Qualitative Design of Compact Transmission Mechanisms with Standard Components

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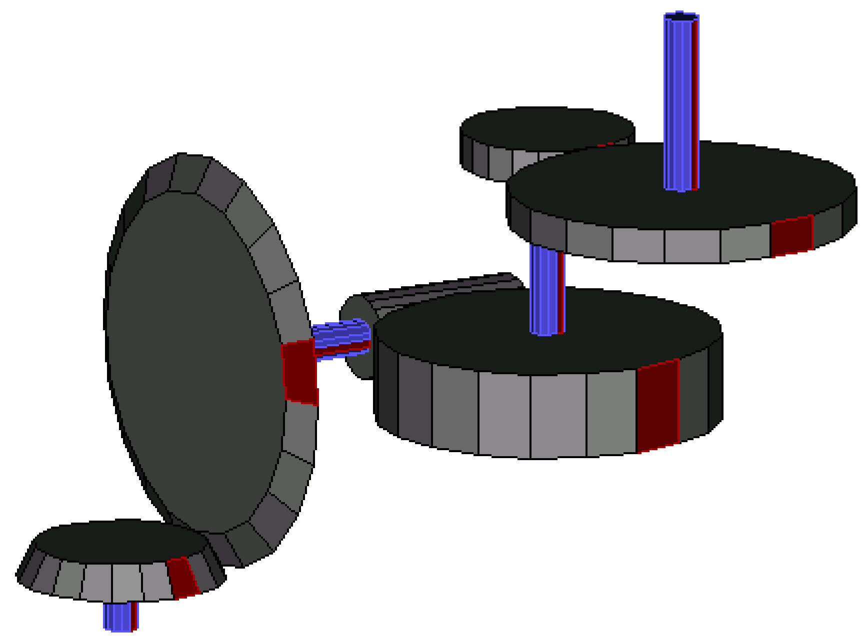

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Introduction

- *General context*

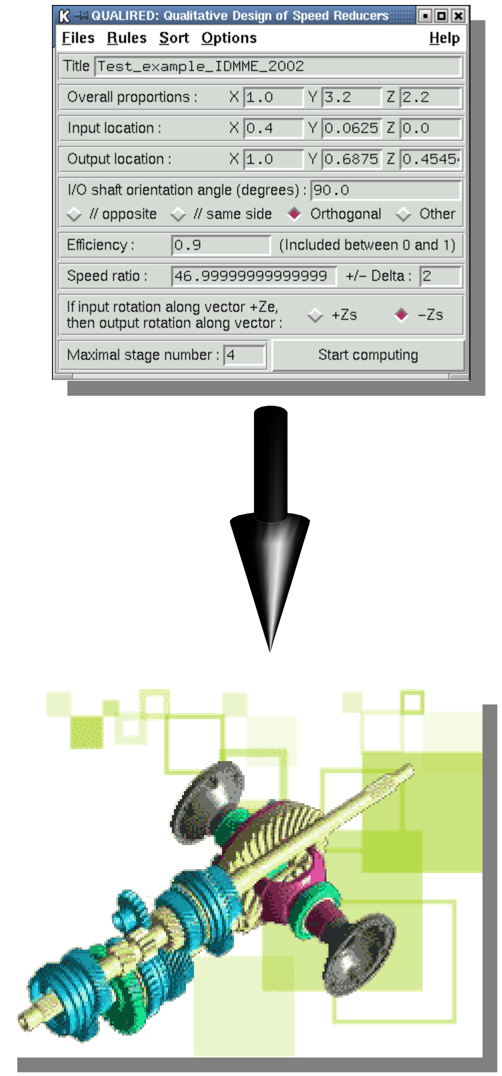
  3D machine design
  from written specifications

- *Purpose of this work*

  A **software wizzard**
  for **preliminary design**
  of transmission mechanisms

- *Type of mechanisms*

  - High ratio transmissions
  - Multi- stage mechanism
    - Which stage ?
    - In what order ?
    - Where in space ?



- *Summary*

  1 - Basic concepts

  2 - Synthesis method

  3 - Concluding example

Context

- References :
  - **[Chakrabarti and Bligh 96]**
    Synthesis of transmission mecanisms with multiple I/O
    Combination of mechanical modules
    Orthogonality restrictions
  - **[Kota and Chiou 92]**
    Synthesis method for compound mechanisms
    Qualitative matrix representation
  - **[Joskowicz and Sacks 93]**
    Kinematic **analysis** of gear boxes and transmissions
  - **[Forbus, Nielsen and Faltings 91]**
    Qualitative kinematics and dynamics for **analysis** of complex mechanisms
- Previous works :
  - **[Fauroux and Sartor 97]**
    Qualitative synthesis method for exploring domain of feasible solutions
  - **[Fauroux, Sanchez, Sartor and Martins 98]**
    Fuzzy logic evaluation of solution
- The idea :
  - Improving synthesis method for transmission mechanisms
  - Including **qualitative analysis** of solutions for getting a better characterization

