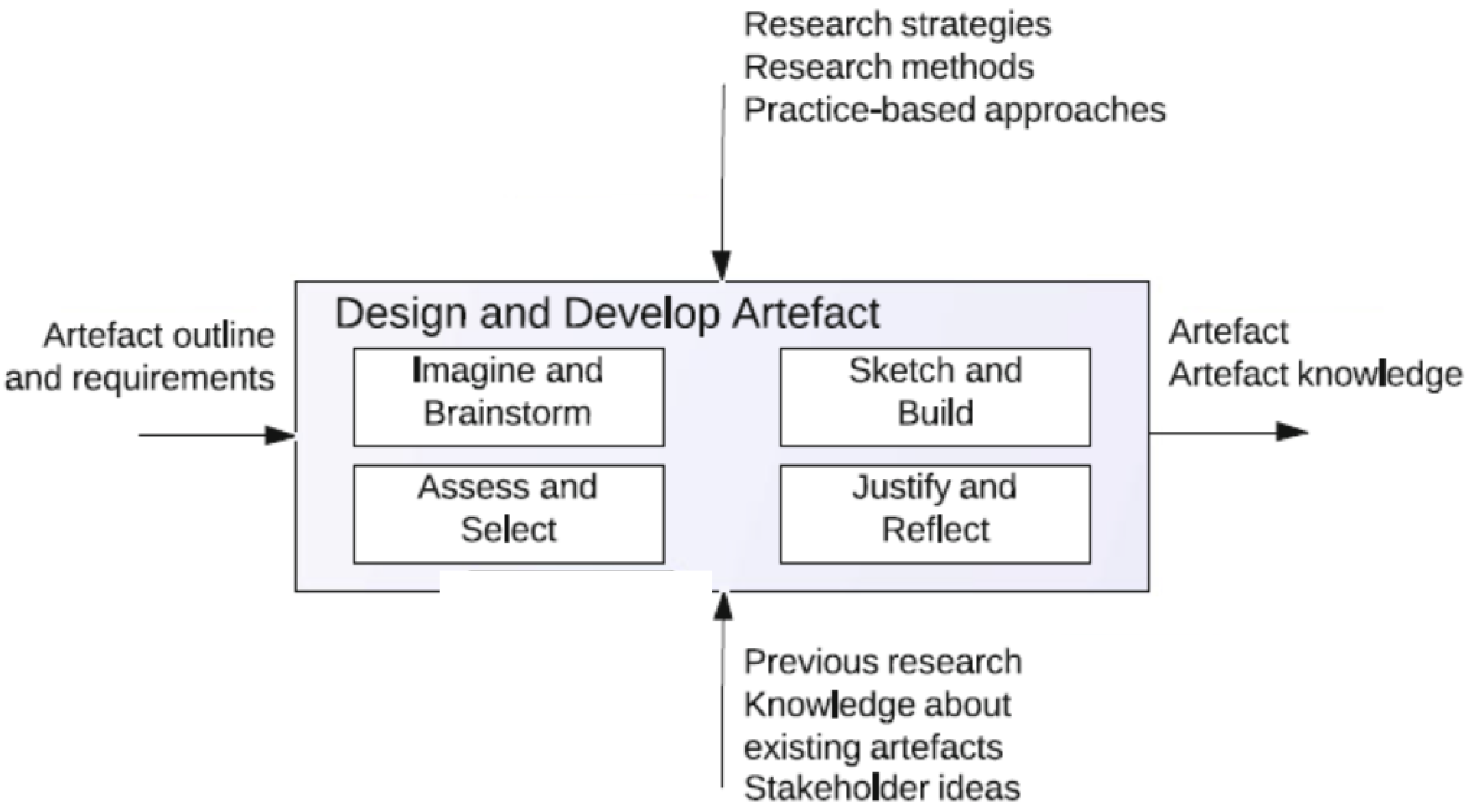
	Design Step		Action	Outcome
Initial Problem	Problem Definition		Surveys, Case Studies, Action Research	Explicit Problem Defenition
	Requirement Definition		Surveys, Case Studies, Action Research	Quantitative & Qualitative Requirements
	Design & Development	Development Design Candidates	Creative Methods, Innovation	Mockups / Rapid Prototyping
		Select the Best Design (Solution)	Optimization	Primary / Secondary Design
		Construct a Prototype	Machining / Rapid Prototyping	Artifact / Fully functional System
	Demonstration		Experiments, Case Studies / Action Research	Demonstrated Prototype (Basic Functionality)
	Evaluate		Experiments, Case Studies / Action Research	Evaluated Prototype (Meeting Requirements)
	Reporting		Summary of the Design Process / Lesson Learned	Final Report
	Redesign			

Design & Development Artifact - Definition

Create an artifact that addresses the explicated problem and fulfill the defined requirements.

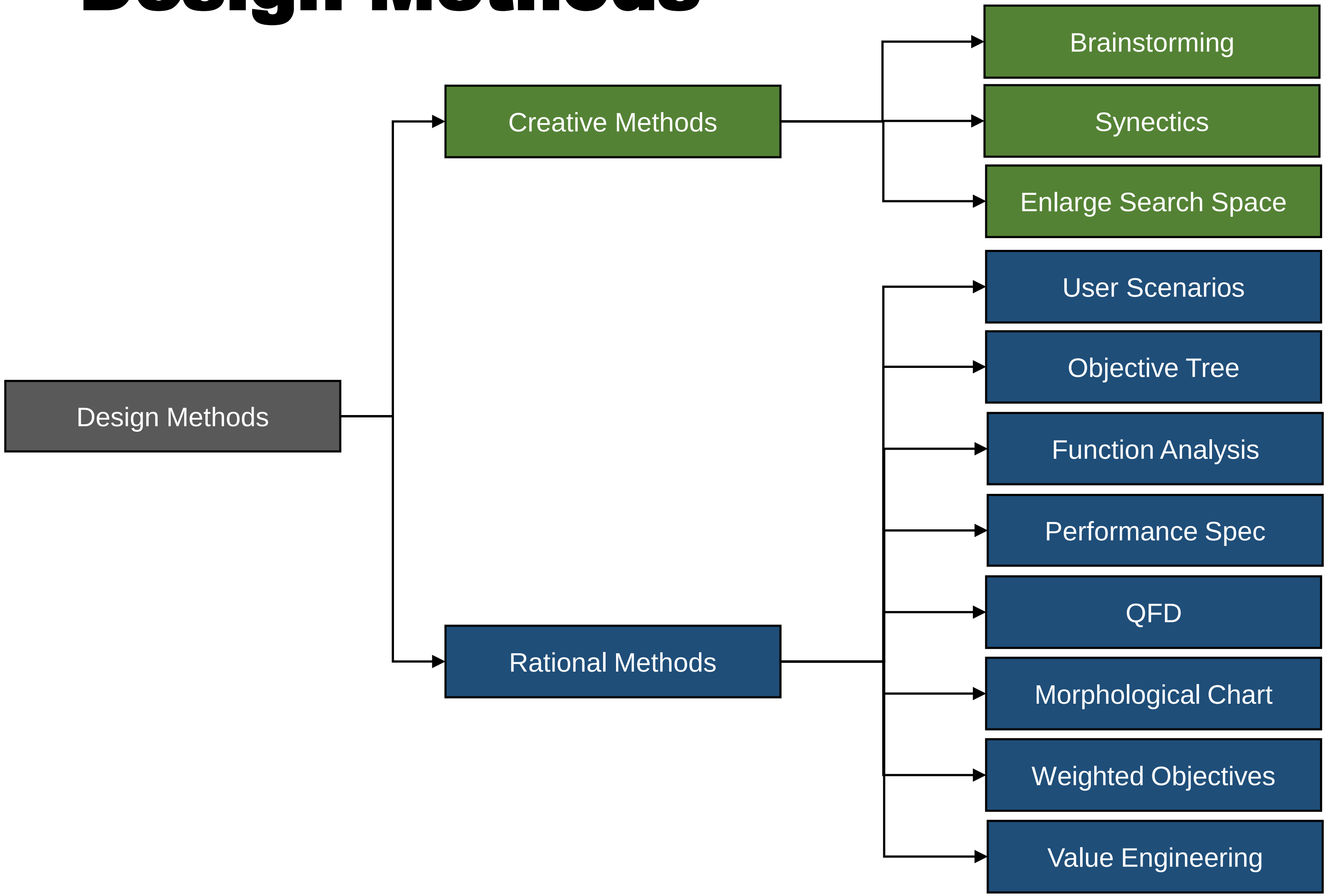
Design & Development Artifact – Definition



Design Methods – Goals

- **Design Methods**
  - **Formalize** procedures of design
    - **Problem** Avoid overlooking factors
    - **Solutions** Widen the search
  - **Externalize** design thinking
    - **Communication** Get your thoughts and thinking processes out of your head and into the charts and diagrams

Design Methods



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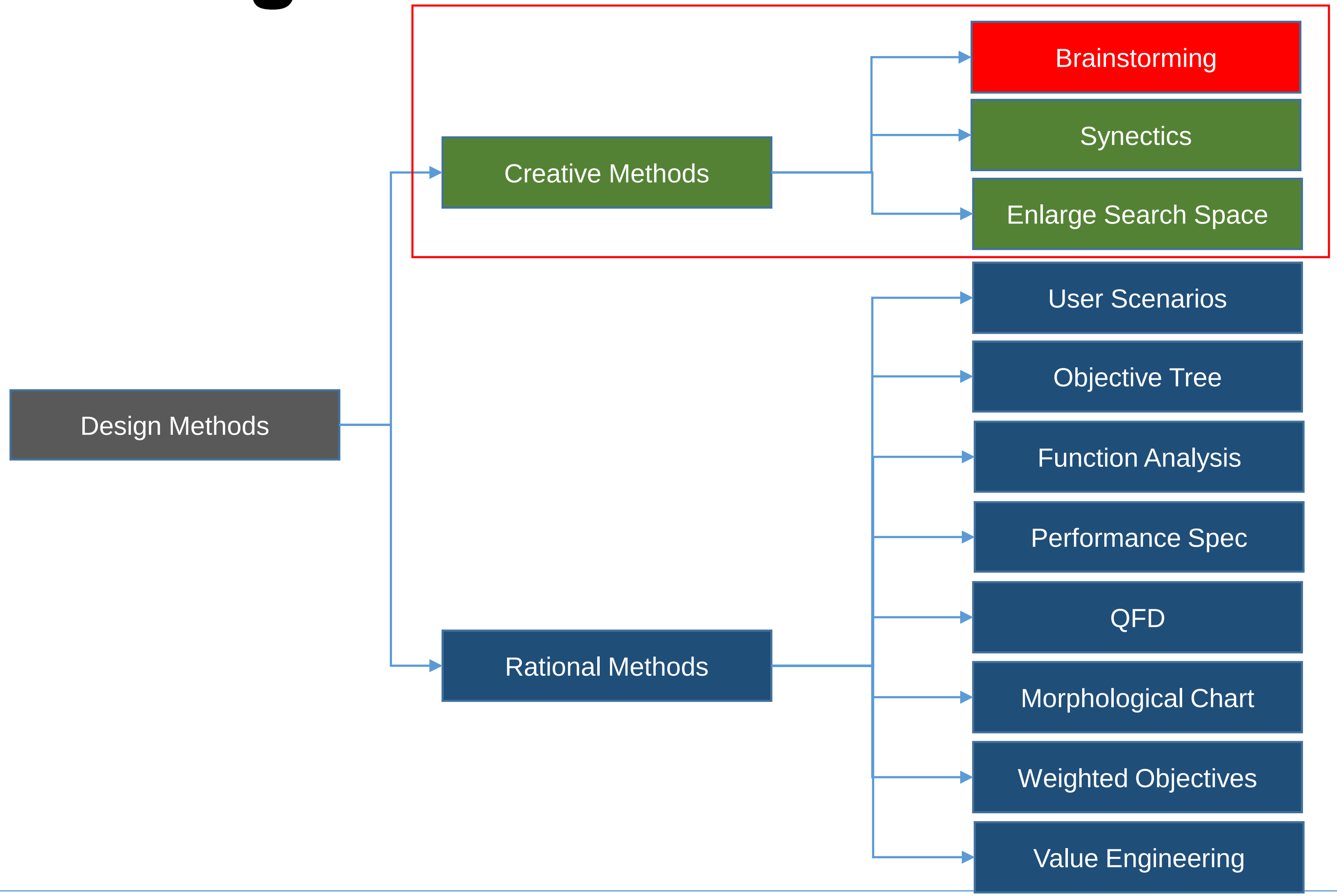
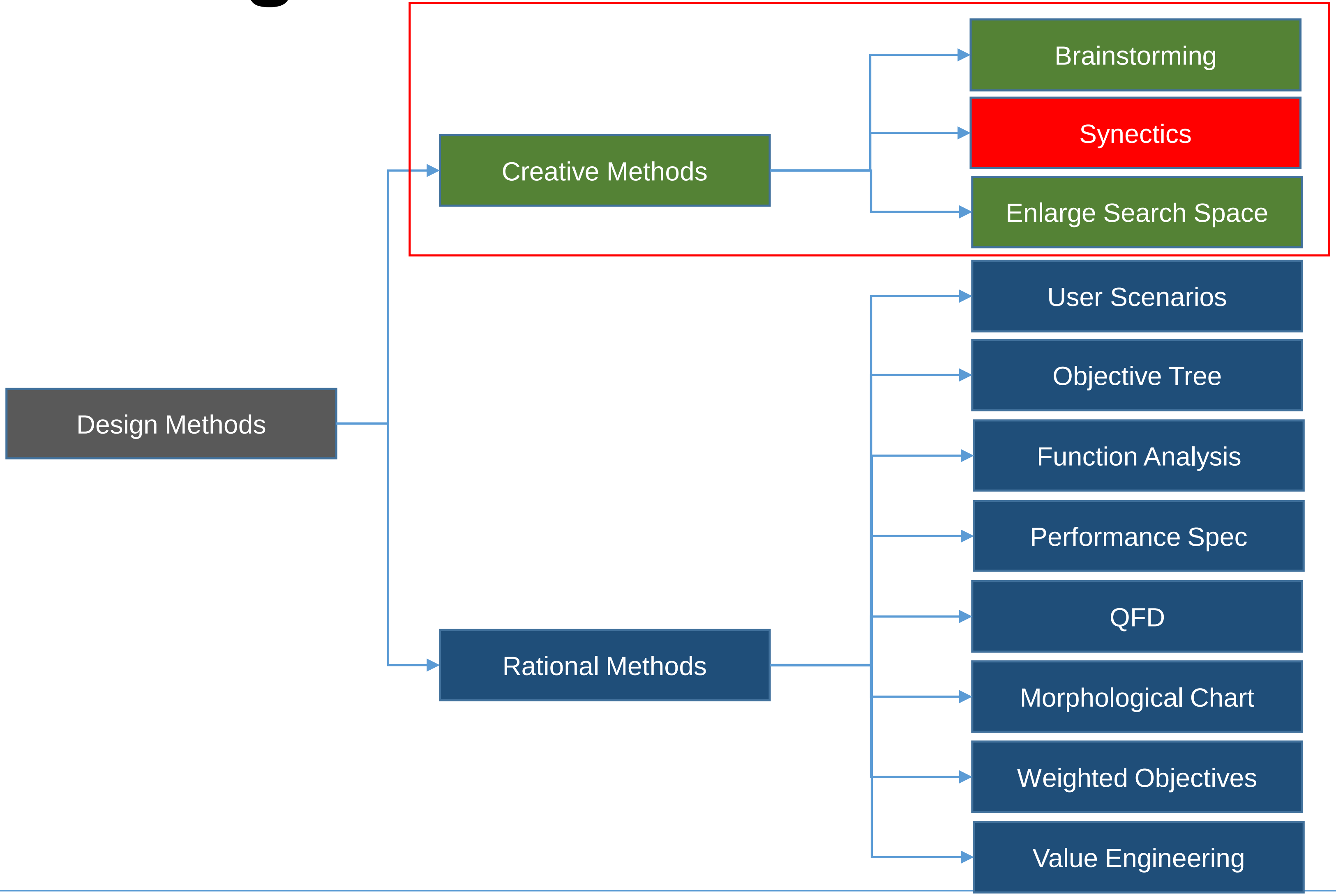
Design Methods – Creative Methods



Brainstorming
Creative Methods - Design Methods

- **Aim**
  - Generating a large number of ideas,
  - Most of the ideas will subsequently be discarded,
  - Few novel ideas being identified as worth following up.
- **Protocol**
  - **Duration:** 20-30 min
  - **Group Leader Role**
    - Formulate the problem statement used as a starting point
    - Ensure that the format of the method is followed,
    - Ensure that it does not degenerate into a round-table discussion
  - **Step 1:**
    - Spend a few minutes, in silence, writing down the first ideas that come into your head
  - **Step 2**:
    - Each group member, in turn, read out one idea from his or her set.
    - The most important rule here is that no criticism is allowed from any other member of the group.
  - **Step 3**:
    - In response to every other person's idea is to try to build on it, to take it a stage further, to use it as a stimulus for other ideas, or to combine it with his or her own ideas.
    - Make a short pause after each idea is read out, to allow a moment for reflection and for writing down further new ideas.
  - **Step 4:**
    - Classify the ideas into related groups

Design Methods – Creative Methods



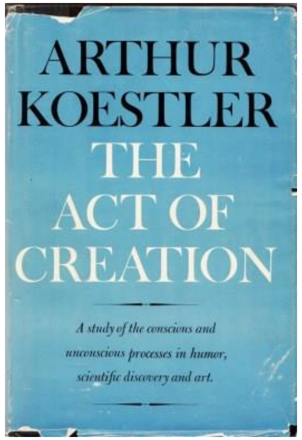
Synectics
Creative Methods - Design Methods

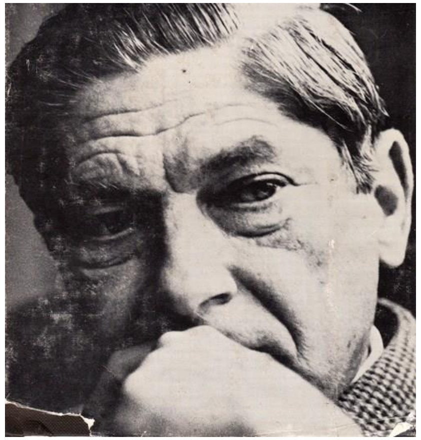
- **Synectics -** Creative thinking often draws on analogical thinking, on the ability to see parallels or connections between apparently dissimilar topics.
- **Analogical Thinking (Definition)** - Analogical thinking is what we do when we use information from one domain (the source or analogy) to help solve a problem in another domain (the target).
- **Bisociation** - A blending of elements drawn from two previously unrelated patterns of thought into a new pattern.
- Blend of **bi- + association**; coined by Hungarian-British author Arthur Koestler in his 1964 book The Act of Creation.

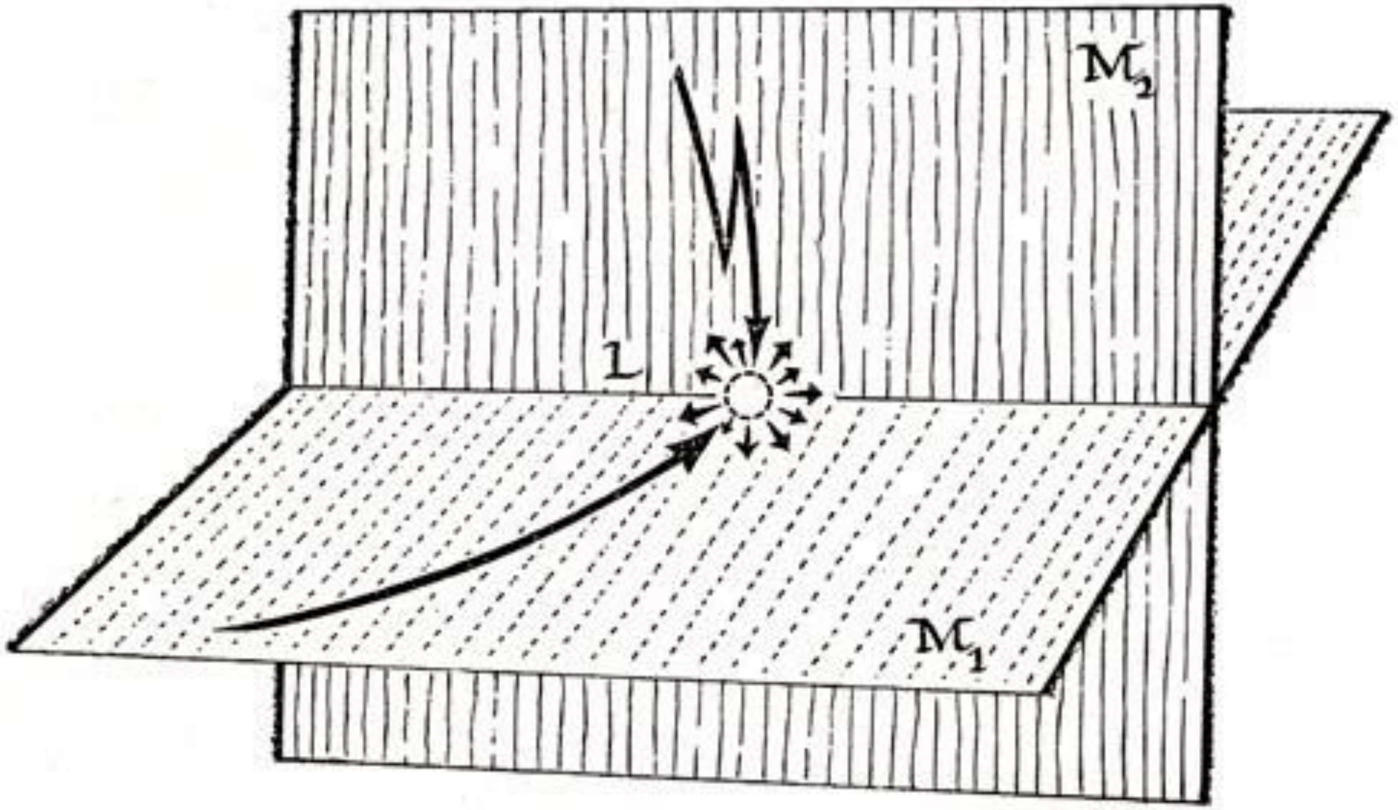
Synectics - Bisociation
Creative Methods - Design Methods

Arthur Koestler

The Act of Creation 1964







Synectics -
Creative Methods - Design Methods

- **Synectics versus Brainstorming**

Method	Brainstorming	Synectics
Number of Solutions	Large	Single
Length of the session	Short	Long

Direct Analogy - Synectics – Types of Analogies
Creative Methods - Design Methods

- **Direct Analogy** – Seeking Biological solution to similar problem
  - Example – Velcro

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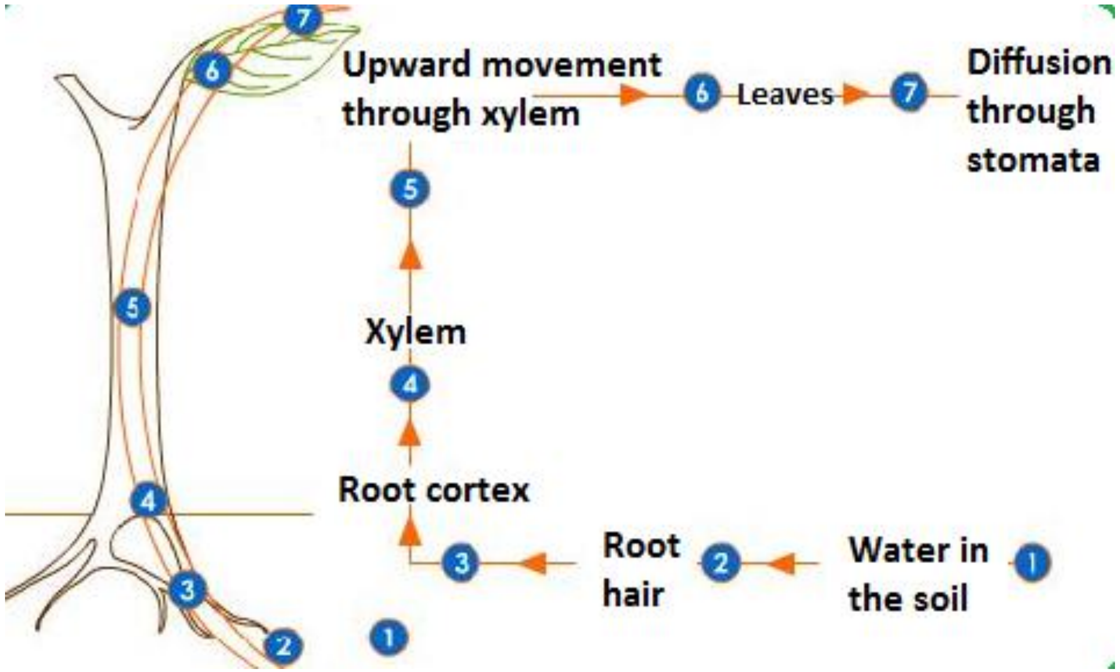
Personal Analogy - Synectics – Types of Analogies Creative Methods - Design Methods

- **Personal Analogy** – The team members imagine what it would be like to use oneself as the system or component that is being designed.