Method Architecture

Mechanism database

Design rule database

Exploration
Generate combinations of mechanisms

Elimination
Apply design rules

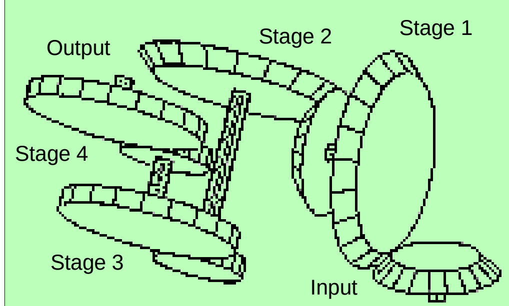
Sorting
Find best solutions sorted by quality

Requirements
- I/O relative orientations
- Efficiency
- Speed ratio
- Sense of rotation
- Stage number

Domain of potential solutions

Domain of feasible solutions complying with design rules

Ordered list of solutions
- CAD models

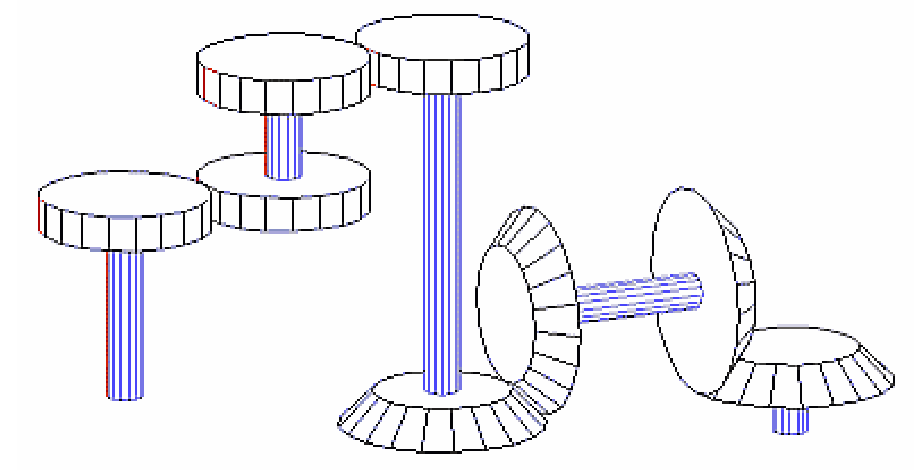


+
- A method improving creativity
- Exhaustive exploration of feasible solutions

-
- Qualitative solutions are too vague
- Many equivalent good solutions
  How to differentiate them ?

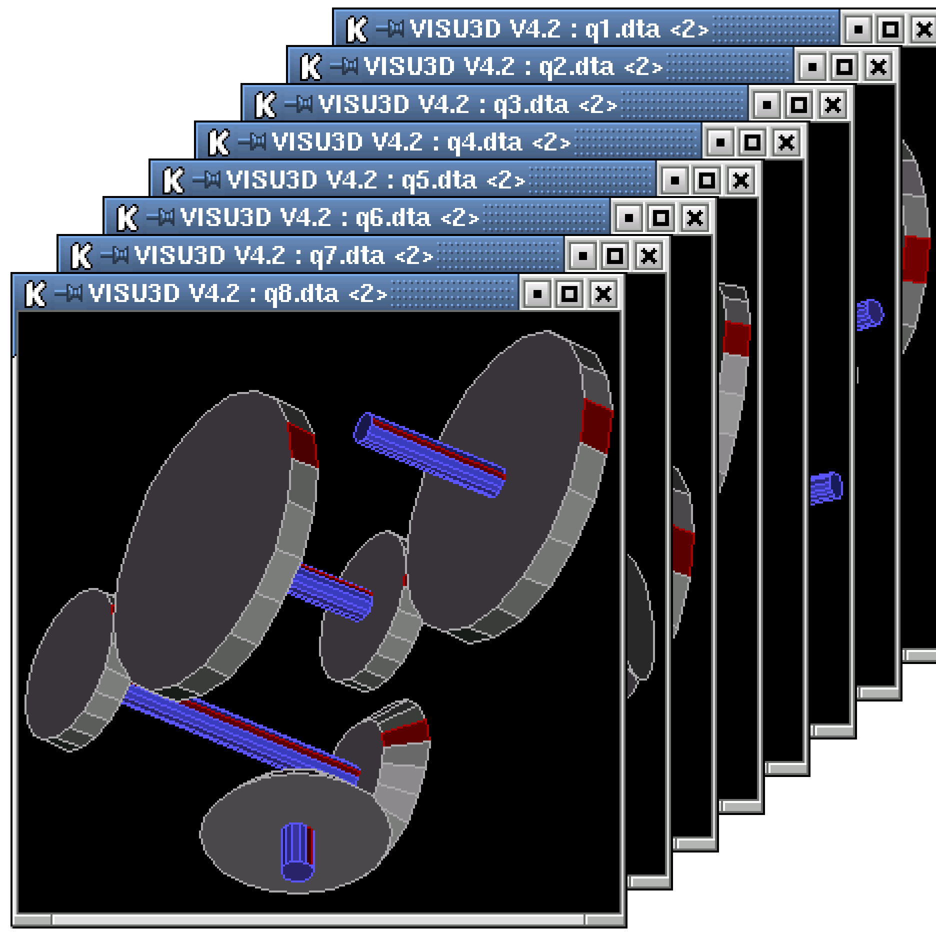
Qualitative Solutions

- Qualitative solutions are too vague
  - Qualitative shape of parts
  - Relative ordering of parts (connectivity)
  - **Not** the final dimensions
  - **Not** the final orientations