Symbolic Analogy - Synectics – Types of Analogies Creative Methods - Design Methods

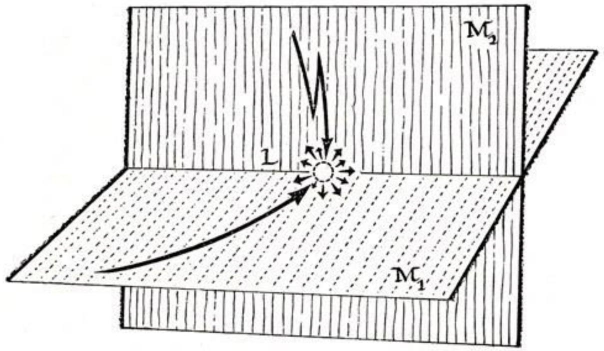
- **Symbolic Analogy** - Symbolic Analogy bases around examinations of objects' properties in an abstract fashion.



Fantasy Analogies - Synectics – Types of Analogies Creative Methods - Design Methods

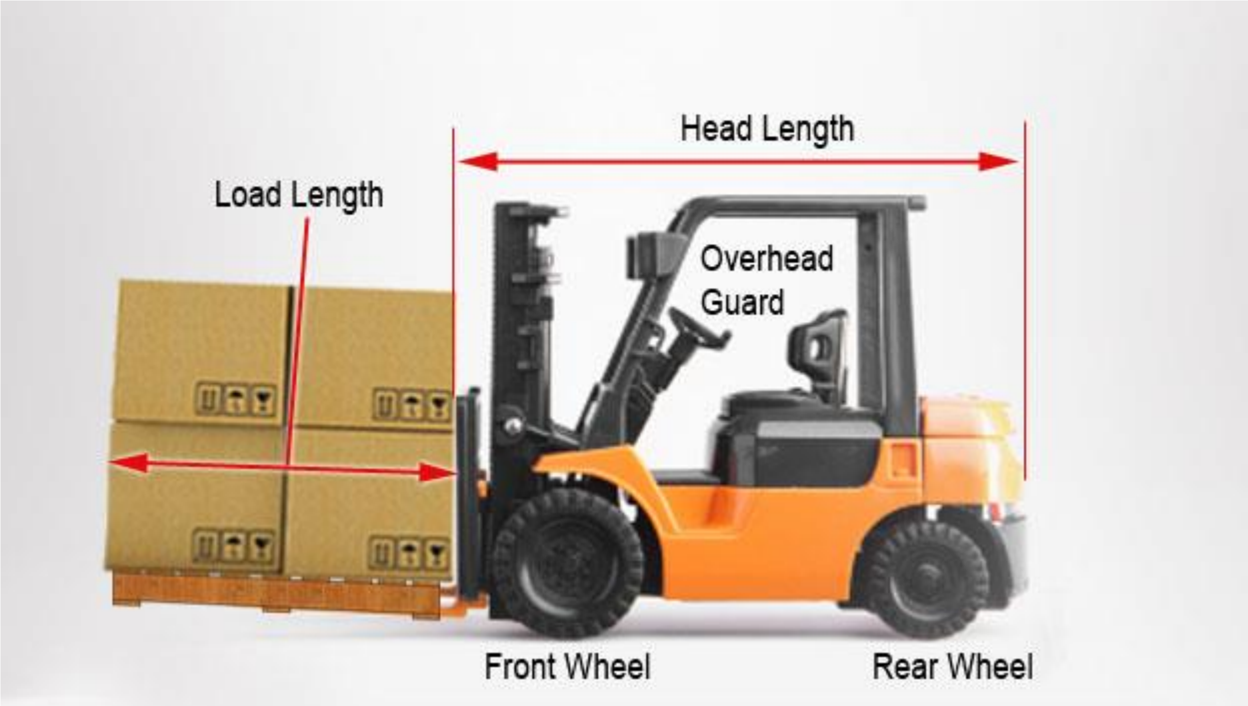
- **Fantasy Analogies** - ‘Impossible' wishes for things to be achieved in some 'magical' way.

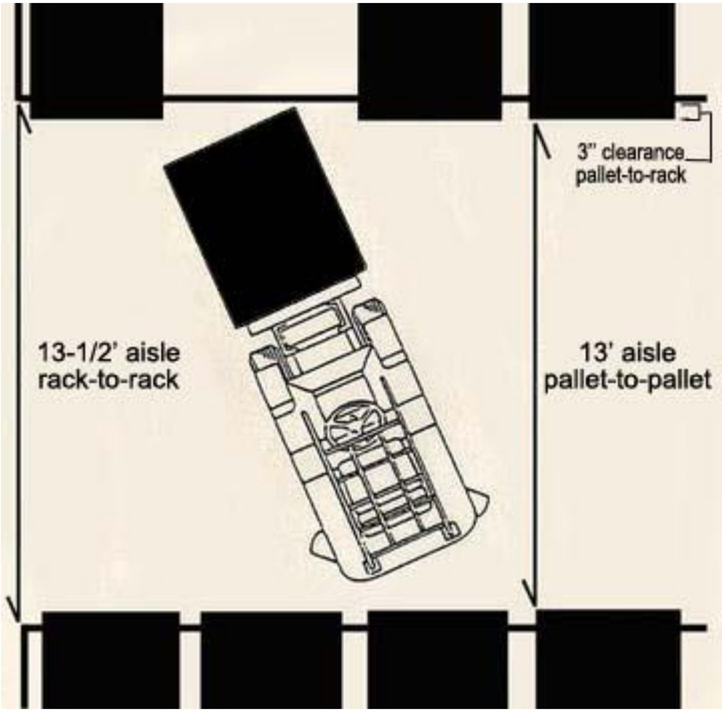
Session Protocol - Synectics
Creative Methods - Design Methods



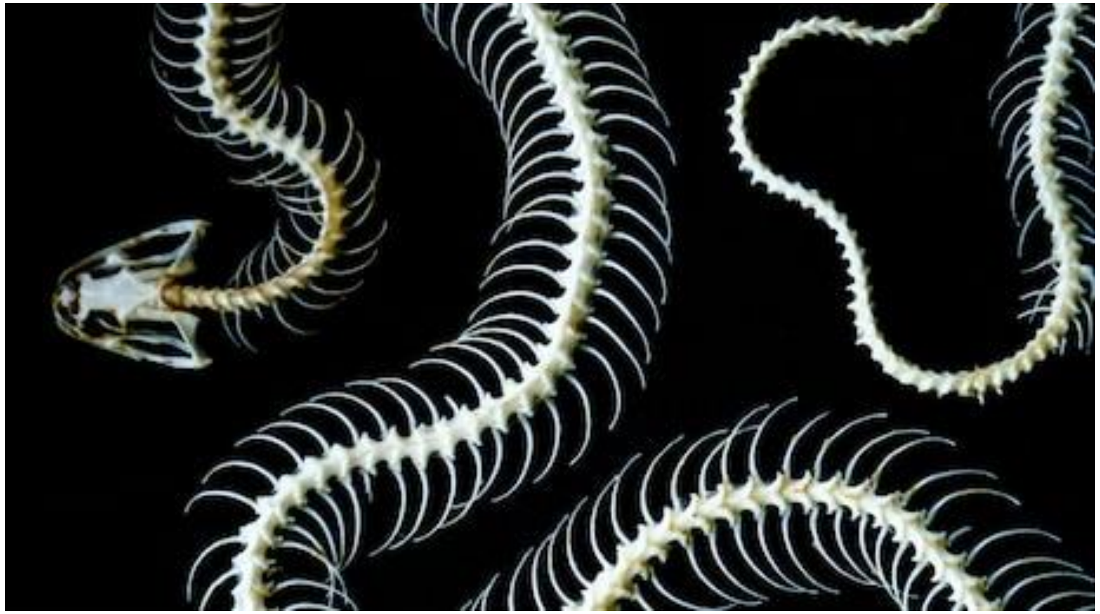
- Session Protocol
  - **Starts with the 'problem as given'** - the problem statement as presented by the client or company management.
  - **Seek Analogies (Understand the Problem)** - help to 'make the strange familiar', i.e. expressing the problem in terms of some more familiar (but perhaps rather distant) analogy.
  - **Conceptualization of the 'problem as understood'** – Understand the key factor or elements of the problem that need to be resolved, or perhaps a complete reformulation of the problem.
  - **Seek Unusual & Creative Analogies (Create Solutions)** - May lead to novel solution concepts. The analogies are used to open up lines of development which are pursued as hard and as imaginatively as possible by the group.

Synectics – Analogies –
Example Fork Lift / Bendi Truck
Creative Methods - Design Methods





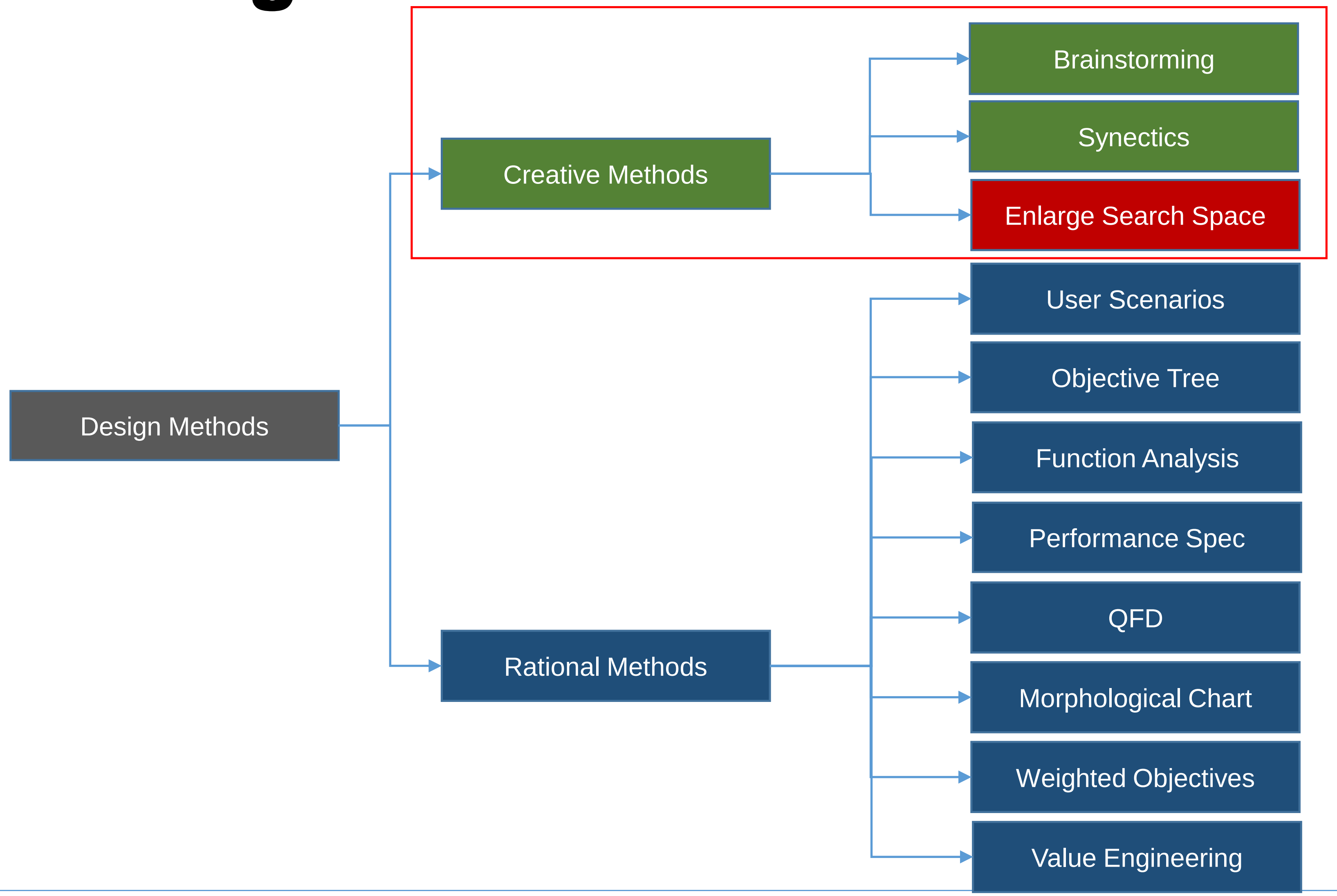
Synectics – Analogies –
Example Fork Lift / Bendi Truck
Creative Methods - Design Methods



Synectics – Analogies – Example ForkLift / Benditruck Creative Methods - Design Methods

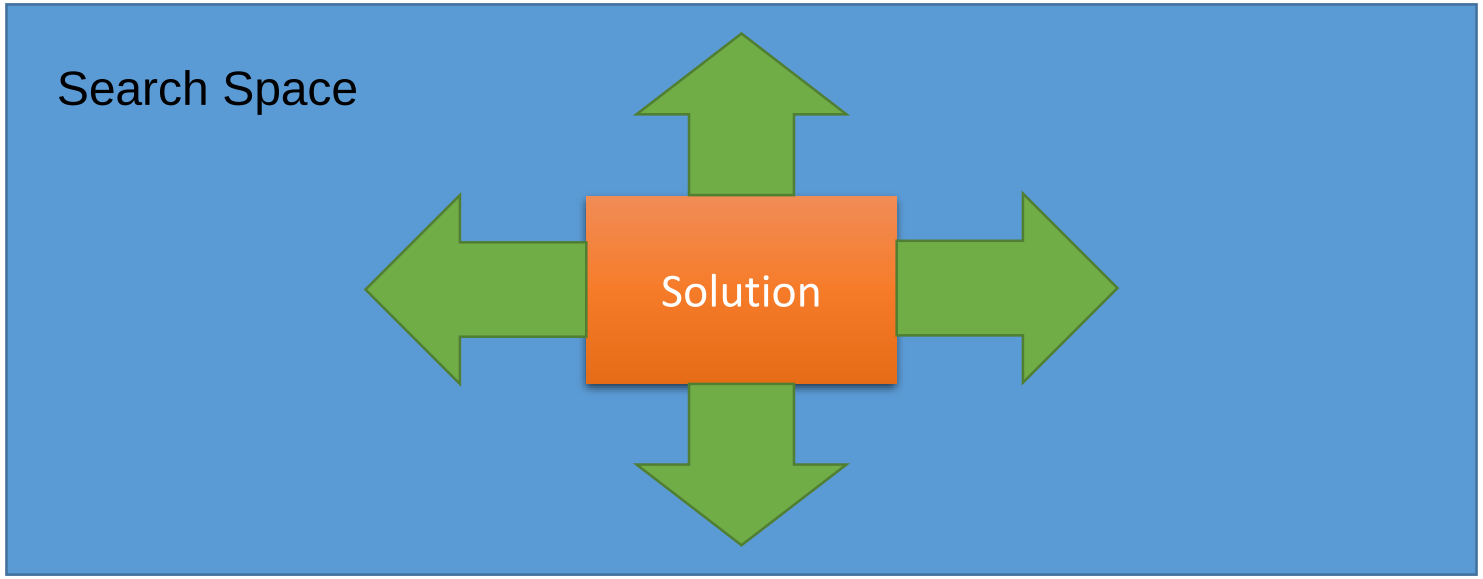
Synectics – Analogies – Example Fork Lift / Bendi Truck Creative Methods - Design Methods

Design Methods – Creative Methods



Enlarge the Search Space
Creative Methods - Design Methods

- **Aim**: A common form of mental block to creative thinking is to assume rather narrow boundaries within which a solution is sought. Many creativity techniques are aids to enlarging the 'search space'.



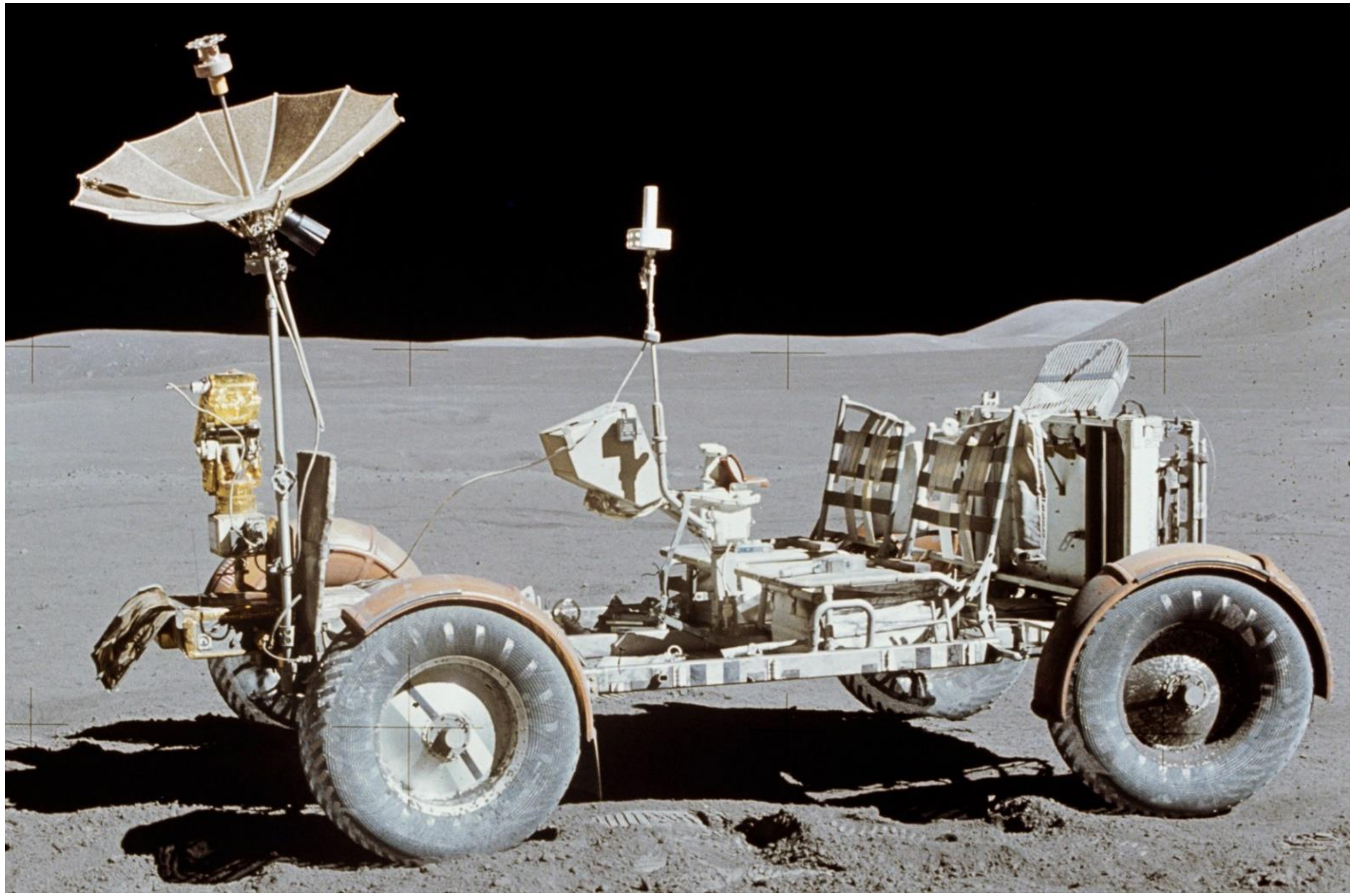
Transformation - Enlarge the Search Space Creative Methods - Design Methods

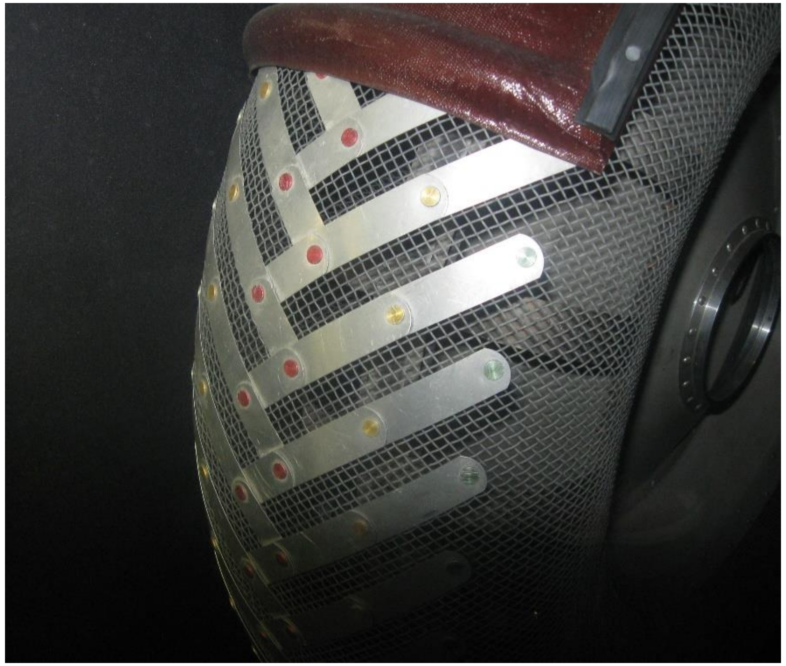
- **Transformation** - 'transform' the search for a solution from one area to another. This often involves applying verbs that will transform the problem in some way, such as

magnify, minify, modify, unify, subdue, subtract, add, divide, multiply, repeat, replace, relax, dissolve, thicken, soften, harden, roughen, flatten, rotate, rearrange, reverse, combine, separate, substitute, eliminate.