A rubber model

Demo



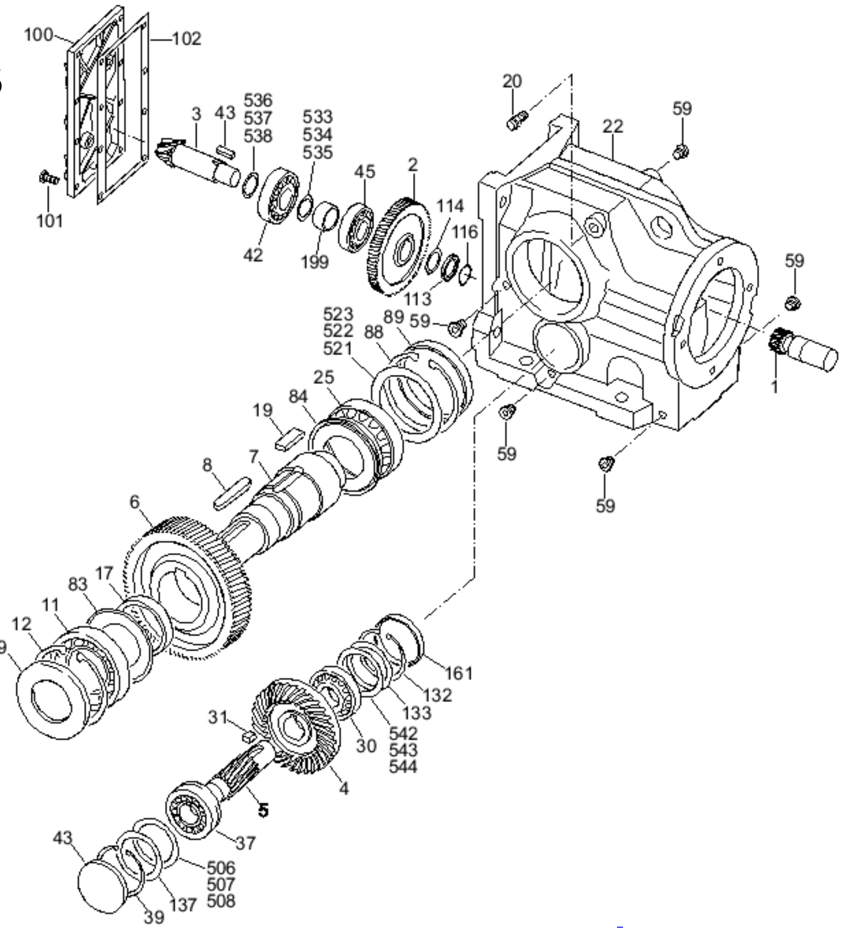
- Good qualitative solutions are often not easy to differentiate
  - Qualitative solutions give a good start to designers...
  - ...but need to be enriched in information

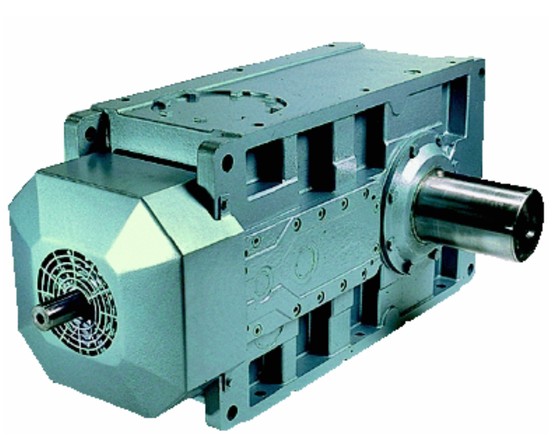
Example : 1008 solutions and 8 rated N° 1
Which to choose ?

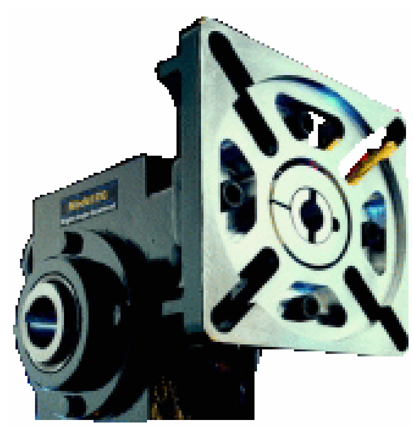
- Idea : try to reproduce human mind

Standard Orientations

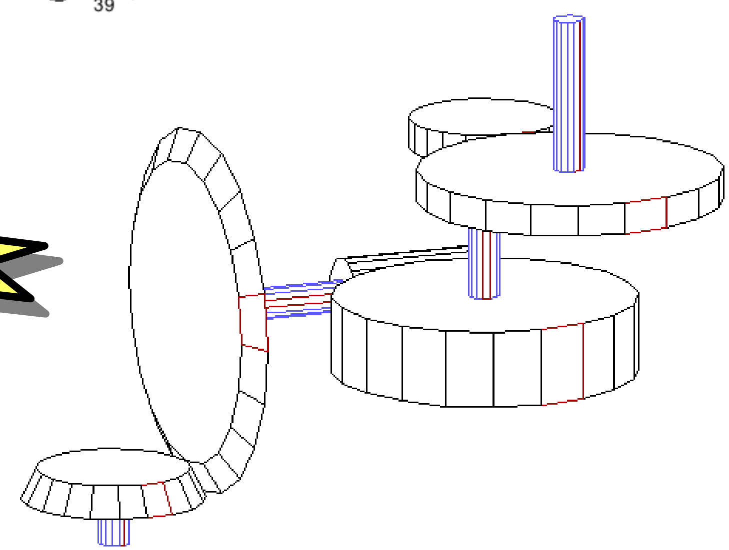
- Enriching the model by orientating stages
- 4 standard values : 0° / 90° / 180° / 270°
  - Strong assumption but corresponding to the vast majority of industrial mechanisms
  - Permits a fast exploration of mechanism layouts
  - May be refined later



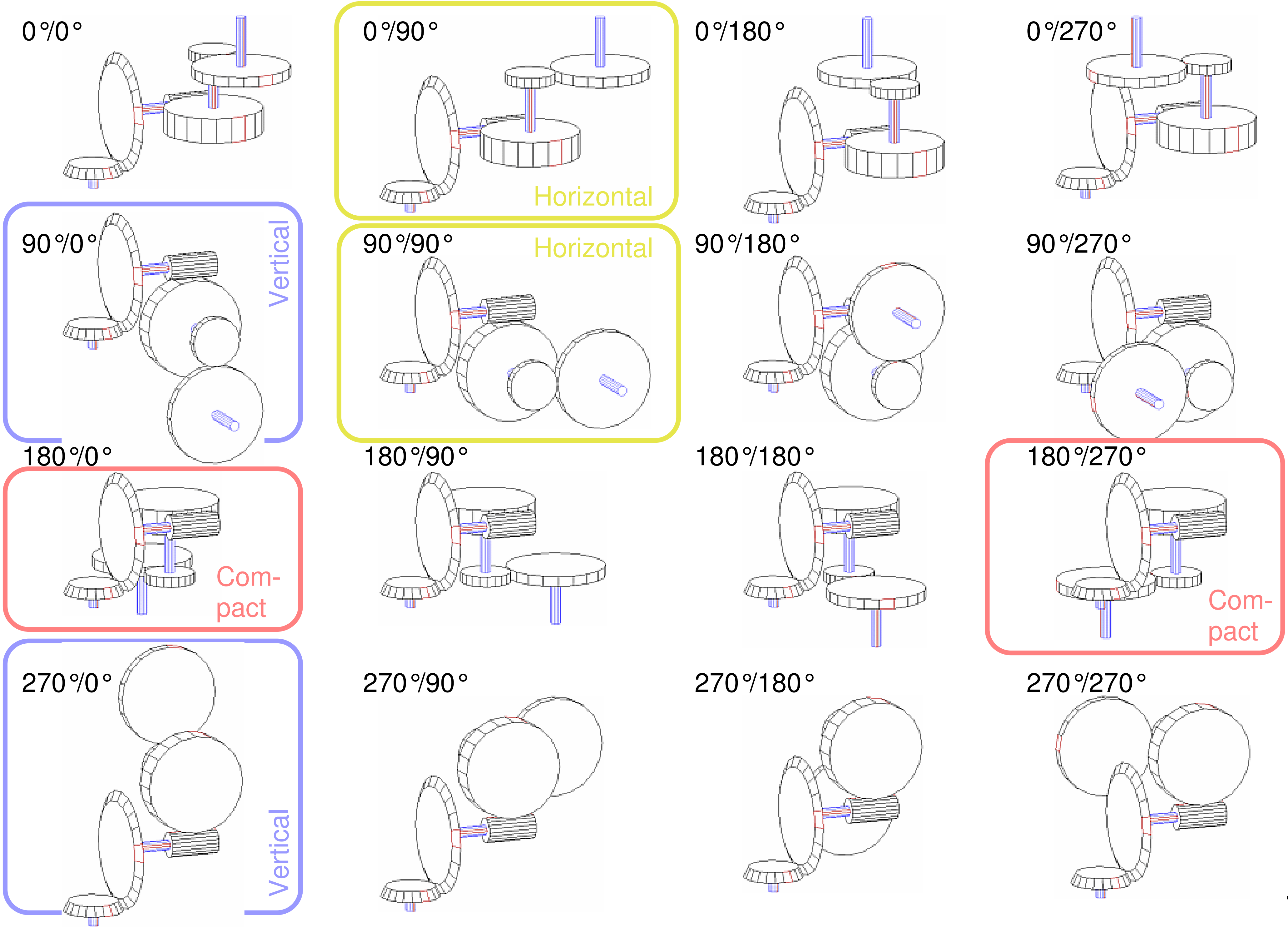




- A given mechanism can take a great number of layouts
  - 2 angles
  - 4 values per angle
  - 16 combinations