Transformation – Example

Enlarge the Search Space
Creative Methods - Design Methods





YouTube https://youtu.be/dlxJ65WRy0E

From the Moon to Mars

YouTube https://youtu.be/4LOOTyuLjLU

NASA Reinvented The Wheel - Shape Memory Alloy Tires

YouTube https://youtu.be/pvKIzldni68

Field Trials Utah: Robot team simulates Mars mission in Utah

Random Input - Enlarge the Search Space Creative Methods - Design Methods

- **Random Input** - Creativity can be triggered by random inputs from whatever source.
  - Opening a dictionary or other book and choosing a word at random and using that to stimulate thought on the problem in hand.
  - Switch on a television set and use the first visual image as the random input stimulus.

Why? Why? Why? - Enlarge the Search Space
Creative Methods - Design Methods

- **Why? Why? Why?** - .
  - Ask a string of questions ':why?' about the problem:
    - 'Why is this device necessary?' ‘
    - Why can't it be eliminated?'
  - Each answer is followed up, with another 'Why?' until a dead end is reached or an unexpected answer prompts an idea for a solution.
  - There may be several answers to any particular 'Why?', and these can be charted as a network of question-and-answer chains.

Counter Planning - Enlarge the Search Space Creative Methods - Design Methods

- Counter Planning
  - **Thesis – Antithesis – Synthesis -** The concept of the dialectic, i.e. pitting an idea (**the thesis**) against its opposite (**the antithesis**) in order to generate a new idea (**the synthesis**).
  - **Conventional - Opposite - Compromise** - Challenge a conventional solution to a problem by proposing its deliberate opposite, and seeking a compromise.
  - **Synthesis** - Two completely different solutions can be deliberately generated, with the intention of combining the best features of each into a new synthesis.

Generalized Creative Methods
Creative Methods - Design Methods

- **'Ah-ha!' moment** - **Generalized Creative Methods**
- This general pattern is the following sequence
  - ***Recognition*** is the first realization or acknowledgement that 'a problem' exists.
  - ***Preparation*** is the application of deliberate effort to understand the problem.
  - ***Incubation*** is a period of leaving it to 'mull over' in the mind, allowing one's subconscious to go to work.
  - ***Illumination*** is the (often quite sudden) perception or formulation of the key idea.
  - ***Verification*** is the hard work of developing and testing the idea.

Generalized Creative Methods
Creative Methods - Design Methods

100%
Creative Work

=

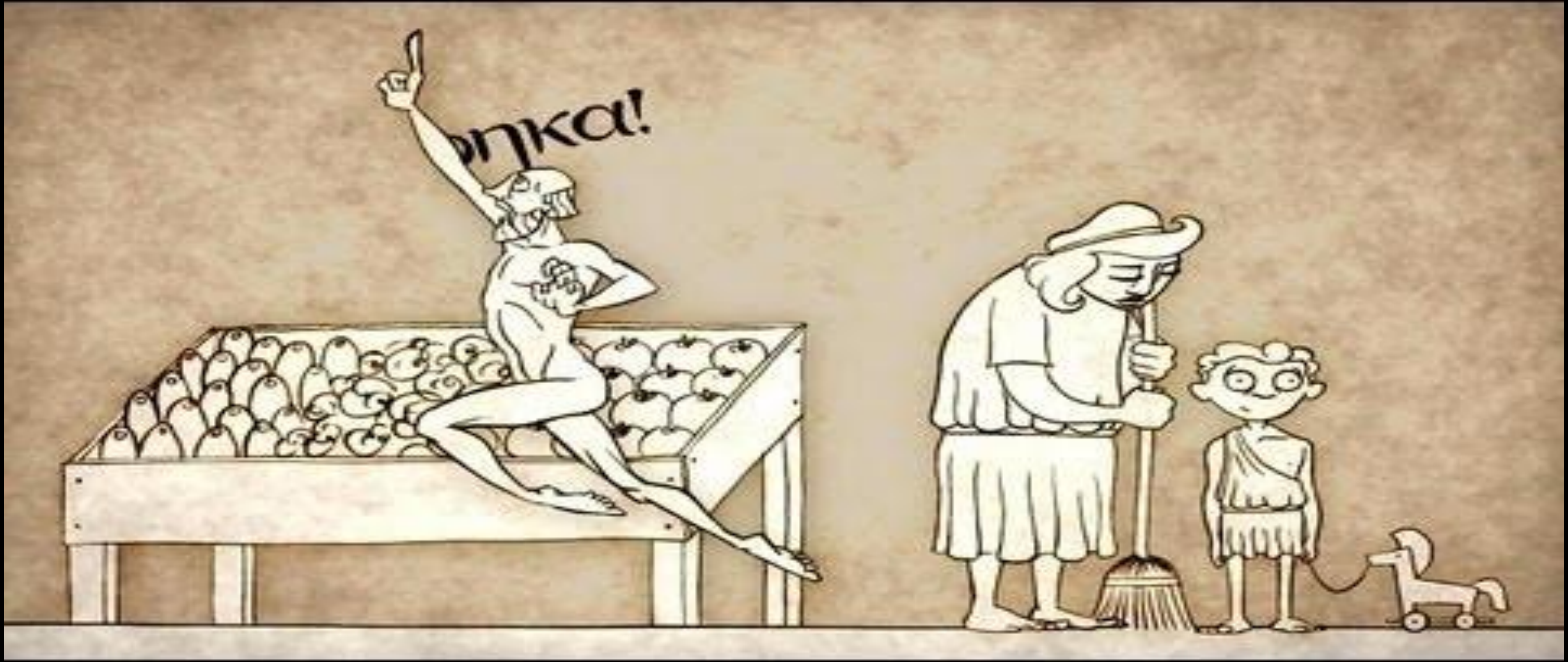
1%
Inspiration

+

99%
Recognition
Preparation
Incubation
Verification

YouTube https://youtu.be/QEoqBjRZr1g

Albert Einstein: How did he come up with ideas? | Understanding Einstein's Mind

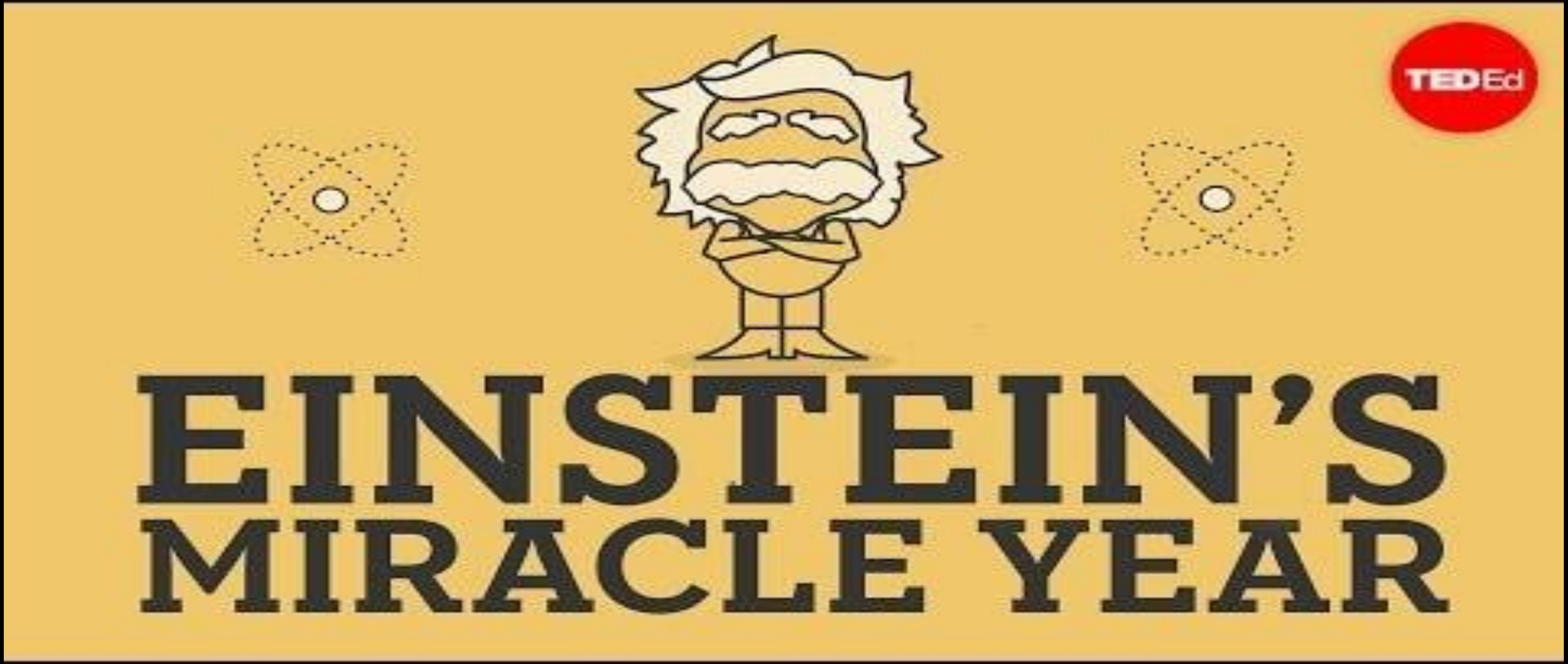


https://youtu.be/ijj58xD5fD

Version 1: How taking a bath led to Archimedes' principle - Mark Salata

YouTube https://youtu.be/0v86Yk14rf8

Version 2: The real story behind Archimedes' Eureka! - Armand D'Angour



YouTube https://youtu.be/91XI7M9l3no

Einstein's miracle year –TED Ed - Larry Lagerstrom

Generalized Creative Methods
Creative Methods - Design Methods

- **Work – Relaxation – Work** - The process is essentially work – relaxation – work, with the creative insight occurring in a period.

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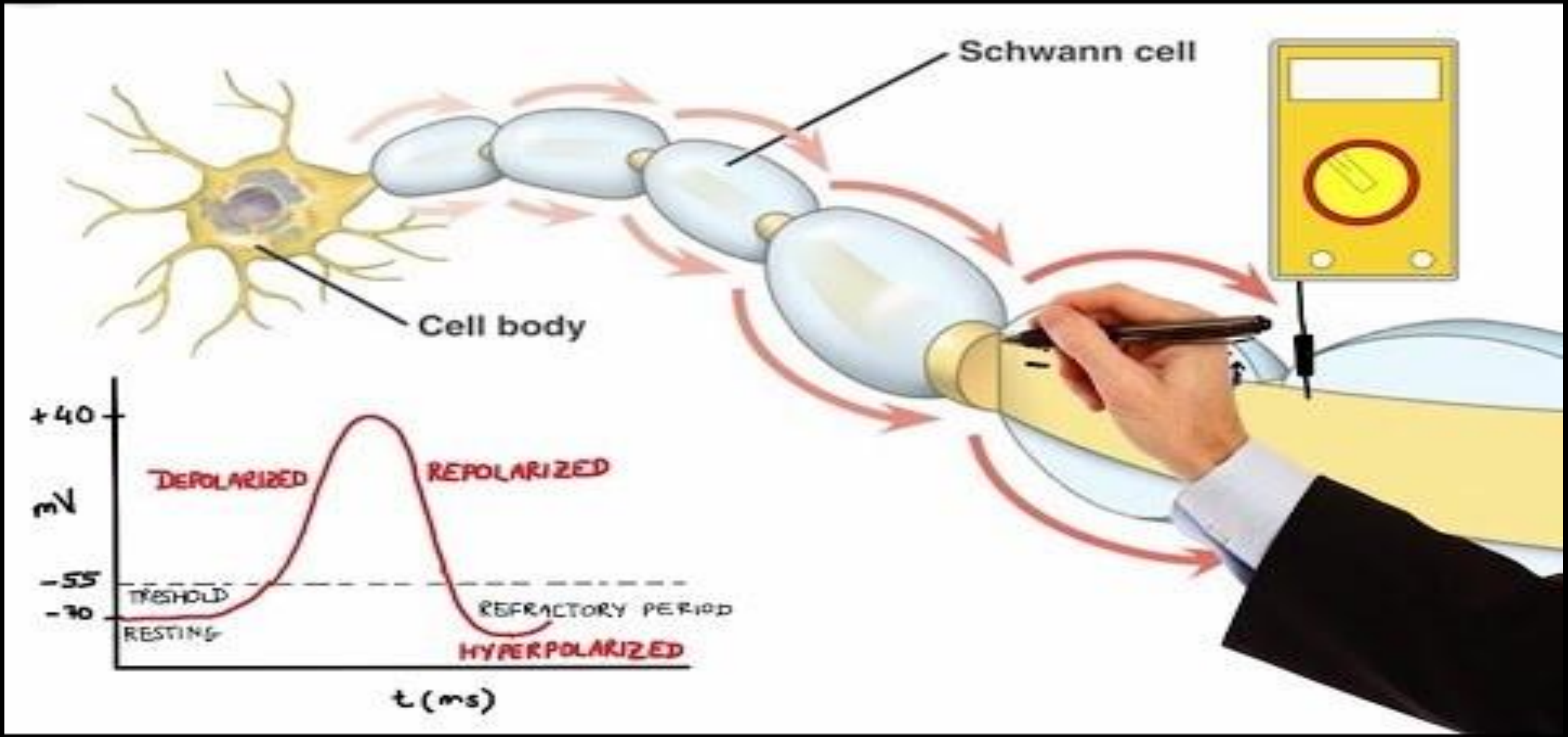

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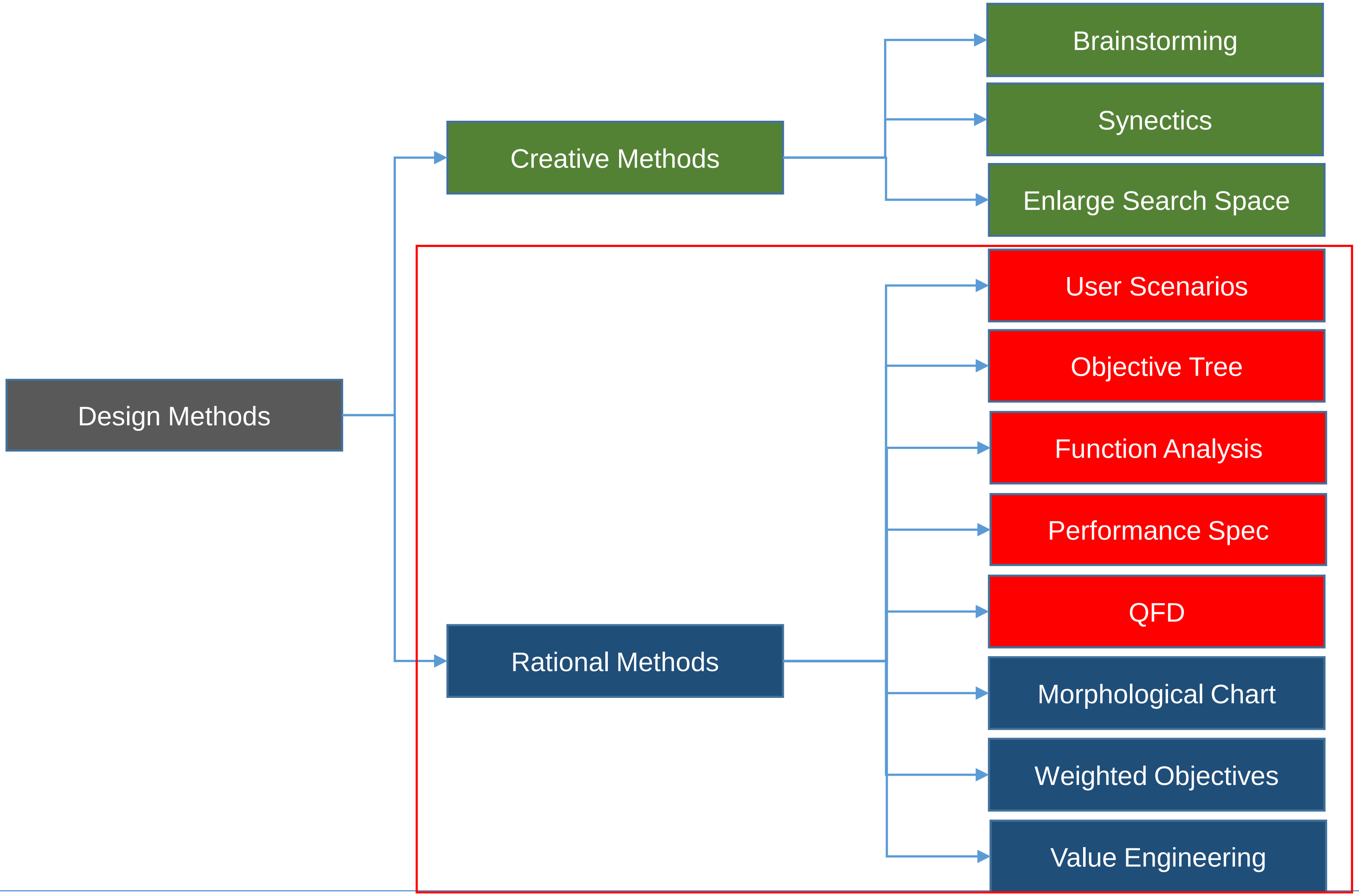
NEURON ACTION POTENTIAL

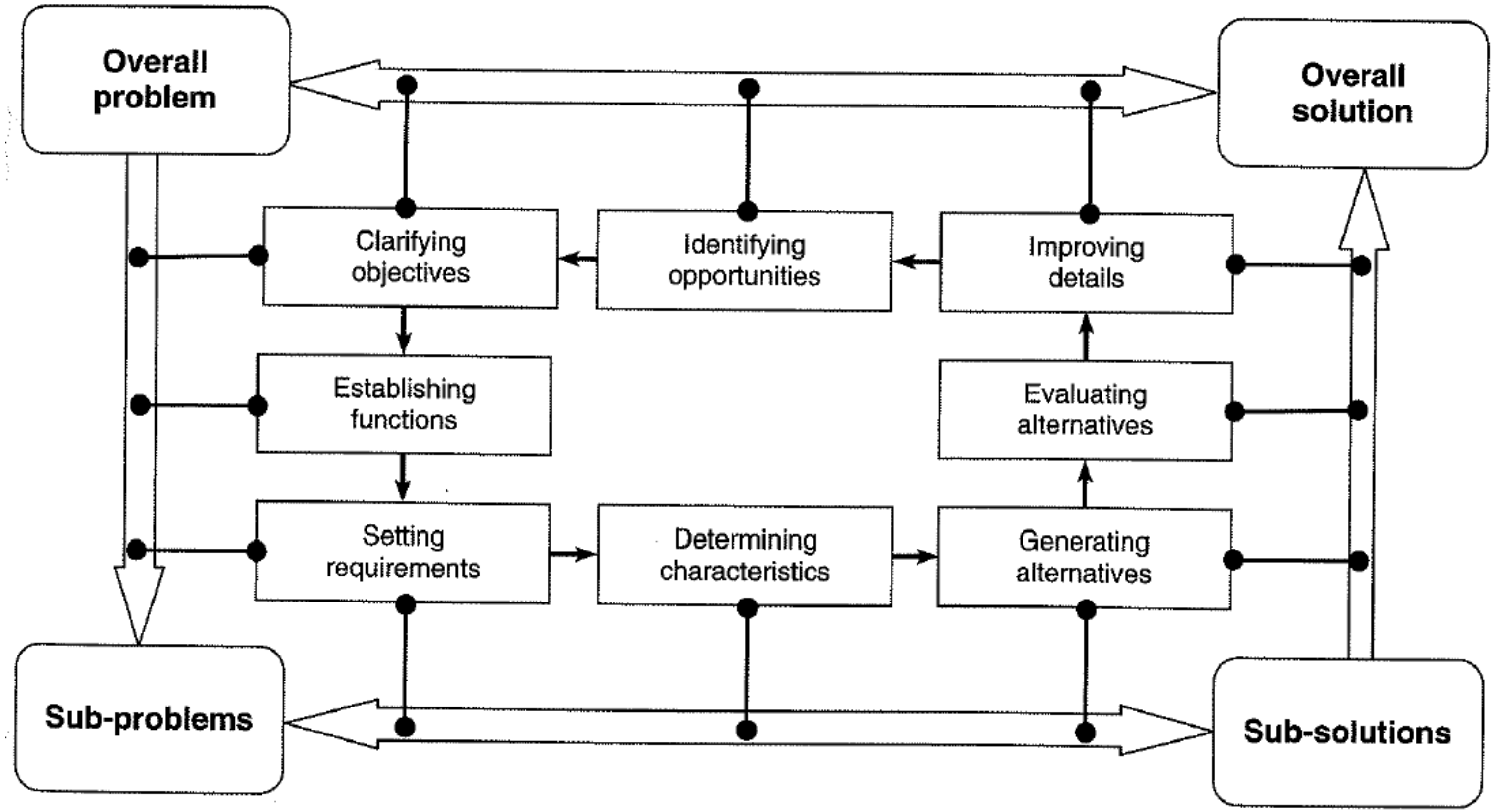
Design Methods – Rational Methods



Rational Methods - Design Methods

General Aim	Method	Specific Aim
Identify Opportunities	User Scenarios	Identify and define an opportunity for a new or improved product.
Clarify Objectives	Objective Tree	Clarify design objectives and sub objectives, and the relationships between them.
Establishing Function	Function Analysis	Establish the functions required, and the system boundary, of a new design.
Setting Requirements	Performance Specification	Make an accurate specification of the performance required of a design solution.
Determining Characteristics	Quality Function Deployments (QFD)	Set targets to be achieved for the engineering characteristics of a product, such that they satisfy customer requirements.
Generating Alternatives	Morphological Chart	Generate the complete range of alternative design solutions for a product.
Evaluating Alternatives	Weighted Objectives	Compare the utility values of alternative design proposals, on the basis of performance against differentially weighted objectives.
Improving Details	Value Engineering	Increase or maintain the value of a product to its purchaser whilst reducing its cost to its producer.