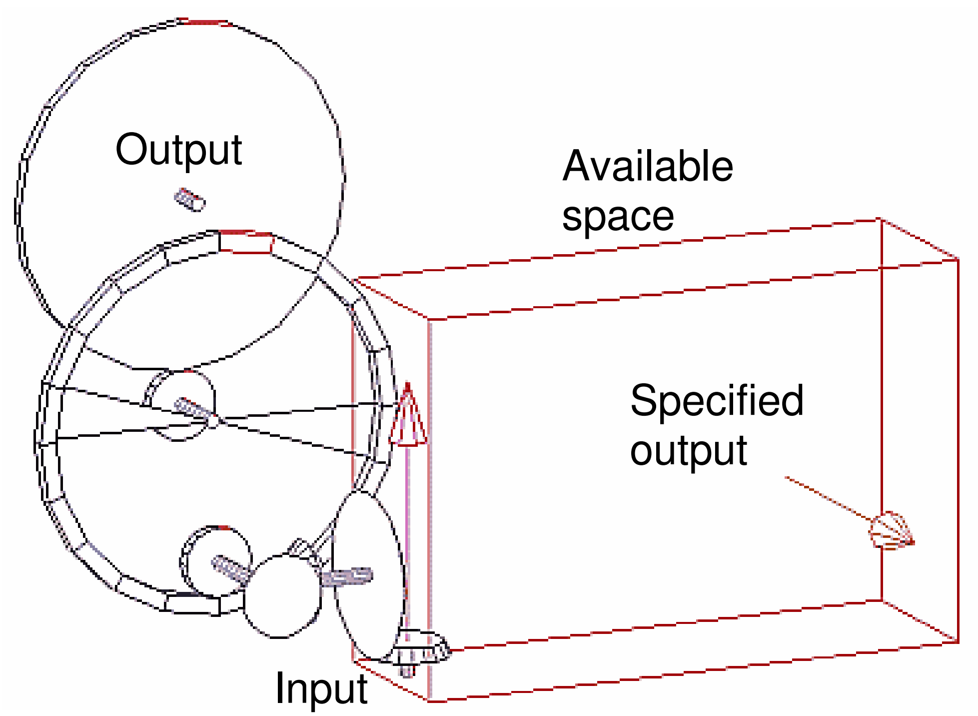


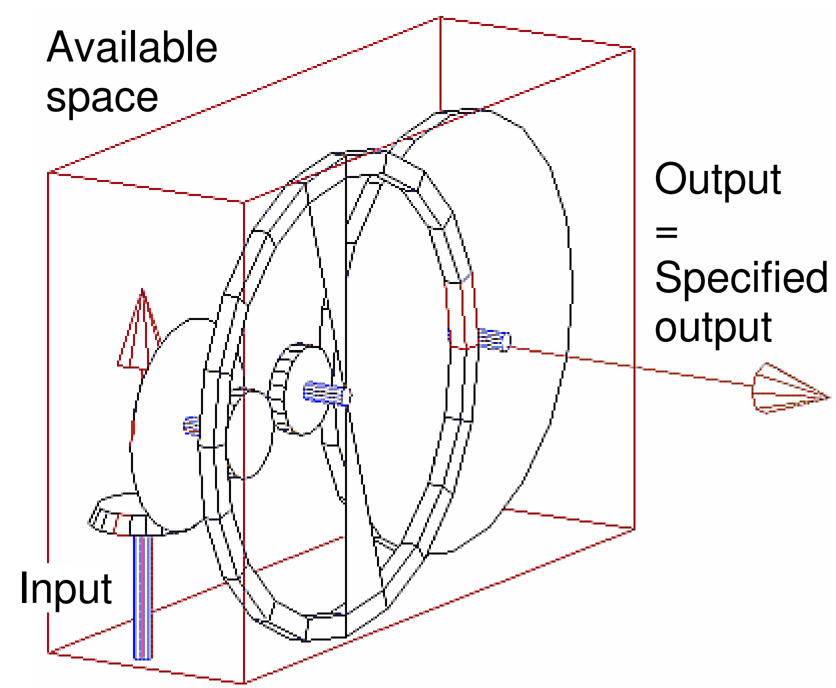
Standard Orientations



Mechanism Compactness

- **Compactness** : a way for differentiating solutions
- Compact = fits the available space
  - No spoilt space inside
  - No big parts crossing outside
- Not Compact
  - Space is horizontal
  - Mechanism is vertical
  - Mechanism is totally outside
- Compact
  - Mechanism has good overall orientation
  - Mechanism has good proportions