Rational Methods - Design Methods



Generating Alternatives

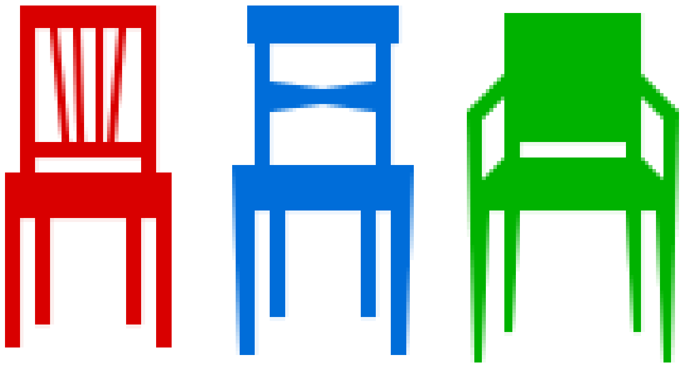
Morphological Chart Method

Generating Alternatives – Introduction Rational Methods - Design Methods

- **Solution Generation** - The generation of solutions is, of course, the essential, central aspect of designing
- **Variation / Modification to an Existing Artifact** - most designing is actually a variation from or modification to an already existing product or machine. Clients and customers usually want improvements rather than novelties.

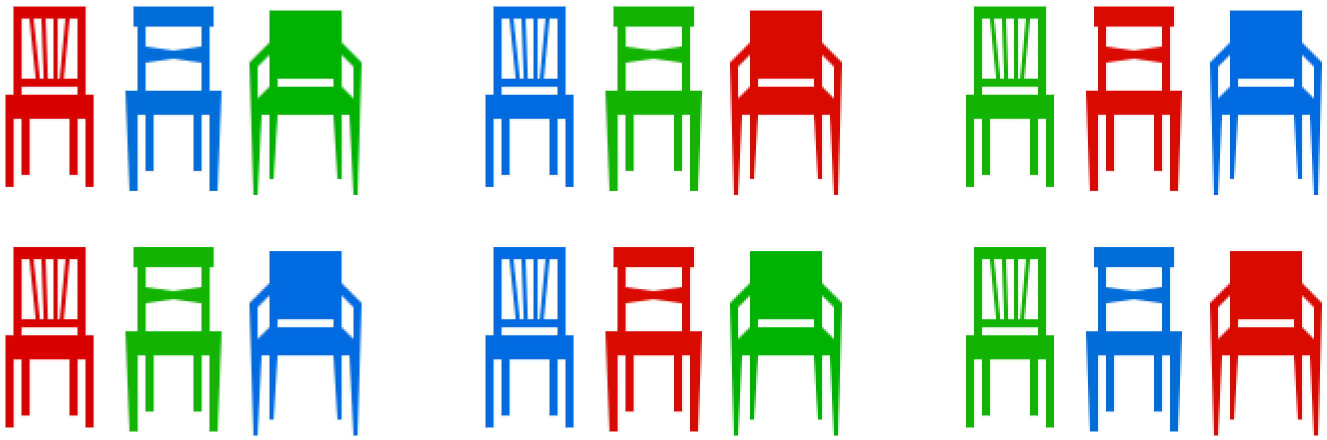
Variation

- *In a display there are 3 students and 3 chairs standing in a row.*
- *In how many different orders can the students sit on these chairs?*



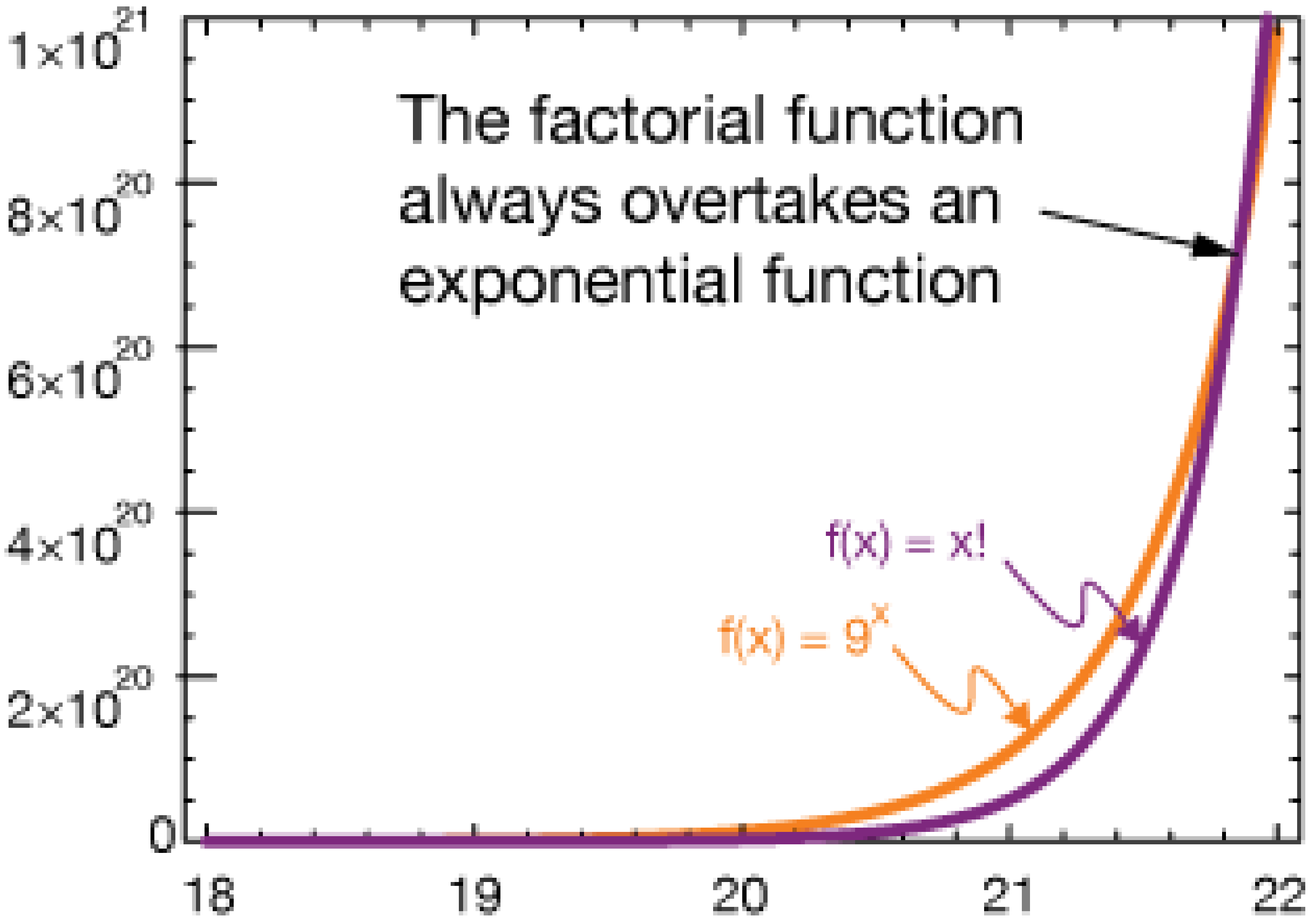
Variation

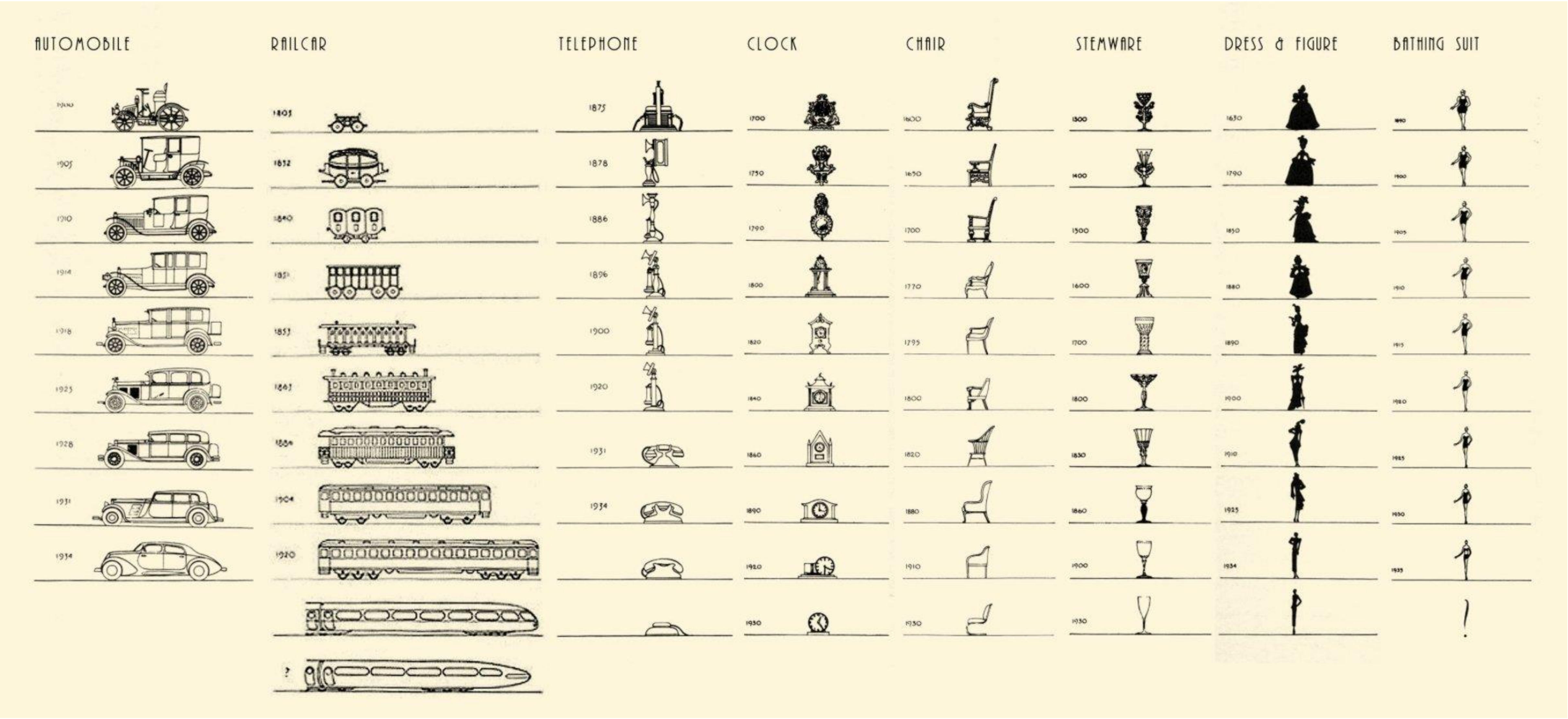
- *3!=1x2x3=6*



Variations (Factorial)

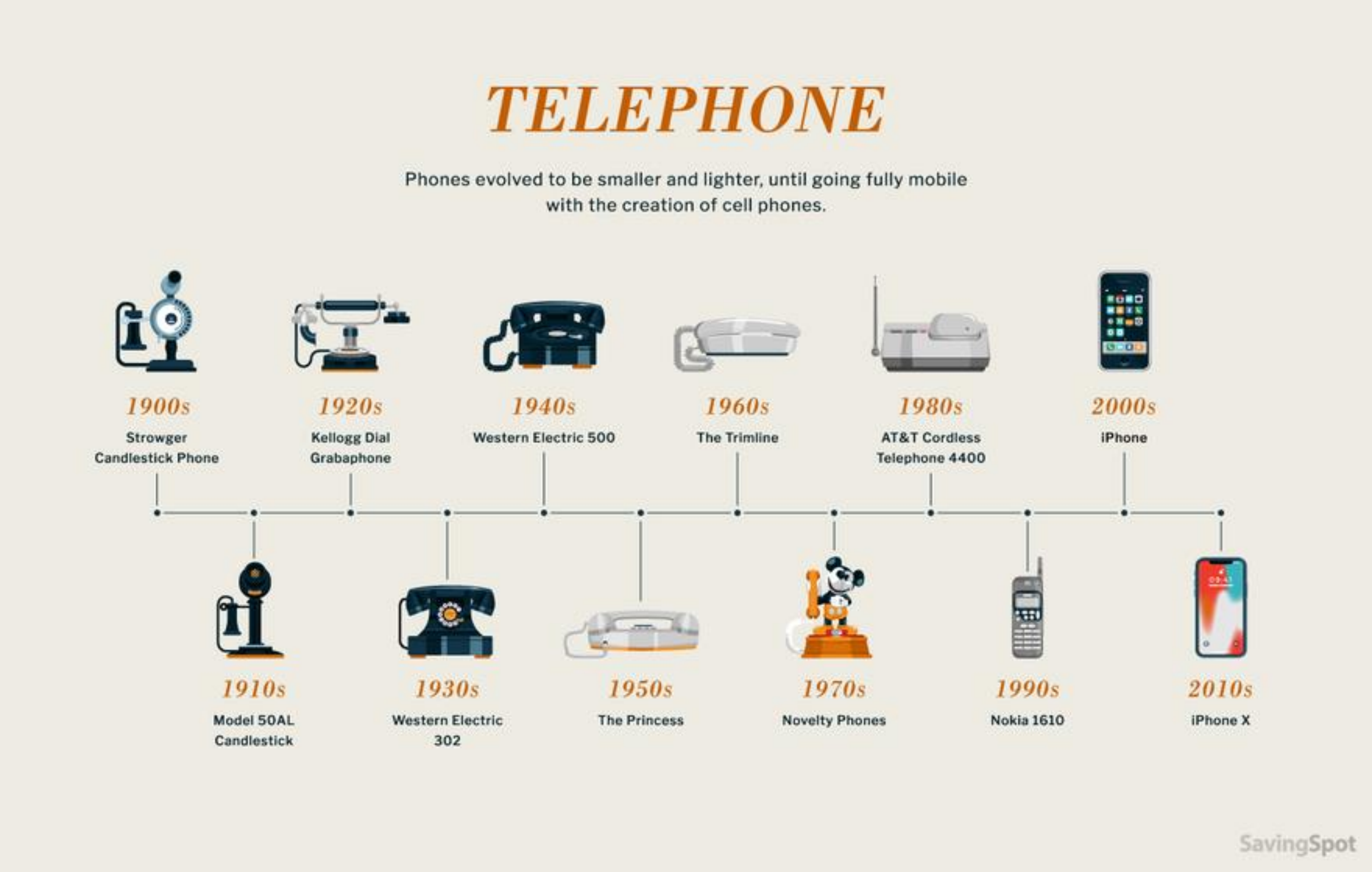
Number of Objects	Factorial	Number of orders
1	1!	1
2	2!	2
3	3!	6
4	4!	24
5	5!	120
6	6!	720
7	7!	5040
8	8!	40,320
9	9!	362,880
10	10!	3,628,800
20	20!	2,432,902,000,000,000,000e=2.4e+18
26	26!	403,291,460,000,000,000,000,000,000=4.0329146e+26


The factorial function always overtakes an exponential function
f(x) = x!
f(x) = 9^x
1×10^21
8×10^20
6×10^20
4×10^20
2×10^20
0
18
19
20
21
22



Raymond Loewy, this chart from 1934

[The Evolution of 8 Objects Americans Use Every Day]


TELEPHONE
Phones evolved to be smaller and lighter, until going fully mobile with the creation of cell phones.
1900s
Strowger Candlestick Phone
1910s
Model 50AL Candlestick
1920s
Kellogg Dial Grabaphone
1930s
Western Electric 302
1940s
Western Electric 500
1950s
The Princess
1960s
The Trimline
1970s
Novelty Phones
1980s
AT&T Cordless Telephone 4400
1990s
Nokia 1610
2000s
iPhone
2010s
iPhone X
SavingSpot

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JKL
5
GHI
4
MNO
6
DEF
3
PRS
7
ABC
2
TUV
8
1
WXY
9
0
OPERATOR
DIAL
999
FIRE
POLICE
AMBULANCE
100
OPERATOR
Speaker
*
#

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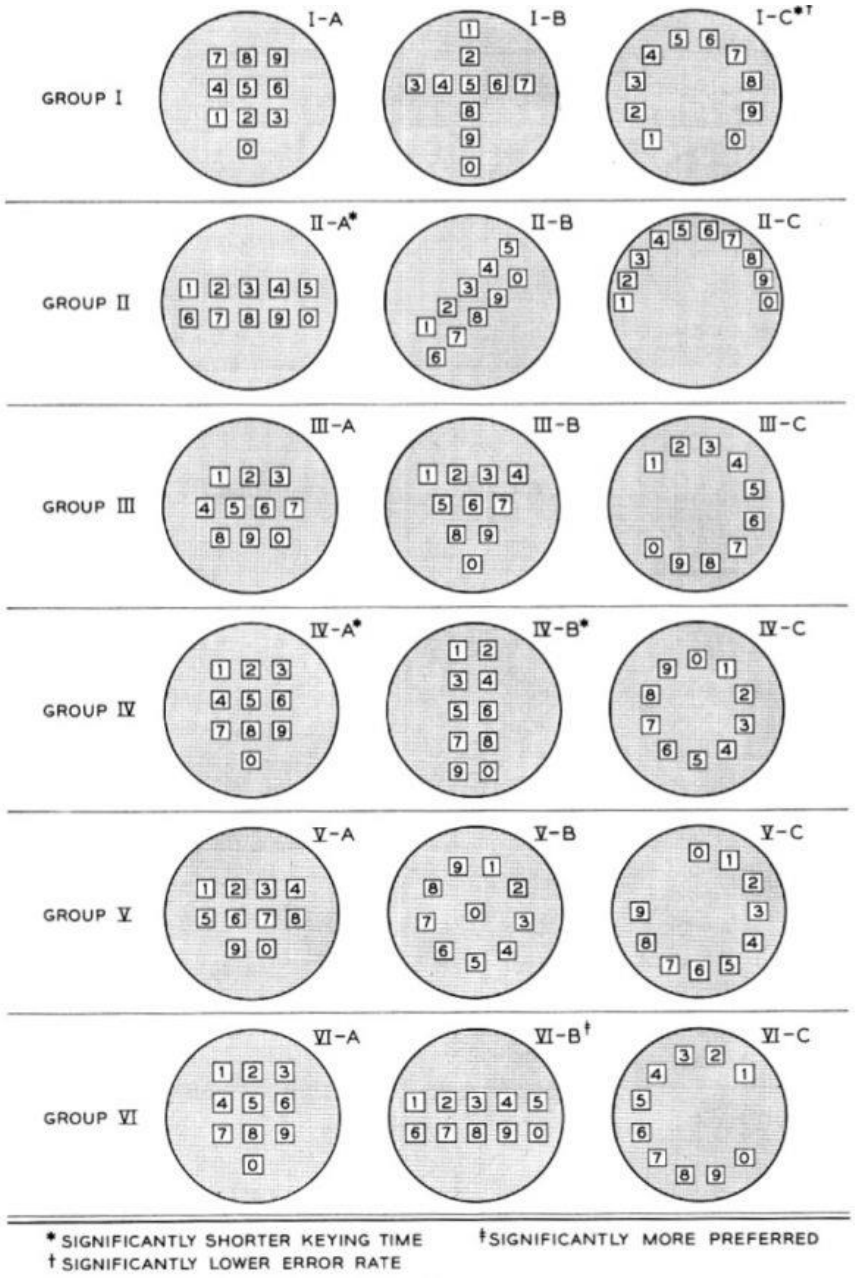
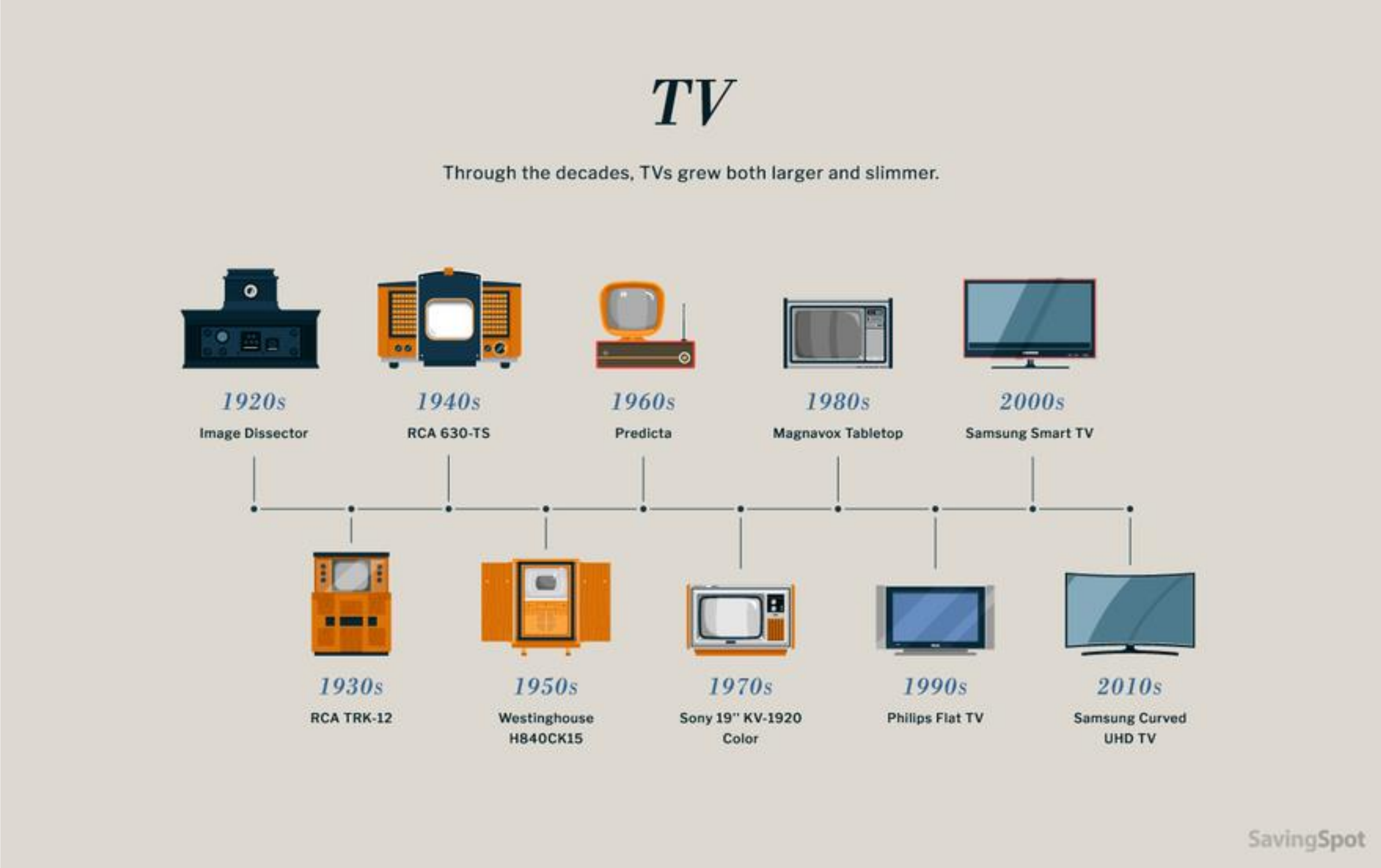
YouTube https://youtu.be/1OADXNGnJok