Standard Mechanisms (1/2)

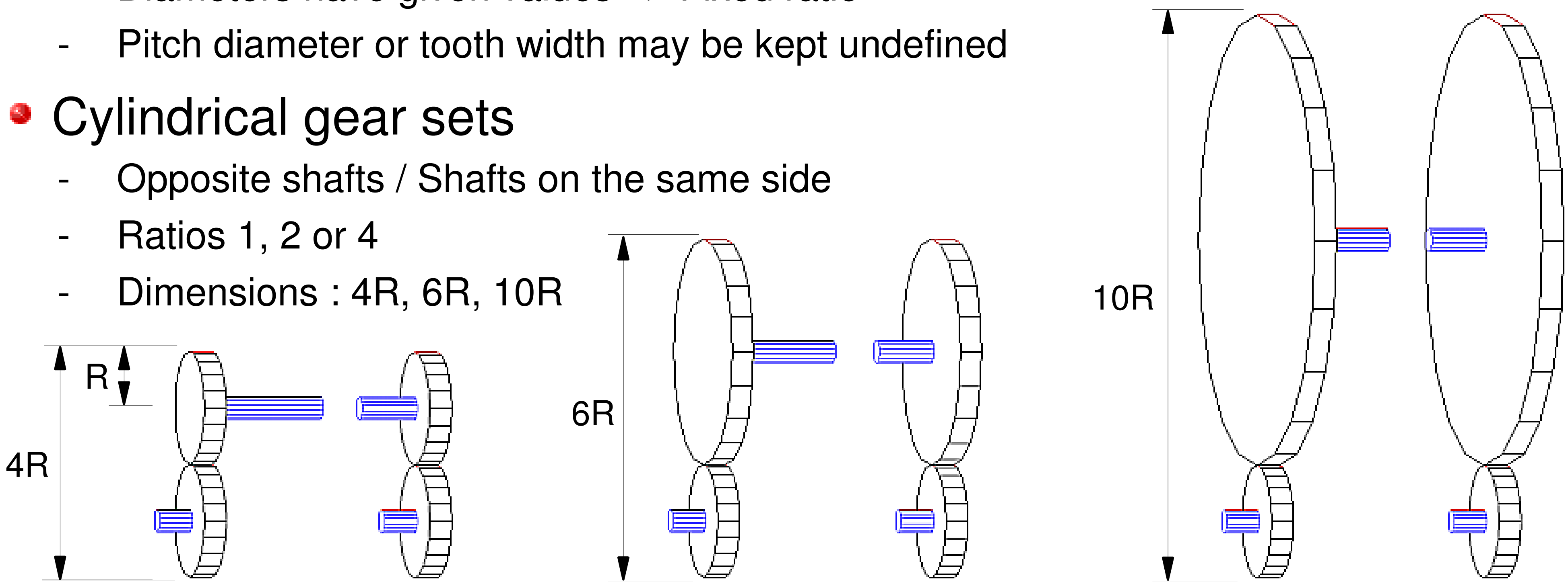
- **Semi- dimensioned** mechanisms

  Example : cylindrical gear

  - Diameters have given values - > Fixed ratio
  - Pitch diameter or tooth width may be kept undefined

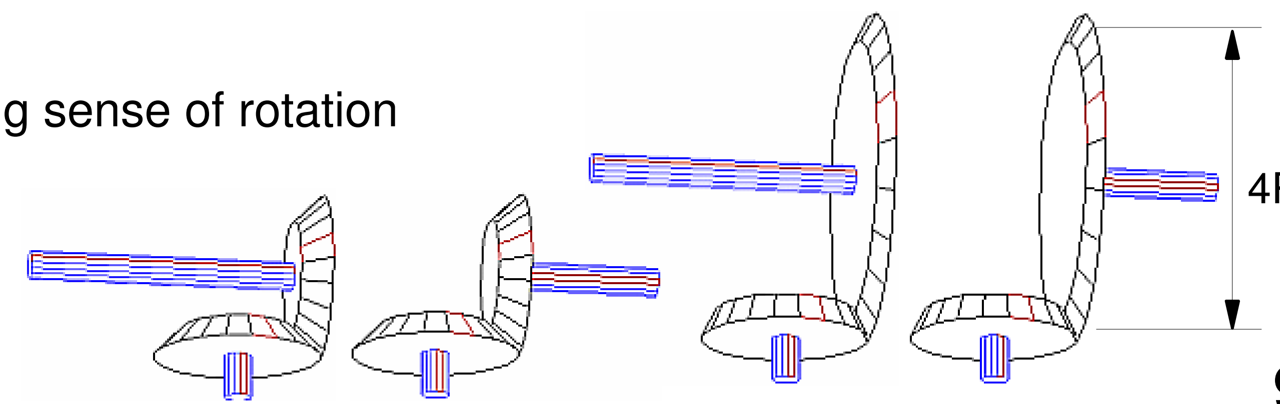
- Cylindrical gear sets

  - Opposite shafts / Shafts on the same side
  - Ratios 1, 2 or 4
  - Dimensions : 4R, 6R, 10R



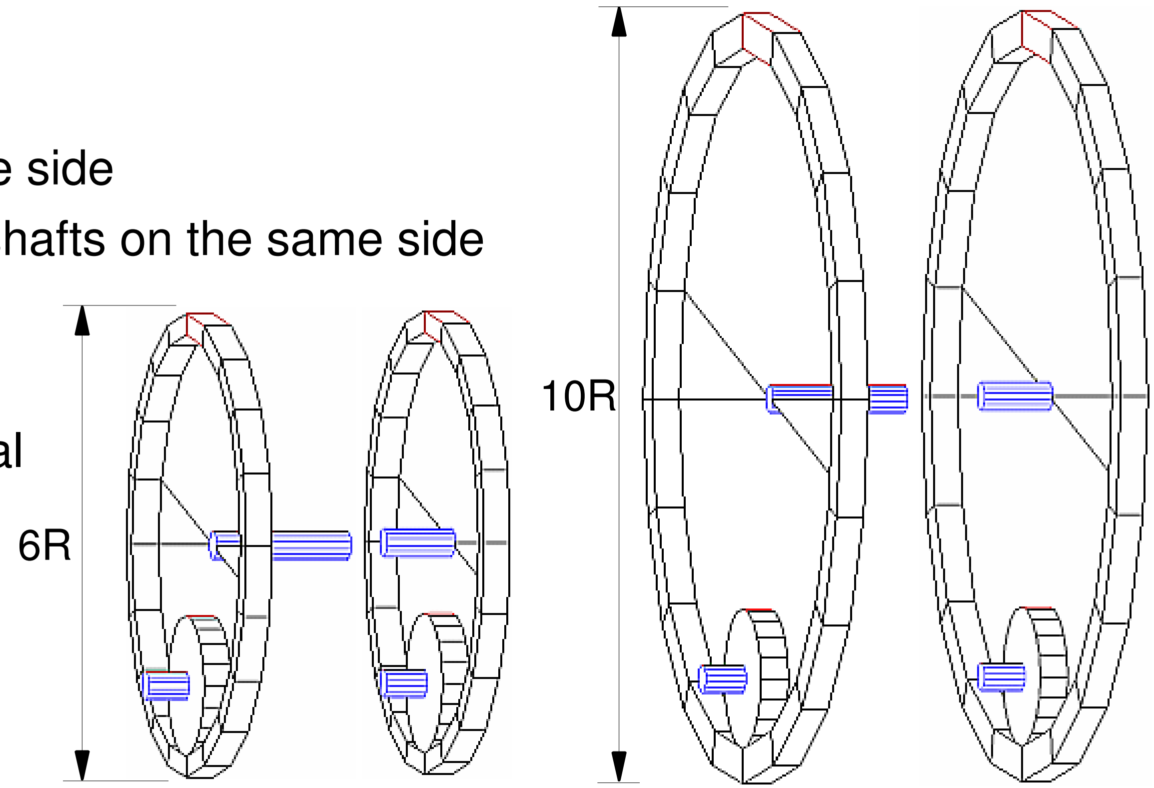
- Bevel gear sets

  - Two shaft settings for reversing sense of rotation
  - Ratios 1, or 2
  - Big wheels are expensive
    so ratios are limited

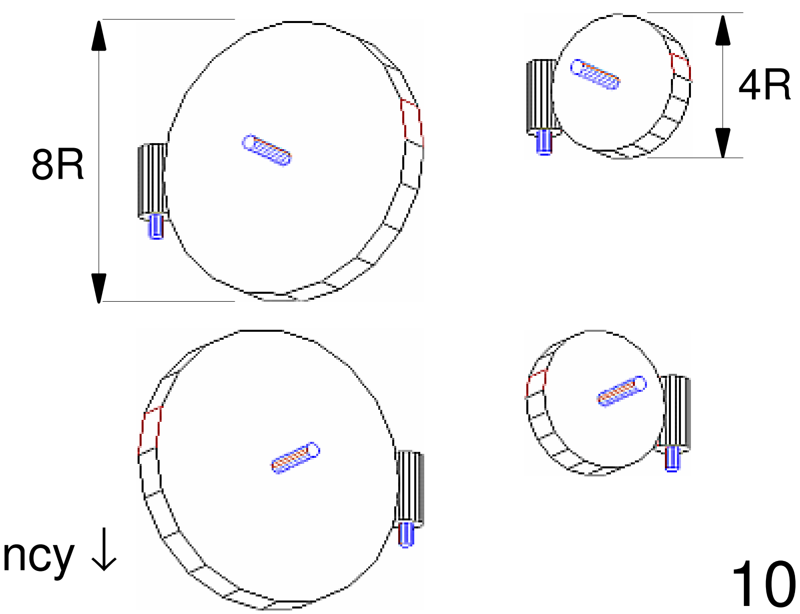


Standard Mechanisms (2/2)