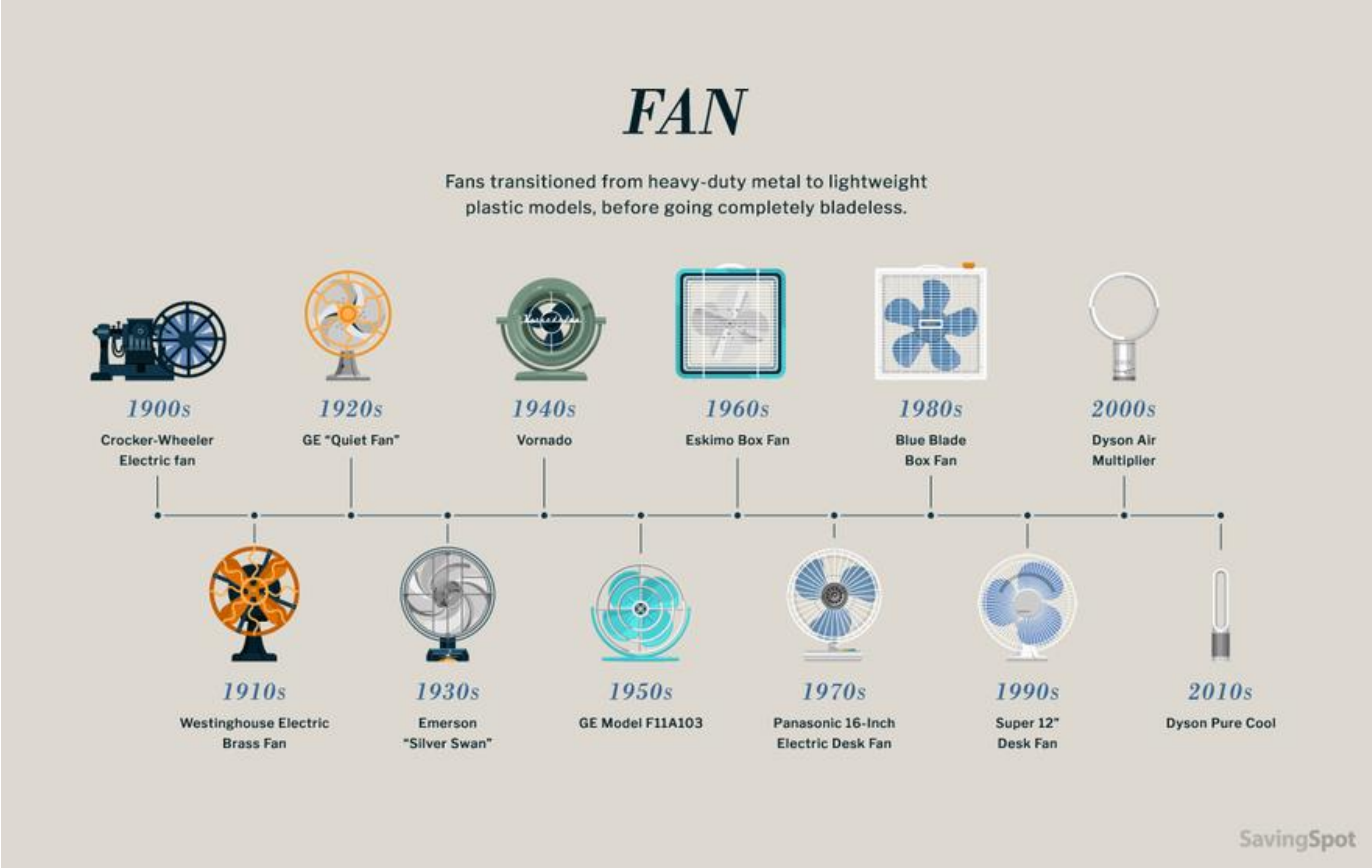
Dial a rotary phone


GROUP I
I-A
I-B
I-C*†
GROUP II
II-A*
II-B
II-C
GROUP III
III-A
III-B
III-C
GROUP IV
IV-A*
IV-B*
IV-C
GROUP V
V-A
V-B
V-C
GROUP VI
VI-A
VI-B‡
VI-C
* SIGNIFICANTLY SHORTER KEYING TIME
† SIGNIFICANTLY LOWER ERROR RATE
‡ SIGNIFICANTLY MORE PREFERRED

YouTube https://youtu.be/kCSzjExvbTQ

Phone Buttons - Numberphile


TV
Through the decades, TVs grew both larger and slimmer.
1920s
Image Dissector
1940s
RCA 630-TS
1960s
Predicta
1980s
Magnavox Tabletop
2000s
Samsung Smart TV
1930s
RCA TRK-12
1950s
Westinghouse H840CK15
1970s
Sony 19" KV-1920 Color
1990s
Philips Flat TV
2010s
Samsung Curved UHD TV
SavingSpot


FAN
Fans transitioned from heavy-duty metal to lightweight plastic models, before going completely bladeless.
1900s
Crocker-Wheeler Electric fan
1920s
GE "Quiet Fan"
1940s
Vornado
1960s
Eskimo Box Fan
1980s
Blue Blade Box Fan
2000s
Dyson Air Multiplier
1910s
Westinghouse Electric Brass Fan
1930s
Emerson "Silver Swan"
1950s
GE Model F11A103
1970s
Panasonic 16-Inch Electric Desk Fan
1990s
Super 12" Desk Fan
2010s
Dyson Pure Cool
SavingSpot

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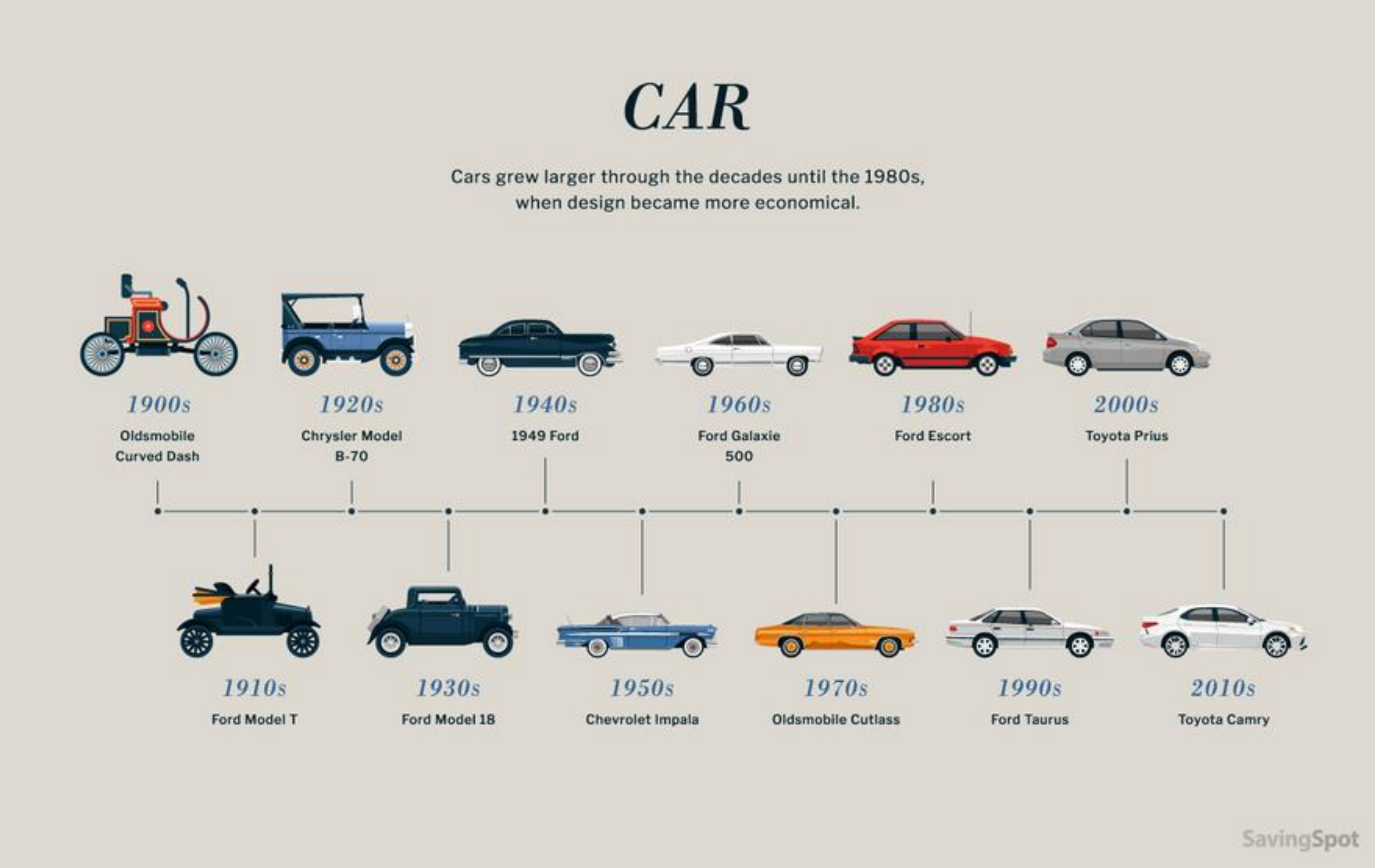
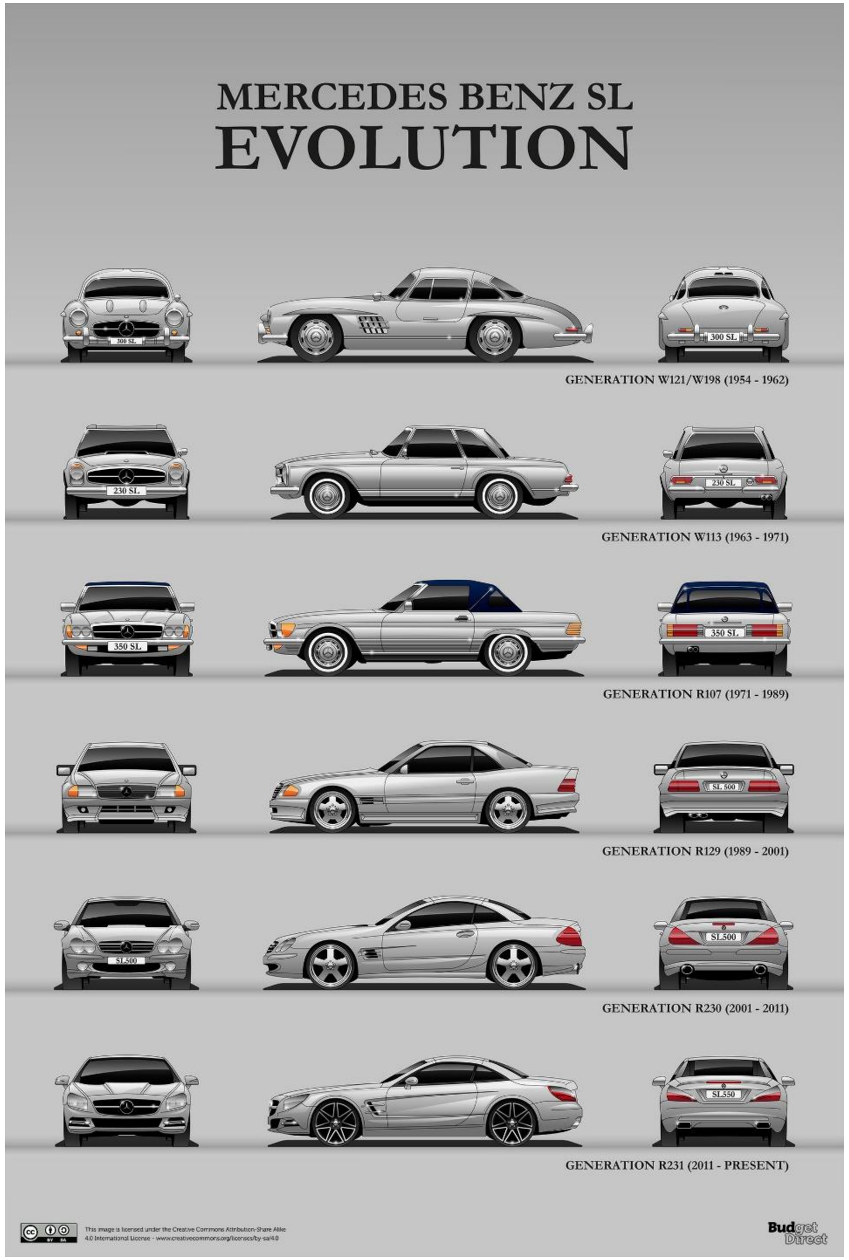
VACUUM CLEANER
Since their inception, vacuum cleaners have evolved to be smaller and more portable, with the goal of making cleaning easier.
1900s
Hoover Model 0
1910s
The Royal Standard
1920s
Hoover 700
1930s
Hoover Model 150
1940s
Electrolux Z36
1950s
The Hamilton Beach Model 14
1960s
The Hoover Constellation
1970s
Interstate Engineering Corporation's Model C-8
1980s
Cyclone
1990s
Dyson DC01 Bagless 'Hoover'
2000s
Roomba
2010s
Dyson 360 Eye
SavingSpot


HEADPHONES
Headphones evolved from bulky over-ear speakers to nearly invisible buds, as the technology focused on music.
1900s
Electrophone
1910s
Baldy Phones
1920s
Brandes Superior
1930s
Ericsson Headphones
1940s
AKG K120 DYN
1950s
Koss SP3 Stereophones
1960s
Koss ESP-6
1970s
Sennheiser HD414
1980s
Walkman Headphone
1990s
Sony MDR-G61
2000s
iPod Earbuds
2010s
Apple AirPods
SavingSpot


CAR
Cars grew larger through the decades until the 1980s, when design became more economical.
1900s
Oldsmobile Curved Dash
1920s
Chrysler Model B-70
1940s
1949 Ford
1960s
Ford Galaxie 500
1980s
Ford Escort
2000s
Toyota Prius
1910s
Ford Model T
1930s
Ford Model 18
1950s
Chevrolet Impala
1970s
Oldsmobile Cutlass
1990s
Ford Taurus
2010s
Toyota Camry
SavingSpot


SNEAKERS
Once used almost exclusively for sports and leisure activities, sneakers evolved into fashion statements.
1900s
The "Pettitt" Match Shoe
1920s
Spring Court G1
1940s
Adolf Dassler Adidas Sportshuehe
1960s
Adidas Stan Smith
1980s
Nike Air Jordans 1
2000s
Nike Free 5.0
1910s
Converse All Star
1930s
B.F. Goodrich PF Flyers
1950s
Adidas Samba
1970s
Nike Waffle Tread
1990s
Nike Air Max 90 (Air Max III)
2010s
Nike VaporMax
SavingSpot


HOME AUDIO SYSTEM
Home audio systems transitioned from ornate wooden designs
to compact, unobtrusive designs.
1900s
Victor Victrola
Talking Machine
1920s
Victrola
Portable
1940s
Admiral Home
Entertainment System
1960s
8-Track Home
Deck
1980s
JVC RC-M90
"Boombox"
2000s
Sonos ZP100
1910s
Edison's Disc
Phonograph Cabinets
1930s
Zenith Z1000
Stratosphere
1950s
Harman Kardon
Festival TA230
1970s
Advent Model 200
1990s
Sony SCD-1
CD Player
2010s
Smart Speakers
SavingSpot


MERCEDES BENZ SL
EVOLUTION
GENERATION W121/W198 (1954 - 1962)
GENERATION W113 (1963 - 1971)
GENERATION R107 (1971 - 1989)
GENERATION R129 (1989 - 2001)
GENERATION R230 (2001 - 2011)
GENERATION R231 (2011 - PRESENT)
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Budget Direct

Generating Alternatives – Morphological Chart Rational Methods - Design Methods

Aim - **Generate the complete range of alternative design solutions** - The aim of the morphological chart method is to generate the complete range of alternative design solutions for a product, and hence to widen the search for potential new solutions.

1. **List the features / functions / design blocks** - List the features or functions that are essential to the product. Whilst not being too long, the list must comprehensively cover the functions, at an appropriate level of generalization.

2. **List the means by which features/functions might be achieved** - For each feature or function list the means by which it might be achieved. These lists might include new ideas as well as known existing components or sub solutions (3-8).

3. **Draw up a chart containing all the possible sub solutions (Morph Chart)**. This morphological chart represents the total solution space for the product, made up of the combinations of sub solutions.

4. **Construction a Solution** - **Identify feasible combinations of sub solutions** - The total number of possible combinations may be very large, and so search strategies may have to be guided by constraints or criteria.

- **Method 1** – choose only a restricted set of sub solutions from each row - say, those that are known to be efficient or practical, or look promising
- **Method 2** - identify the infeasible sub solutions, or incompatible pairs of sub solutions, and so rule out those combinations that would include them

Generating Alternatives – Morphological Chart Rational Methods - Design Methods

- **When to stop generating solutions**
  - **Generate broad range of the design space**
    - **Representative**
    - **Diverse**
    - **Creative**
  - **20 solutions**
  - **Method 1** – choose only a restricted set of sub solutions from each row - say, those that are known to be efficient or practical, or look promising
  - **Method 2** - identify the infeasible sub solutions, or incompatible pairs of sub solutions, and so rule out those combinations that would include them

Example: Water Bottle Morphological Chart

Example: Water Bottle Morphological Chart – Step 1

- 1. **List the features / functions / design blocks** - List the features or functions that are essential to the product. Whilst not being too long, the list must comprehensively cover the functions, at an appropriate level of generalization.

Design Block				
Mouth Piece				
Container				
Handle				
Geometry D:H Ratio				
Shape				

Example: Water Bottle Morphological Chart – Step 2 & 3

2. List the means by which features/functions might be achieved - For each feature or function list the means by which it might be achieved. These lists might include new ideas as well as known existing components or sub solutions.

3. **Draw up a chart containing all the possible sub solutions (Morph Chart)**. This morphological chart represents the total solution space for the product, made up of the combinations of sub solutions.

Design Block	Option 1	Option 2	Option 3	Option 4
Mouth Piece	Twist Top	Faucet	Rubber Nipple	Pull Top
Container	Plastic	Disposal	Metal	Glass
Handle	Top	Body	Attached (pouch)	
Geometry D:H Ratio	<1:2	1:2 – 1:3	> 1:3	
Shape	Ergonomic	Pouch	Straight	Ribbed

Number of solutions
4x4x3x3x4=576

Example: Water Bottle Morphological Chart – Step 4

4. **Identify feasible combinations of sub solutions** - The total number of possible combinations may be very large, and so search strategies may have to be guided by constraints or criteria.

Metal Water Bottle

Design Block	Option 1	Option 2	Option 3	Option 4
Mouth Piece	Twist Top	Faucet	Rubber Nipple	Pull Top
Container	Plastic	Disposal	Metal	Glass
Handle	Top	Body	Attached (pouch)	
Geometry D:H Ratio	<1:2	1:2 – 1:3	> 1:3	
Shape	Ergonomic	Pouch	Constant Diameter	Ribbed

Note: Skip a line (design block)

Example: Water Bottle Morphological Chart – Step 4

4. **Identify feasible combinations of sub solutions** - The total number of possible combinations may be very large, and so search strategies may have to be guided by constraints or criteria.

Water Pouch Backpack

Design Block	Option 1	Option 2	Option 3	Option 4
Mouth Piece	Twist Top	Faucet / Spigot	Rubber Nipple	Pull Top
Container	Plastic	Disposal	Metal	Glass
Handle	Top	Body	Attached (pouch)	
Geometry D:H Ratio	<1:2	1:2 – 1:3	> 1:3	
Shape	Ergonomic	Pouch	Constant Diameter	Ribbed

Note: Skip a line (design block)

Example: Water Bottle Morphological Chart – Step 4

4. **Identify feasible combinations of sub solutions** - The total number of possible combinations may be very large, and so search strategies may have to be guided by constraints or criteria.

Water bottle Disposable

Design Block	Option 1	Option 2	Option 3	Option 4
Mouth Piece	Twist Top	Faucet / Spigot	Rubber Nipple	Pull Top
Container	Plastic	Disposal	Metal	Glass
Handle	Top	Body	Attached (pouch)	
Geometry D:H Ratio	<1:2	1:2 – 1:3	> 1:3	
Shape	Ergonomic	Pouch	Constant Diameter	Ribbed

Note: Multiple options of the same design block

Example: Water Bottle Morphological Chart – Step 4

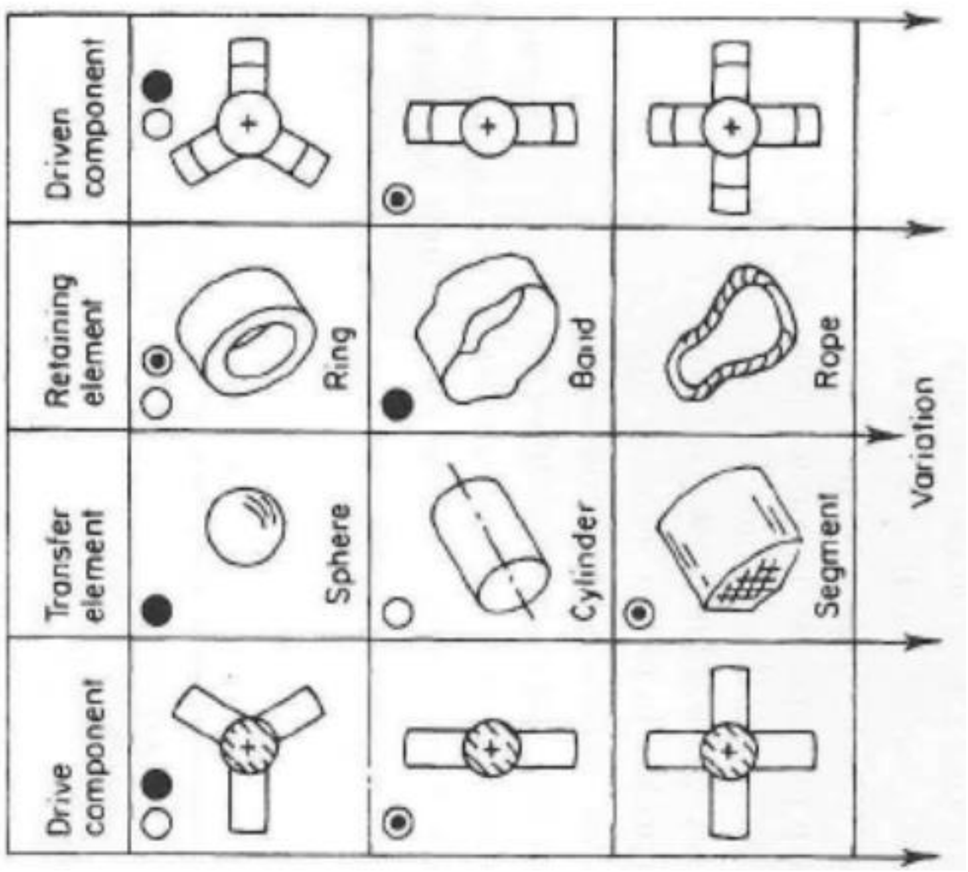
4. **Identify feasible combinations of sub solutions** - The total number of possible combinations may be very large, and so search strategies may have to be guided by constraints or criteria.

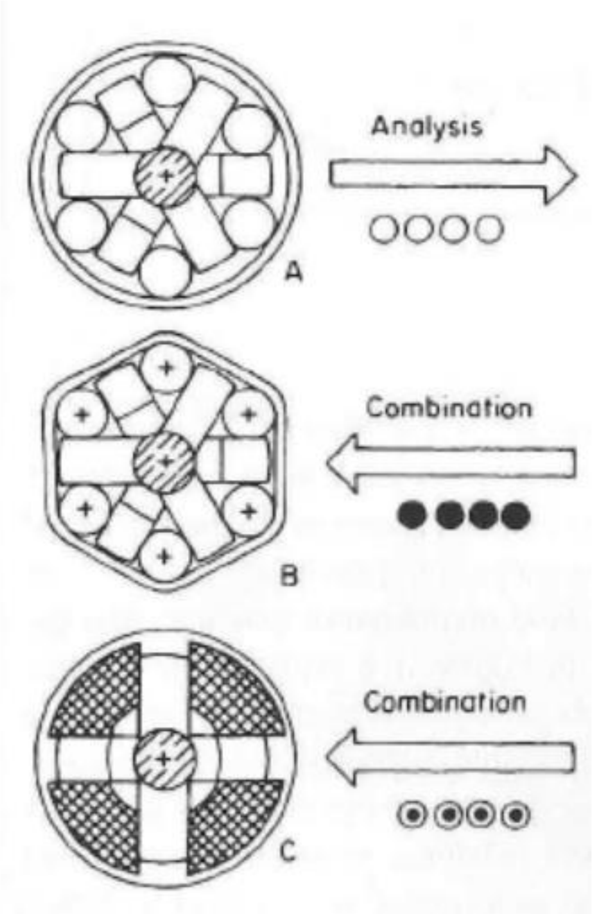
Design Block	Option 1	Option 2	Option 3	Option 4
Mouth Piece	Twist Top	Faucet / Spigot	Rubber Nipple	Pull Top
Container	Plastic	Disposal	**Metal**	Glass
Handle	Top	Body	Attached (pouch)	
Geometry D:H Ratio	<1:2	1:2 – 1:3	> 1:3	
Shape	Ergonomic	**Pouch**	Constant Diameter	Ribbed

Note: Non Reasonable solutions

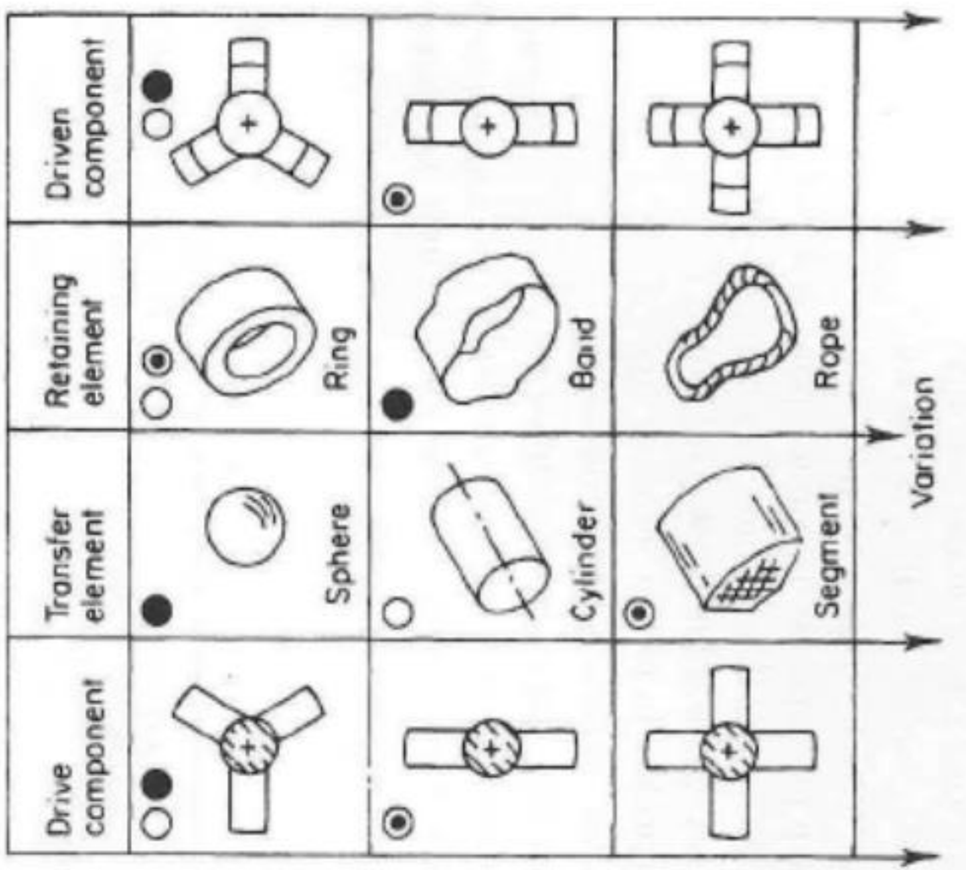
Example: Shaft Coupling Morphological Chart

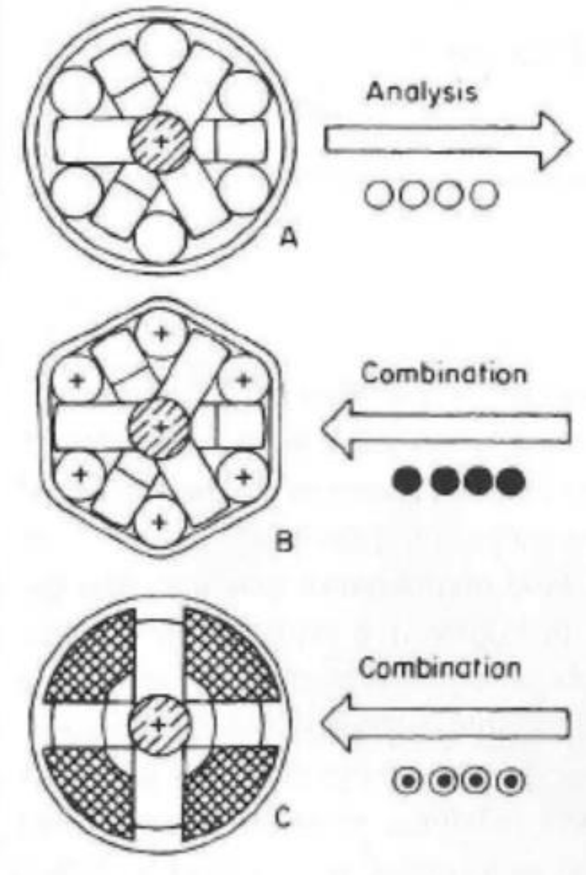
Example: Shaft Coupling Morphological Chart





Example: Shaft Coupling Morphological Chart





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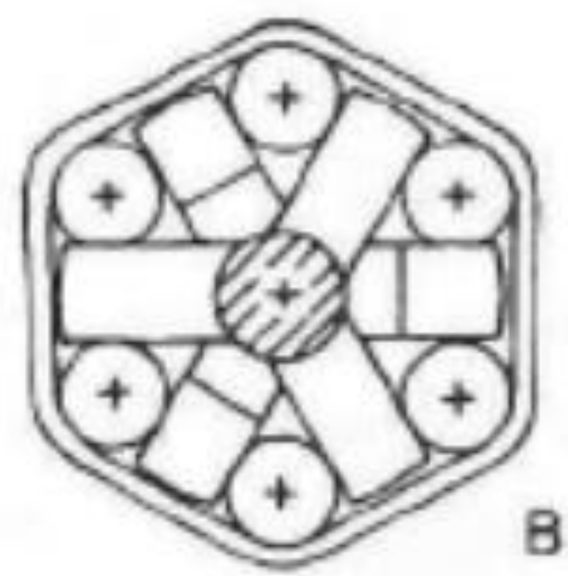
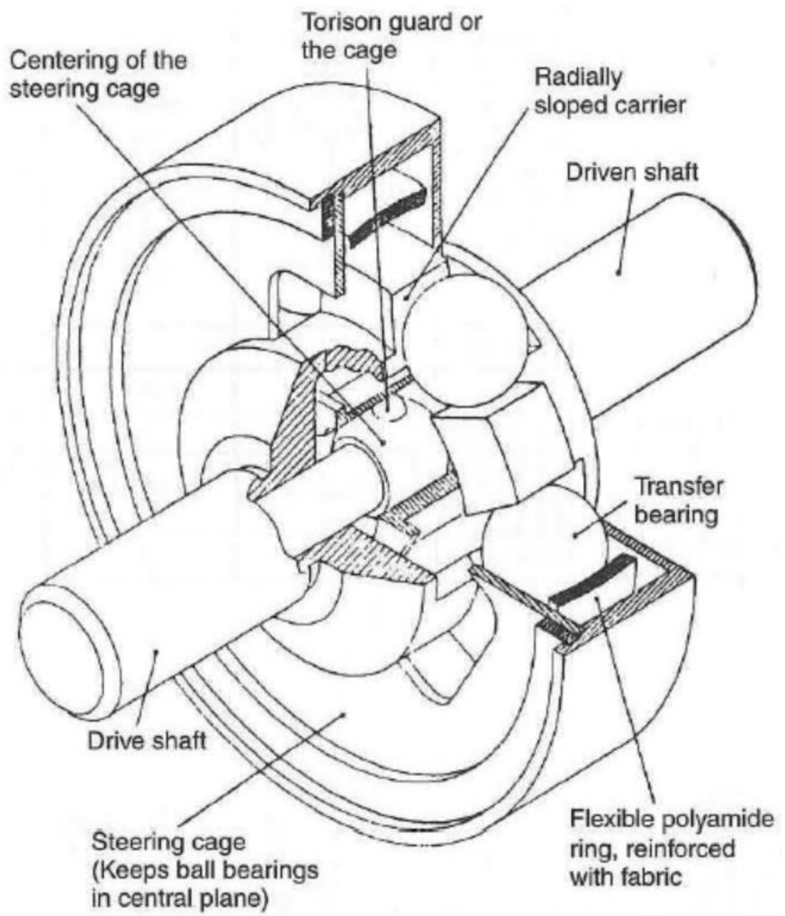
Example: Shaft Coupling Morphological Chart





Example: Fork Lift Truck Morphological Chart

Example: Fork Lift Truck Morphological Chart

Feature	Means				
Support	Wheels	Track	Air cushion	Slides	Pedipulators
Propulsion	Driven wheels	Air thrust	Moving cable	Linear induction	
Power	Electric	Petrol	Diesel	Bottled gas	Steam
Transmission	Gears and shafts	Belts	Chains	Hydraulic	Flexible cable
Steering	Turning wheels	Air thrust	Rails		
Stopping	Brakes	Reverse thrust	Ratchet		
Lifting	Hydraulic ram	Rack and pinion	Screw	Chain or rope hoist	
Operator	Seated at front	Seated at rear	Standing	Walking	Remote control

Example: Fork Lift Truck Morphological Chart

Feature	Means				
Support	Wheels	Track	Air cushion	Slides	Pedipulators
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Operator	Seated at front	Seated at rear	Standing	Walking	Remote control

Example: Fork Lift Truck Morphological Chart

YouTube https://youtu.be/FSrcMaid0mg

Aliens - Power Loader

Evaluating Alternatives

Weighted Objectives Method

Weighted Objectives Method
Rational Methods - Design Methods

- **Aim** - **Compare the utility values of alternative design proposals** - The aim of the weighted objectives method is to compare the utility values of alternative design proposals, on the basis of performance against differentially weighted objectives.

1. **List the design objectives** - These may need modification from an initial listi an objectives tree can also be a *useful* feature of this method.

2. **Rank-order the list of objectives** - Pair-wise comparisons may help to establish the rank order.

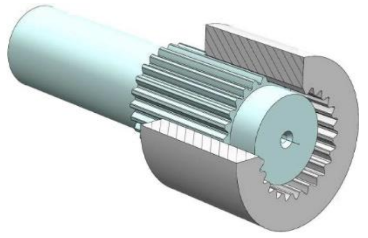
3. **Assign relative weightings to the objectives** - These numerical values should be on an interval scalei an alternative is to assign relative weights at different levels of an objectives tree, so that all weights sum to 1.0.

4. **Tabulate the objectives parameters for each design candidate**

5. **Establish performance parameters or utility scores for each of the objectives** - Both quantitative and qualitative objectives should be reduced to performance on simple points scales.

6. **Calculate and compare the relative utility values of the alternative designs** - Multiply each parameter score by its weighted value: the 'best' alternative has the highest sum value. Comparison and discussion of utility value profiles may be a better design aid than simply choosing the 'best'.

Example: Shaft Hub – Dynamics Test Rig



Example: Test Rig
Weighted Objectives Method – Step 1

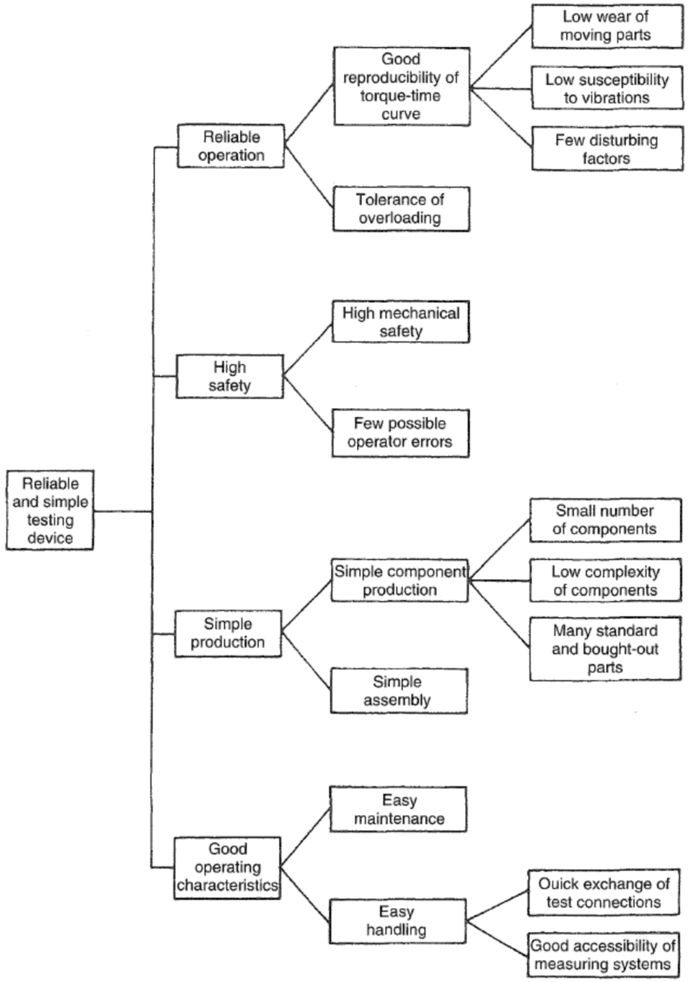
List the design objectives - These may need modification from an initial list of an objectives tree can also be a *useful* feature of this method.

- **Quantitative assessment - performance** - An objective should be stated in such a way that a quantitative assessment can be made of the performance achieved by a design on that objective.

Example: Test Rig

Objectives

- (A) Reliable Operation
- (B) High Safety
- (C) Simple Production
- (D) Good Operational Characteristics



Example: Test Rig
Weighted Objectives Method – Step 2

Rank-order the list of objectives - Pair-wise comparisons help to establish the rank order.

Step 2.1 - Each objective is considered in turn against each of the others. A figure 1 or 0 is entered into the relevant matrix cell in the chart, depending on whether the first objective is considered more or less important than the second, and so on.

For example, start with objective A and work along the chart row, asking 'Is A more important than B?' ... 'than C?' . . . 'than D?', etc. If it is considered more important, a 1 is entered in the matrix cell; if it is considered less important, a 0 is entered.

Verification Note: The upper right triangle matrix is inverted to the bottom lower triangle matric (inverse symmetry along the diagonal)

Step 2.2 – Sum up the rows and order the objective according to their ranks

Objectives	A	B	C	D	E	Row totals
A	—	0	0	0	1	1
B	1	—	1	1	1	4
C	1	0	—	1	1	3
D	1	0	0	—	1	2
E	0	0	0	0	—	0

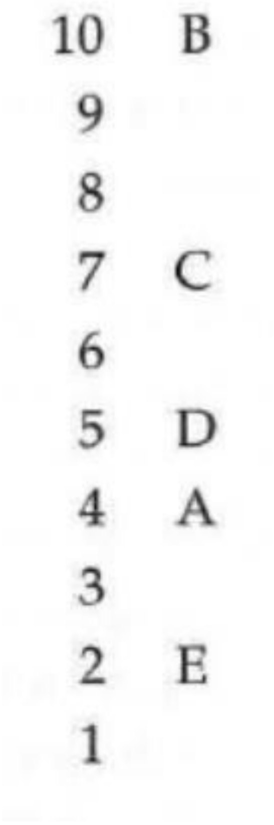
Ranked Order of Objectives

B
C
D
A
E

Example: Test Rig
Weighted Objectives Method – Step 3

Assign relative weightings to the objectives –

3.1 Version 1 - Assign a numerical value to each objective, representing its weight relative to the other objectives.



B	10	10/28	0.35
C	7	7/28	0.25
D	5	5/28	0.18
A	4	4/28	0.15
E	2	2/28	0.07

Example: Test Rig
Weighted Objectives Method – Step 3

Assign relative weightings to the objectives –

3.1 Version 2 - Decide to share a certain number of 'points' - say, 100 - amongst all the objectives, awarding points on relative value and making tradeoffs and adjustments between the points awarded to different objectives until acceptable relative allocations are achieved.

B	35
C	25
D	18
A	15
E	7

B	**0.35**
C	**0.25**
D	**0.18**
A	**0.15**
E	**0.07**

Example: Test Rig
Weighted Objectives Method – Step 3

3.2 Repeat the weight assignment to each level of the objective tree (Bottom left corner of each triangle)

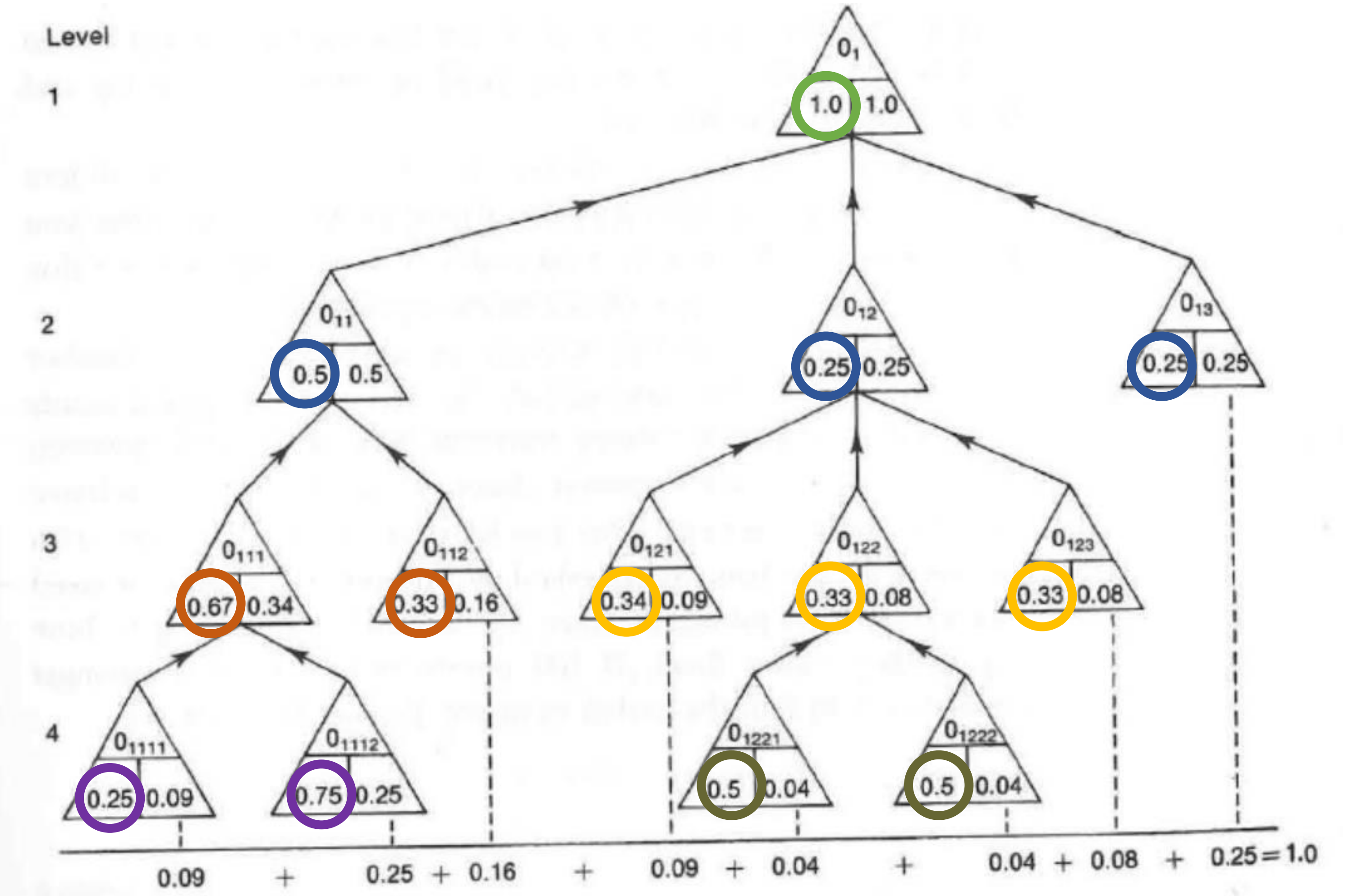
Note: the sum of all the branches are equal to 1

Level 1: 1

Level 2: 0.5+0.25+0.25=1

Level 3: 0.67+0.34=1 ; 0.34+0.33+0.33=1

Level 4: 0.25+0.75=1 ; 0.5+0.5=1



Example: Test Rig
Weighted Objectives Method – Step 3

3.3 Calculate the TRUE value of the weight of each objective using the value of the weight of the objective of the above value (bottom right of each triangle)

Level 2:

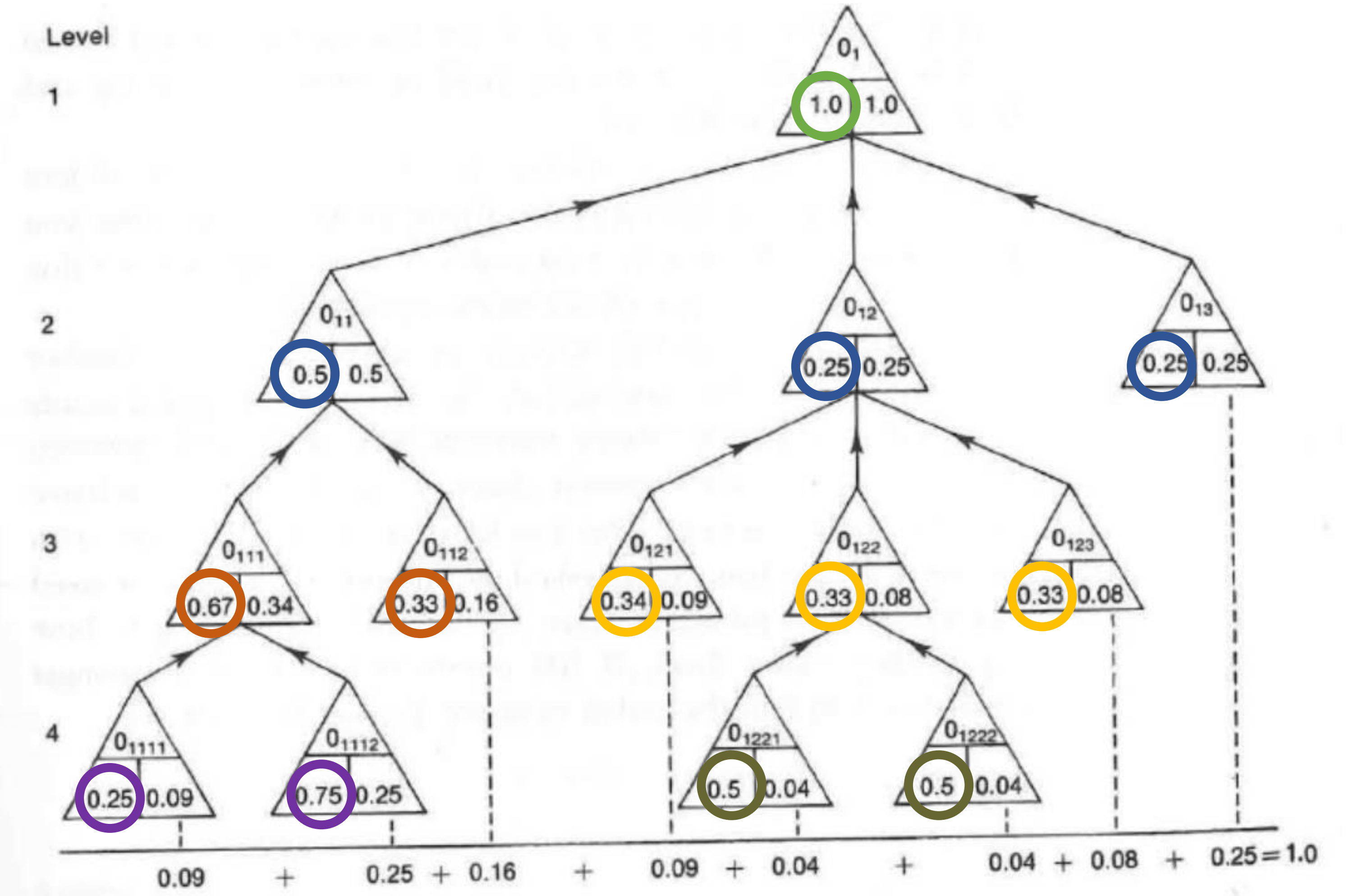
- 1x0.5=0.5
- 1x0.25=0.25
- 1x0.25=0.25

Level 3:

- 0.5x0.67=0.34
- 0.5x0.33=0.16

Level 4:

- 0.67x0.25=0.09
- 0.67x0.75=0.25



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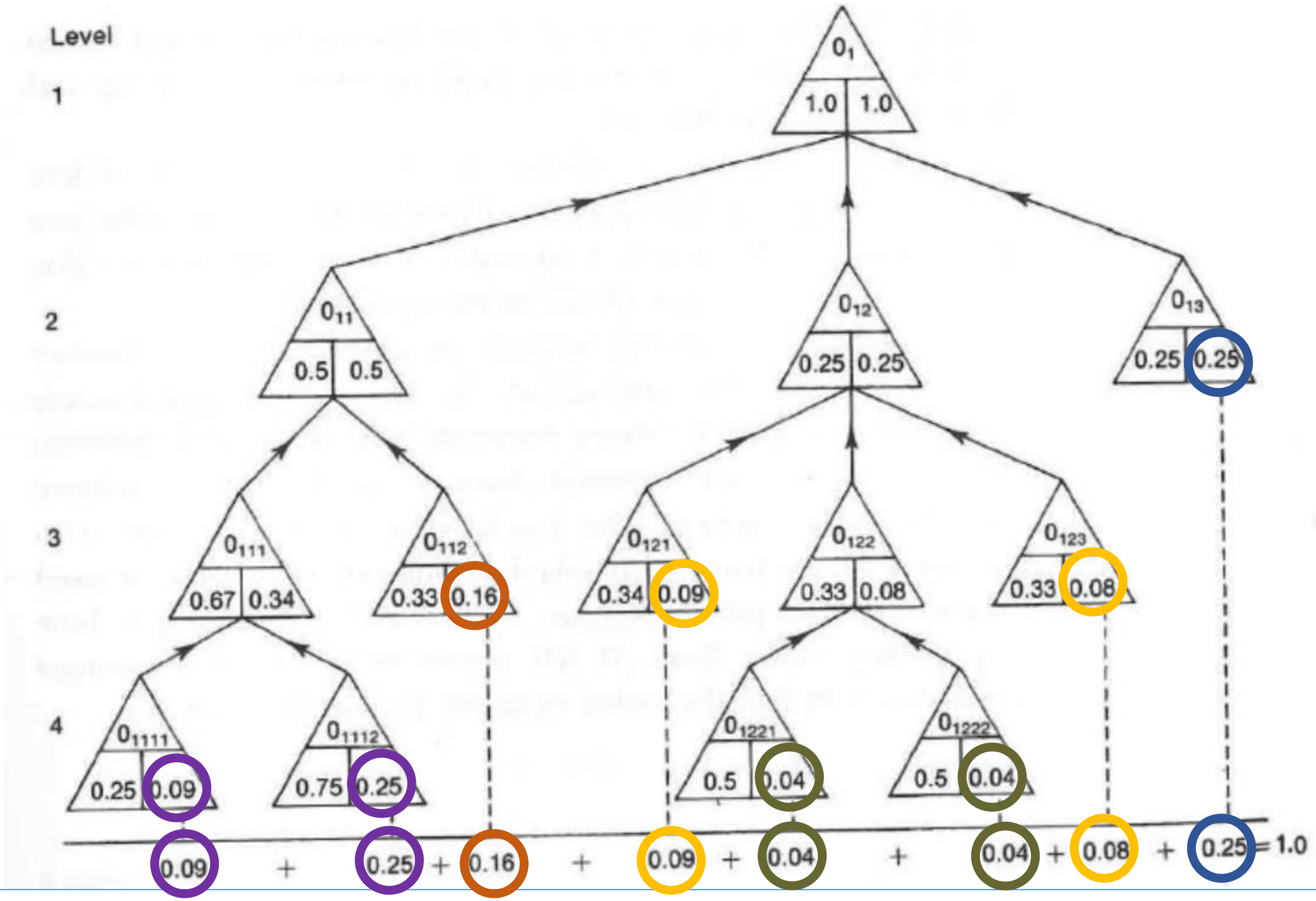
Example: Test Rig
Weighted Objectives Method – Step 3

3.4 Drop down all the TRUE weights of all the objectives

Note: The sum of all the weights mare equal to zero



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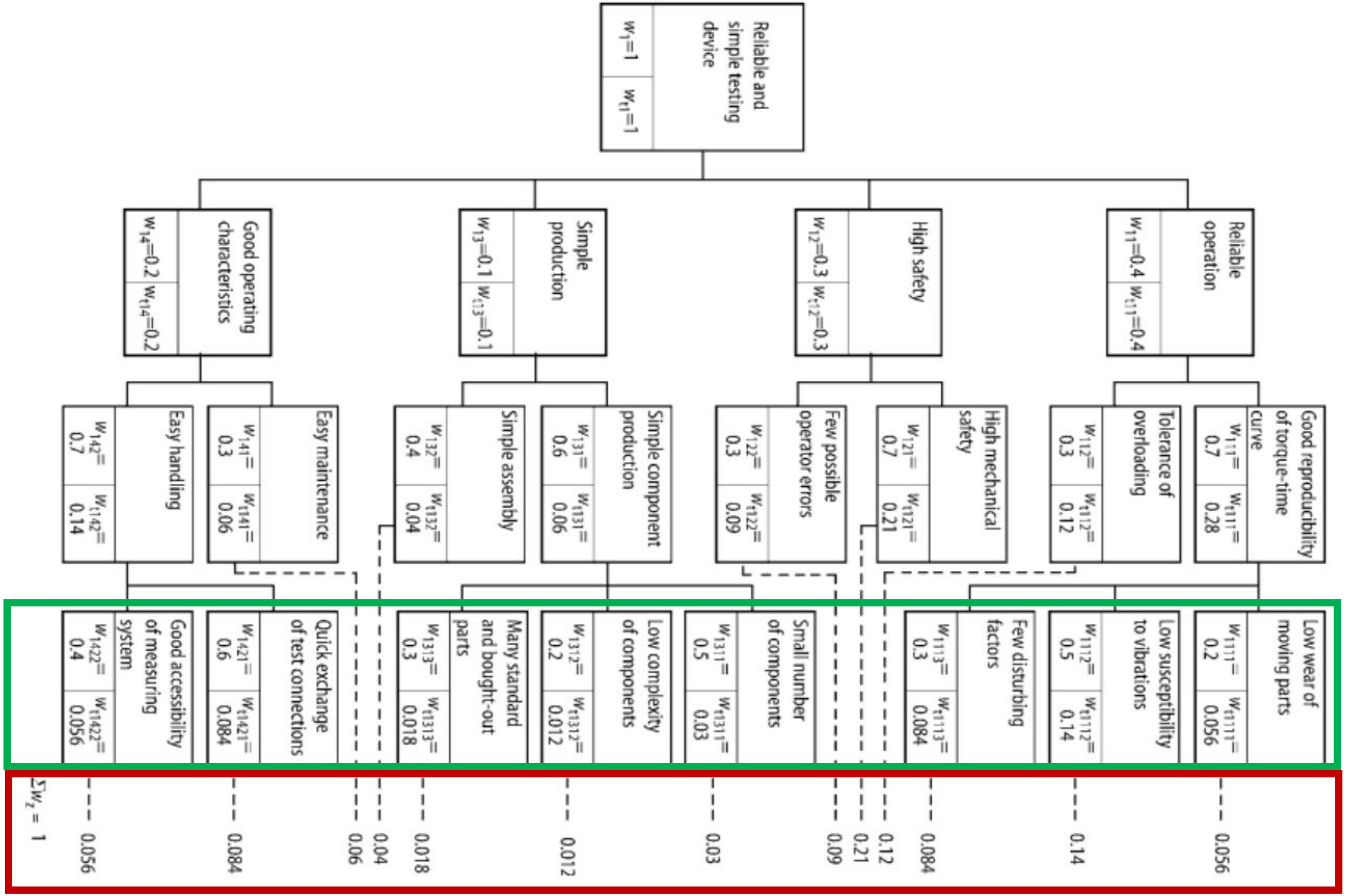
Reliable and simple testing device
$w_1=1$ $w_{t1}=1$
Reliable operation
$w_{11}=0.4$ $w_{t11}=0.4$
High safety
$w_{12}=0.3$ $w_{t12}=0.3$
Simple production
$w_{13}=0.1$ $w_{t13}=0.1$
Good operating characteristics
$w_{14}=0.2$ $w_{t14}=0.2$
Good reproducibility of torque-time curve
$w_{111}=$ 0.7 $w_{t111}=$ 0.28
Tolerance of overloading
$w_{112}=$ 0.3 $w_{t112}=$ 0.12
High mechanical safety
$w_{121}=$ 0.7 $w_{t121}=$ 0.21
Few possible operator errors
$w_{122}=$ 0.3 $w_{t122}=$ 0.09
Simple component production
$w_{131}=$ 0.6 $w_{t131}=$ 0.06
Simple assembly
$w_{132}=$ 0.4 $w_{t132}=$ 0.04
Easy maintenance
$w_{141}=$ 0.3 $w_{t141}=$ 0.06
Easy handling
$w_{142}=$ 0.7 $w_{t142}=$ 0.14
Low wear of moving parts
$w_{1111}=$ 0.2 $w_{t1111}=$ 0.056
Low susceptibility to vibrations
$w_{1112}=$ 0.5 $w_{t1112}=$ 0.14
Few disturbing factors
$w_{1113}=$ 0.3 $w_{t1113}=$ 0.084
Small number of components
$w_{1311}=$ 0.5 $w_{t1311}=$ 0.03
Low complexity of components
$w_{1312}=$ 0.2 $w_{t1312}=$ 0.012
Many standard and bought-out parts
$w_{1313}=$ 0.3 $w_{t1313}=$ 0.018
Quick exchange of test connections
$w_{1421}=$ 0.6 $w_{t1421}=$ 0.084
Good accessibility of measuring system
$w_{1422}=$ 0.4 $w_{t1422}=$ 0.056
$\Sigma w_z = 1$
0.056
0.084
0.06
0.04
0.018
0.012
0.03
0.09
0.21
0.12
0.084
0.14
0.056

No	Evaluation criteria	Wt.	Parameters	Unit	Variant V_1 Magn. m_{i1}	Value V_{i1}	Weighted value WV_{i1}	Variant V_2 Magn. m_{i2}	Value V_{i2}	Weighted value WV_{i2}	Variant V_3 Magn. m_{i3}	Value V_{i3}	Weighted value WV_{i3}	Variant V_4 Magn. m_{i4}	Value V_{i4}	Weighted value WV_{i4}
1	Low wear of moving parts	0.056	Amount of wear	-	high	3	0.168	low	6	0.336	average	4	0.224	low	6	0.336
2	Low susceptibility to vibrations	0.14	Natural frequency	s^{-1}	410	3	0.420	2370	7	0.980	2370	7	0.980	< 410	2	0.280
3	Few disturbing factors	0.084	Disturbing factors	-	high	2	0.168	low	7	0.588	low	6	0.504	(average)	4	0.336
4	Tolerance of overloading	0.12	Overload reserve	%	5	5	0.600	10	7	0.840	10	7	0.840	20	8	0.960
5	High mechanical safety	0.21	Expected mechan. safety	-	average	4	0.840	high	7	1.470	high	7	1.470	very high	8	1.680
6	Few possible operator errors	0.09	Possibilities of operator errors	-	high	3	0.270	low	7	0.630	low	6	0.540	average	4	0.360
7	Small number of components	0.03	No. of components	-	average	5	0.150	average	4	0.120	average	4	0.120	low	6	0.180
8	Low complexity of components	0.012	Complexity of components	-	low	6	0.072	low	7	0.084	average	5	0.060	high	3	0.036
9	Many standard and bought-out parts	0.018	Proportion of standard and bought-out components	-	low	2	0.036	average	6	0.108	average	6	0.108	high	8	0.144
10	Simple assembly	0.04	Simplicity of assembly	-	low	3	0.120	average	5	0.200	average	5	0.200	high	7	0.280
11	Easy maintenance	0.06	Time and cost or maintenance	-	average	4	0.240	low	8	0.480	low	7	0.420	high	3	0.180
12	Quick exchange of test connections	0.084	Estimated time needed to exchange test connections	min	180	4	0.336	120	7	0.588	120	7	0.588	180	4	0.336
13	Good accessibility of measuring systems	0.056	Accessibility of measuring systems	-	good	7	0.392	good	7	0.392	good	7	0.392	average	5	0.280
		$\Sigma w_i =$ 1.0				$OV_1 = 51$ $R_1 = 0.39$	$OWV_1 =$ 3.812 $WR_1 = 0.38$		$OV_2 = 85$ $R_2 = 0.65$	$OWV_2 =$ 6.816 $WR_2 = 0.68$		$OV_3 = 78$ $R_3 = 0.60$	$OWV_3 =$ 6.446 $WR_3 = 0.64$		$OV_4 = 68$ $R_4 = 0.52$	$OWV_4 =$ 5.388 $WR_4 = 0.54$

Example: Test Rig
Weighted Objectives Method – Step 4

Tabulate the objectives parameters for each design candidate

No.	Evaluation criteria	Wt.	Objective Parameters	Unit	Variant V_1 (e.g. Eng.$_1$)			...	Variant V_2 (e.g. Eng.$_2$)			...	Variant V_j			...	Variant V_m		
					Magn. m_{i1}	Value v_{i1}	Weighted value WV_{i1}		Magn. m_{i2}	Value v_{i2}	Weighted value WV_{i2}		Magn. m_{ij}	Value v_{ij}	Weighted value WV_{ij}		Magn. m_{im}	Value v_{im}	Weighted value WV_{im}
1	Low fuel consumption	0.3	Fuel consumption	$\frac{g}{kWh}$	240			...	300			...	m_{1j}			...	m_{1m}		
2	Light weight construction	0.15	Mass per unit power	$\frac{kg}{kW}$	1.7			...	2.7			...	m_{2j}			...	m_{2m}		
3	Simple production	0.1	Simplicity of components	–	low			...	average			...	m_{3j}			...	m_{3m}		
4	Long service life	0.2	Service life	km	80 000			...	150 000			...	m_{4j}			...	$m4_{m}$		
⋮	⋮	⋮	⋮	⋮	⋮				⋮				⋮				⋮		
i		W_i			m_{i1}			...	m_{i2}			...	m_{ij}			...	m_{im}		
⋮	⋮	⋮	⋮	⋮	⋮				⋮				⋮				⋮		
n		W_n			m_{n1}			...	m_{n2}			...	m_{nj}			...	m_{nm}		
		$\sum_{i=1}^{n} W_i = 1$																	

No	Evaluation criteria	Wt.	Parameters	Unit	Variant V_1			Variant V_2			Variant V_3			Variant V_4		
					Magn. m_{i1}	Value v_{i1}	Weighted value wv_{i1}	Magn. m_{i2}	Value v_{i2}	Weighted value wv_{i2}	Magn. m_{i3}	Value v_{i3}	Weighted value wv_{i3}	Magn. m_{i4}	Value v_{i4}	Weighted value wv_{i4}
1	Low wear of moving parts	0.056	Amount of wear	-	high	3	0.168	low	6	0.336	average	4	0.224	low	6	0.336
2	Low susceptibility to vibrations	0.14	Natural frequency	s^{-1}	410	3	0.420	2370	7	0.980	2370	7	0.980	< 410	2	0.280
3	Few disturbing factors	0.084	Disturbing factors	-	high	2	0.168	low	7	0.588	low	6	0.504	(average)	4	0.336
4	Tolerance of overloading	0.12	Overload reserve	%	5	5	0.600	10	7	0.840	10	7	0.840	20	8	0.960
5	High mechanical safety	0.21	Expected mechan. safety	-	average	4	0.840	high	7	1.470	high	7	1.470	very high	8	1.680
6	Few possible operator errors	0.09	Possibilities of operator errors	-	high	3	0.270	low	7	0.630	low	6	0.540	average	4	0.360
7	Small number of components	0.03	No. of components	-	average	5	0.150	average	4	0.120	average	4	0.120	low	6	0.180
8	Low complexity of components	0.012	Complexity of components	-	low	6	0.072	low	7	0.084	average	5	0.060	high	3	0.036
9	Many standard and bought-out parts	0.018	Proportion of standard and bought-out components	-	low	2	0.036	average	6	0.108	average	6	0.108	high	8	0.144
10	Simple assembly	0.04	Simplicity of assembly	-	low	3	0.120	average	5	0.200	average	5	0.200	high	7	0.280
11	Easy maintenance	0.06	Time and cost or maintenance	-	average	4	0.240	low	8	0.480	low	7	0.420	high	3	0.180
12	Quick exchange of test connections	0.084	Estimated time needed to exchange test connections	min	180	4	0.336	120	7	0.588	120	7	0.588	180	4	0.336
13	Good accessibility of measuring systems	0.056	Accessibility of measuring systems	-	good	7	0.392	good	7	0.392	good	7	0.392	average	5	0.280
		$\Sigma w_i = 1.0$				$OV_1 = 51$ $R_1 = 0.39$	$OWV_1 = 3.812$ $WR_1 = 0.38$		$OV_2 = 85$ $R_2 = 0.65$	$OWV_2 = 6.816$ $WR_2 = 0.68$		$OV_3 = 78$ $R_3 = 0.60$	$OWV_3 = 6.446$ $WR_3 = 0.64$		$OV_4 = 68$ $R_4 = 0.52$	$OWV_4 = 5.388$ $WR_4 = 0.54$

Example: Test Rig
Weighted Objectives Method – Step 5

5. **Establish performance parameters or utility scores for each of the objectives** - Both quantitative and qualitative objectives should be reduced to performance on simple points scales.

11-point scale	Meaning	5-point scale	Meaning
0	Totally useless solution	0	Inadequate
1	Inadequate solution		
2	Very poor solution	1	Weak
3	Poor solution		
4	Tolerable solution		
5	Adequate solution	2	Satisfactory
6	Satisfactory solution		
7	Good solution	3	Good
8	Very good solution		
9	Excellent solution	4	Excellent
10	Perfect or ideal solution		

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Value scale			
Use-value analysis		Guideline VDI 2225	
Pts.	Meaning	Pts.	Meaning
0	absolutely useless solution	0	unsatisfactory
1	very inadequate solution		
2	weak solution	1	just tolerable
3	tolerable solution		
4	adequate solution	2	adequate
5	satisfactory solution		
6	good solution with few drawbacks	3	good
7	good solution		
8	very good solution	4	very good (ideal)
9	solution exceeding the requirement		
10	ideal solution		

11-point scale	Meaning	5-point scale	Meaning
0	Totally useless solution	0	Inadequate
1	Inadequate solution		
2	Very poor solution	1	Weak
3	Poor solution		
4	Tolerable solution		
5	Adequate solution	2	Satisfactory
6	Satisfactory solution		
7	Good solution	3	Good
8	Very good solution		
9	Excellent solution	4	Excellent
10	Perfect or ideal solution		

Value Scale		Parameter magnitudes			
Use-value analysis Pts	VDI 2225 Pts	Fuel consumption g/kWh	Mass per unit power kg/kW	Simplicity of components	Service life
0	0	400	3.5	extremely complicated	$20 \cdot 10^3$
1		380	3.3		30
2	1	360	3.1	complicated	40
3		340	2.9		60
4	2	320	2.7	average	80
5		300	2.5		100
6	3	280	2.3	simple	120
7		260	2.1		140
8	4	240	1.9	extremely simple	200
9		220	1.7		300
10		200	1.5		$500 \cdot 10^3$

No	Evaluation criteria	Wt.	Parameters	Unit	Variant V_1			Variant V_2			Variant V_3			Variant V_4		
		w_i			Magn. m_{i1}	Value v_{i1}	Weighted value wv_{i1}	Magn. m_{i2}	Value v_{i2}	Weighted value wv_{i2}	Magn. m_{i3}	Value v_{i3}	Weighted value wv_{i3}	Magn. m_{i4}	Value v_{i4}	Weighted value wv_{i4}
1	Low wear of moving parts	0.056	Amount of wear	-	high	3	0.168	low	6	0.336	average	4	0.224	low	6	0.336
2	Low susceptibility to vibrations	0.14	Natural frequency	s^{-1}	410	3	0.420	2370	7	0.980	2370	7	0.980	<410	2	0.280
3	Few disturbing factors	0.084	Disturbing factors	-	high	2	0.168	low	7	0.588	low	6	0.504	(average)	4	0.336
4	Tolerance of overloading	0.12	Overload reserve	%	5	5	0.600	10	7	0.840	10	7	0.840	20	8	0.960
5	High mechanical safety	0.21	Expected mechan. safety	-	average	4	0.840	high	7	1.470	high	7	1.470	very high	8	1.680
6	Few possible operator errors	0.09	Possibilities of operator errors	-	high	3	0.270	low	7	0.630	low	6	0.540	average	4	0.360
7	Small number of components	0.03	No. of components	-	average	5	0.150	average	4	0.120	average	4	0.120	low	6	0.180
8	Low complexity of components	0.012	Complexity of components	-	low	6	0.072	low	7	0.084	average	5	0.060	high	3	0.036
9	Many standard and bought-out parts	0.018	Proportion of standard and bought-out components	-	low	2	0.036	average	6	0.108	average	6	0.108	high	8	0.144
10	Simple assembly	0.04	Simplicity of assembly	-	low	3	0.120	average	5	0.200	average	5	0.200	high	7	0.280
11	Easy maintenance	0.06	Time and cost for maintenance	-	average	4	0.240	low	8	0.480	low	7	0.420	high	3	0.180
12	Quick exchange of test connections	0.084	Estimated time needed to exchange test connections	min	180	4	0.336	120	7	0.588	120	7	0.588	180	4	0.336
13	Good accessibility of measuring systems	0.056	Accessibility of measuring systems	-	good	7	0.392	good	7	0.392	good	7	0.392	average	5	0.280
		$\Sigma w_i = 1.0$				$OV_1 = 51$ $R_1 = 0.39$	$OWV_1 = 3.812$ $WR_1 = 0.38$		$OV_2 = 85$ $R_2 = 0.65$	$OWV_2 = 6.816$ $WR_2 = 0.68$		$OV_3 = 78$ $R_3 = 0.60$	$OWV_3 = 6.446$ $WR_3 = 0.64$		$OV_4 = 68$ $R_4 = 0.52$	$OWV_4 = 5.388$ $WR_4 = 0.54$

No.	Evaluation criteria	Wt.	Parameters	Unit	Variant V_1 (e.g. $Eng._1$) Magn. m_{i1}	Value v_{i1}	Weighted value WV_{i1}	Variant V_2 (e.g. $Eng._2$) Magn. m_{i2}	Value v_{ij}	Weighted value WV_{ij}	…	Variant V_j Magn. m_{ij}	Value v_{ij}	Weighted value WV_{ij}	…	Variant V_m Magn. m_{im}	Value v_{im}	Weighted value WV_{im}
1	Low fuel consumption	0.3	Fuel consumption	$\frac{g}{kWh}$	240	8	2.4	300	5	1,5	…	m_{1j}	v_{1j}	WV_{1j}	…	m_{1m}	v_{1m}	WV_{1m}
2	Lightweight construction	0.15	Mass per unit power	$\frac{kg}{kW}$	1,7	9	1.35	2.7	4	0,6	…	m_{2j}	v_{2j}	WV_{2j}	…	m_{2m}	v_{2m}	WV_{2m}
3	Simple production	0.1	Simplicity of components	-	complicated	2	0.2	average	5	0,5	…	m_{3j}	v_{3j}	WV_{3j}	…	m_{3m}	v_{3m}	WV_{3m}
4	Long service life	0.2	Service life	km	80 000	4	0.8	150 000	7	1,4	…	m_{4j}	v_{4j}	WV_{4j}	…	$m4_m$	v_{4m}	WV_{4m}
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮		⋮	⋮	⋮		⋮	⋮	⋮
i		w_i			m_{i1}	v_{i1}	WV_{i1}	m_{i2}	v_{i2}	WV_{i2}	…	m_{ij}	v_{ij}	WV_{ij}	…	m_{im}	v_{im}	WV_{im}
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮		⋮	⋮	⋮		⋮	⋮	⋮
n		w_n			m_{n1}	v_{n1}	WV_{n1}	m_{n2}	v_{n2}	WV_{n2}	…	m_{nj}	v_{nj}	WV_{nj}	…	m_{nm}	v_{nm}	WV_{nm}
		$\sum_{i=1}^{n} w_i =$				OV_1 R_1	OWV_1 WR_1		OV_2 R_2	OWV_2 WR_2			OV_j R_j	OWV_j WR_j			OV_m R_m	OWV_m WR_m

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Example: Test Rig
Weighted Objectives Method – Step 5

5. **Calculate and compare the relative utility values of the alternative designs** - Multiply each parameter score by its weighted value: the 'best' alternative has the highest sum value. Comparison and discussion of utility value profiles may be a better design aid than simply choosing the 'best'.

$$\text{Unweighted: } OV_j = \sum_{i=1}^{n} v_{ij}$$

$$\text{Weighted: } OWV_j = \sum_{i=1}^{n} w_i \cdot v_{ij} = \sum_{i=1}^{n} wv_{ij}$$

$$\text{Unweighted: } R_j = \frac{OV_j}{v_{\max} \cdot n} = \frac{\sum_{i=1}^{n} v_{ij}}{v_{\max} \cdot n}$$

$$\text{Weighted: } WR_j = \frac{OWV_j}{v_{\max} \cdot \sum_{i=1}^{n} w_i} = \frac{\sum_{i=1}^{n} w_i \cdot v_{ij}}{v_{\max} \cdot \sum_{i=1}^{n} w_i}$$

Evaluation criteria			Parameters		Variant V_1 (e.g. $Eng._1$)			Variant V_2 (e.g. $Eng._2$)			...	Variant V_j			...	Variant V_m		
No.		Wt.		Unit	Magn. m_{i1}	Value v_{i1}	Weighted value WV_{i1}	Magn. m_{i2}	Value v_{ij}	Weighted value WV_{ij}		Magn. m_{ij}	Value v_{ij}	Weighted value WV_{ij}		Magn. m_{im}	Value v_{im}	Weighted value WV_{im}
1	Low fuel consumption	$\boxed{0.3}$	Fuel consumption	$\frac{g}{kWh}$	240	8	2.4	300	5	1,5	...	m_{1j}	$\boxed{v_{1j}}$	$\boxed{WV_{1j}}$	...	m_{1m}	v_{1m}	WV_{1m}
2	Lightweight construction	0.15	Mass per unit power	$\frac{kg}{kW}$	1,7	9	1.35	2.7	4	0,6	...	m_{2j}	v_{2j}	WV_{2j}	...	m_{2m}	v_{2m}	WV_{2m}
3	Simple production	0.1	Simplicity of components	-	compli-cated	2	0.2	average	5	0,5	...	m_{3j}	v_{3j}	WV_{3j}	...	m_{3m}	v_{3m}	WV_{3m}
4	Long service life	0.2	Service life	km	80 000	4	0.8	150 000	7	1,4	...	m_{4j}	v_{4j}	WV_{4j}	...	$m4_m$	v_{4m}	WV_{4m}
⋮	⋮	⋮						⋮	⋮	⋮		⋮	⋮	⋮		⋮	⋮	⋮
i		w_i						m_{i2}	v_{i2}	WV_{i2}	...	m_{ij}	v_{ij}	WV_{ij}	...	m_{im}	v_{im}	WV_{im}
⋮	⋮	⋮						⋮	⋮	⋮		⋮	⋮	⋮		⋮	⋮	⋮
n		w_n						m_{n2}	v_{n2}	WV_{n2}	...	m_{nj}	v_{nj}	WV_{nj}	...	m_{nm}	v_{nm}	WV_{nm}
		$\sum_{i=1}^{n} w_j = 1$							OV_2 R_2	OWV_2 WR_2			$\boxed{OV_j}$ $\boxed{R_j}$	$\boxed{OWV_j}$ $\boxed{WR_j}$			OV_m R_m	OWV_m WR_m

Unweighted: $\boxed{R_j = \frac{OV_j}{v_{max} \cdot n}}$

Weighted: $\boxed{WR_j = \frac{OWV_j}{v_{max} \cdot \sum_{i=1}^{n} w_i}}$

Unweighted: $\boxed{OV_j} = \sum_{i=1}^{n} \boxed{v_{ij}}$ Weighted: $\boxed{OWV_j} = \sum_{i=1}^{n} \boxed{\boxed{w_i}\ \boxed{v_{ij}}}$

No.	Evaluation criteria	Wt.	Parameters	Unit	Variant V_1			Variant V_2			Variant V_3			Variant V_4		
					Magn. m_{i1}	Value v_{i1}	Weighted value wv_{i1}	Magn. m_{i2}	Value v_{i2}	Weighted value wv_{i2}	Magn. m_{i3}	Value v_{i3}	Weighted value wv_{i3}	Magn. m_{i4}	Value v_{i4}	Weighted value wv_{i4}
1	Low wear of moving parts	0.056	Amount of wear	-	high	3	0.168	low	6	0.336	average	4	0.224	low	6	0.336
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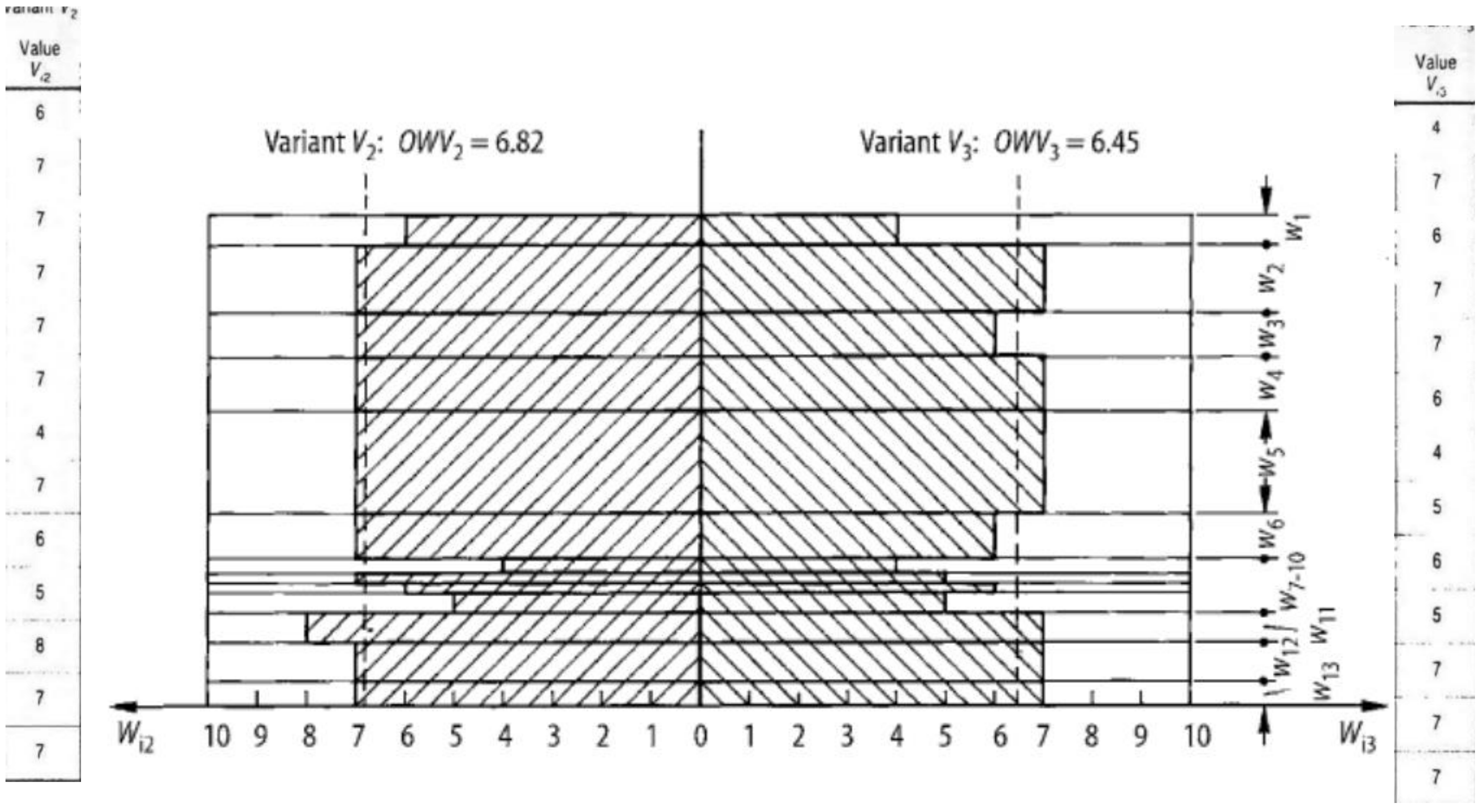
4	Tolerance of overloading	0.12	Overload reserve	%	5	5	0.600	10	7	0.840	10	7	0.840	20	8	0.960
5	High mechanical safety	0.21	Expected mechan. safety	-	average	4	0.840	high	7	1.470	high	7	1.470	very high	8	1.680
6	Few possible operator errors	0.09	Possibilities of operator errors	-	high	3	0.270	low	7	0.630	low	6	0.540	average	4	0.360
7	Small number of components	0.03	No. of components	-	average	5	0.150	average	4	0.120	average	4	0.120	low	6	0.180
8	Low complexity of components	0.012	Complexity of components	-	low	6	0.072	low	7	0.084	average	5	0.060	high	3	0.036
9	Many standard and bought-out parts	0.018	Proportion of standard and bought-out components	-	low	2	0.036	average	6	0.108	average	6	0.108	high	8	0.144
10	Simple assembly	0.04	Simplicity of assembly	-	low	3	0.120	average	5	0.200	average	5	0.200	high	7	0.280
11	Easy maintenance	0.06	Time and cost of maintenance	-	average	4	0.240	low	8	0.480	low	7	0.420	high	3	0.180
12	Quick exchange of test connections	0.084	Estimated time needed to exchange test connections	min	180	4	0.336	120	7	0.588	120	7	0.588	180	4	0.336
13	Good accessibility of measuring systems	0.056	Accessibility of measuring systems	-	good	7	0.392	good	7	0.392	good	7	0.392	average	5	0.280
		$\Sigma w_i =$ 1.0				$OV_1 = 51$ $R_1 = 0.39$	$OWV_1 =$ 3.812 $WR_1 = 0.38$		$OV_2 = 85$ $R_2 = 0.65$	$OWV_2 =$ 6.816 $\boxed{WR_2 = 0.68}$		$OV_3 = 78$ $R_3 = 0.60$	$OWV_3 =$ 6.446 $\boxed{WR_3 = 0.64}$		$OV_4 = 68$ $R_4 = 0.52$	$OWV_4 =$ 5.388 $WR_4 = 0.54$

Example: Test Rig
Weighted Objectives Method – Value Profile

Utility values were calculated for each objective, for each of four alternative designs. The second alternative (variant V2) emerges as the 'best' solution, with an overall utility value of 6.816.

However, variant V3 seems quite comparable, with an overall utility value of 6.446. A comparison of the 'value profiles' of these two alternatives was therefore made. This is shown in the figure , where the thickness of each bar in the chart represents the relative weight of each objective, and its length represents the score for that objective achieved by the particular design.



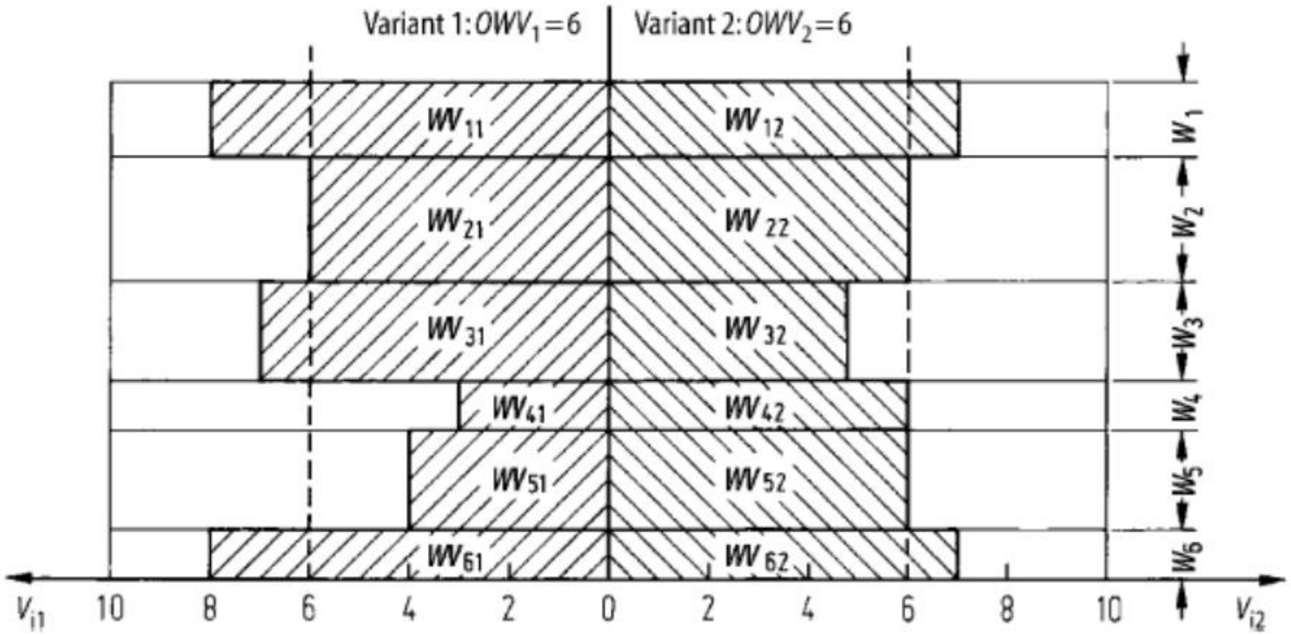
Weighted Objectives Method – Value Profile

Weak spots can be identified from below average values for individual evaluation criteria. Careful attention must be paid to them, particularly in the case of promising variants with good overall values, and they ought if possible to be eliminated during further development.

The identification of weak spots may be facilitated by graphs of the sub values—by the so-called **value profiles** illustrated in figure.

The lengths of the bars correspond to the values and the thicknesses to the weightings. The areas of the bars then indicate the weighted subvalues, and the cross-hatched area the overall weighted value of a solution variant. It is clear that, in order to improve a solution, it is essential to improve those subvalues that provide a greater contribution to the overall value than the rest.

In the figure, variant 2 is better than variant 1, although both have the same overall weighted value.



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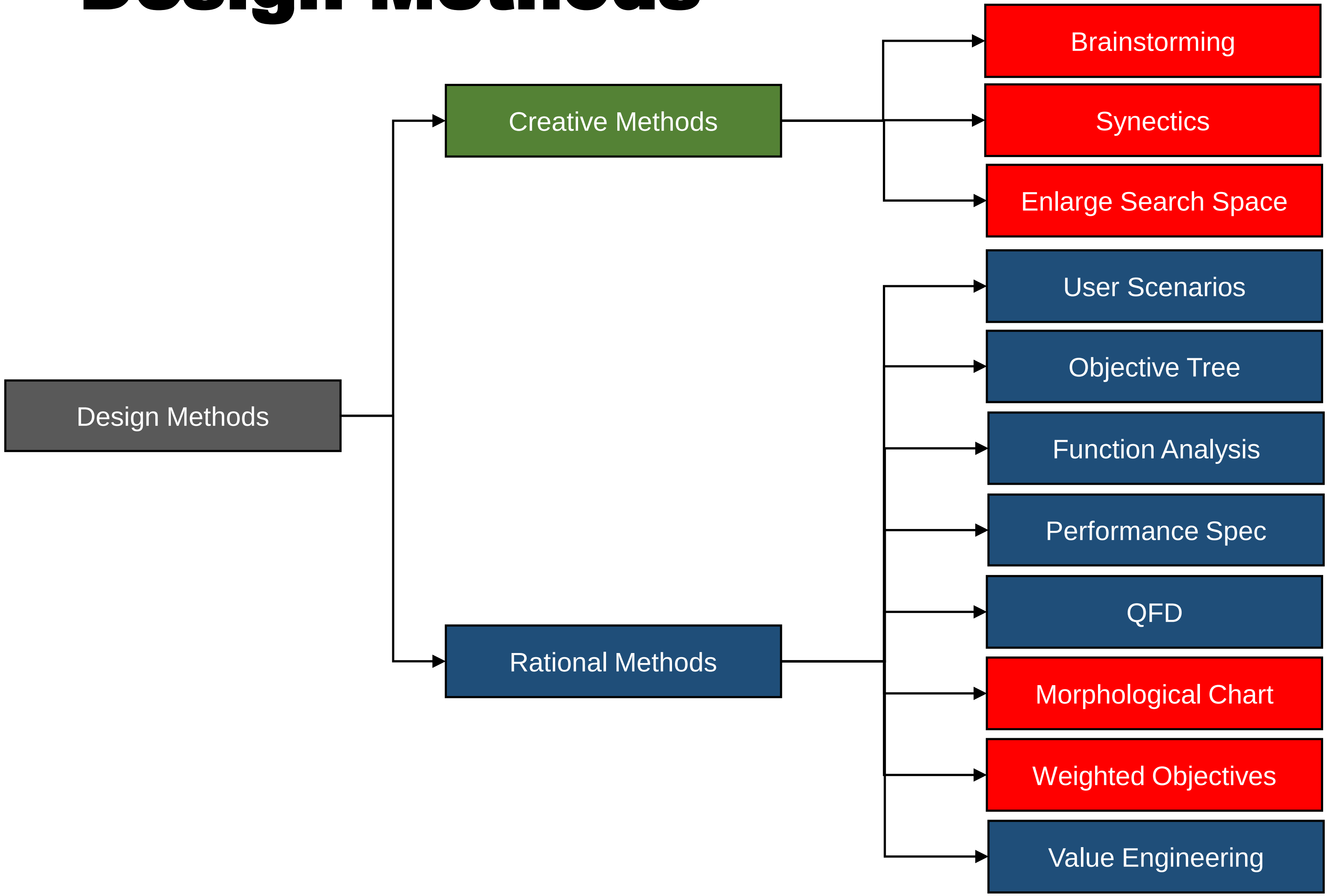

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  - Chapters 4,10,11,12, Engineering Design Methods, Nigel Cross, Wiley
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- Videos