- Internal cylindrical gear sets
  - Opposite shafts / Shafts on the same side
  - Ratio 2 gives part interference with shafts on the same side
  - Ratios 3 or 5
  - Dimensions : 6R or 10R
  - With same overall dimension, internal gear sets reduce more than external ones

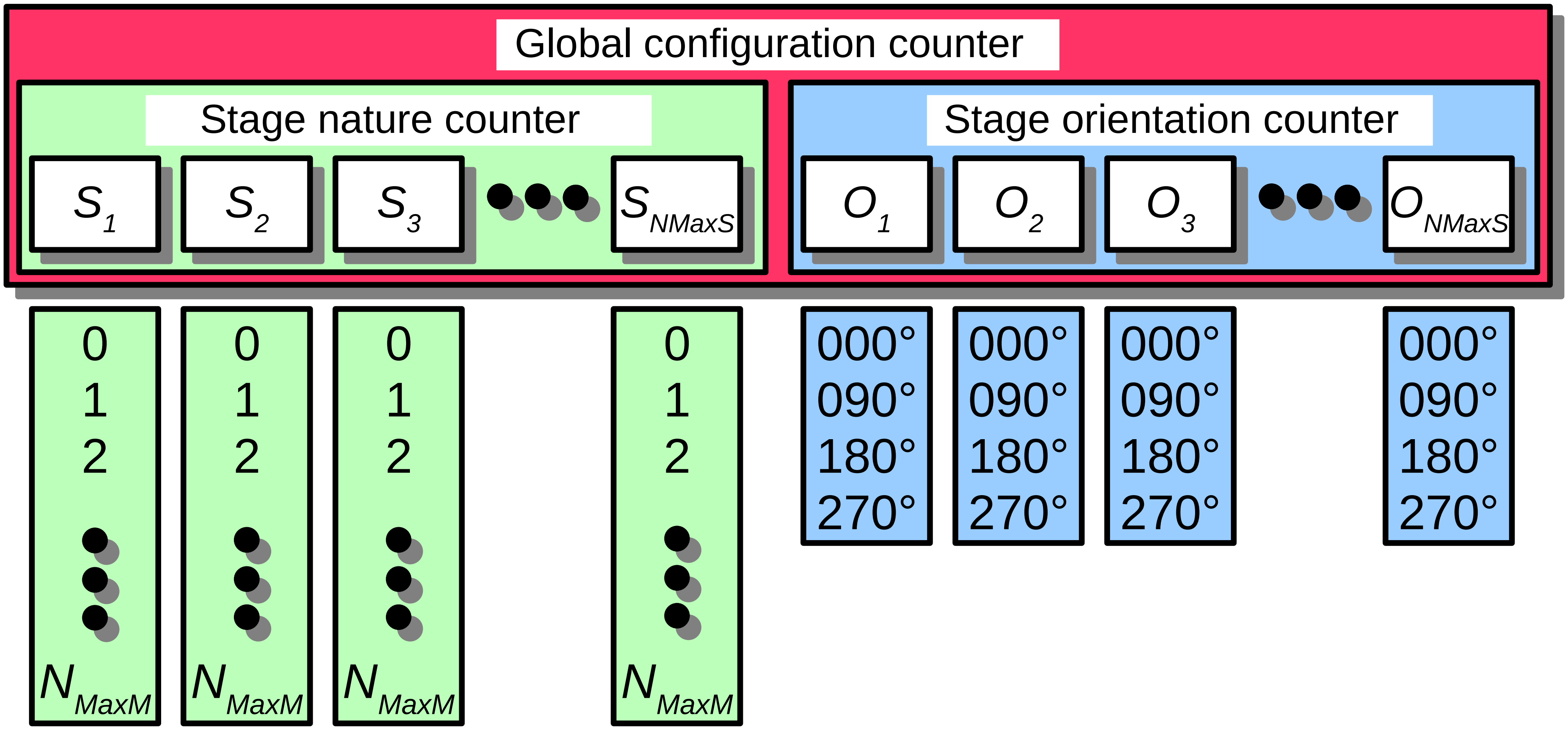


- Worm gear sets
  - Great ratios but efficiency sometimes small
  - Two shaft settings
  - Ratios 8, 16 or 32
  - 4 threads / 32 teeth, ratio 8, efficiency 85%
  - 1 thread / 16 teeth, ratio 16, efficiency 75%
  - 1 thread / 32 teeth, ratio 32, efficiency 67%
  - Number of threads $\uparrow \Rightarrow$ ratio $\downarrow$ but efficiency $\uparrow$
  - Number of teeth $\uparrow \Rightarrow$ ratio $\uparrow$, dimensions $\uparrow$ but efficiency $\downarrow$



Exploration

- Combinatorial exploration
- Global **hybrid** configuration counter :
  - Stage nature (base N_{MaxM})
  - Stage orientation (base 4)



Elimination Rules

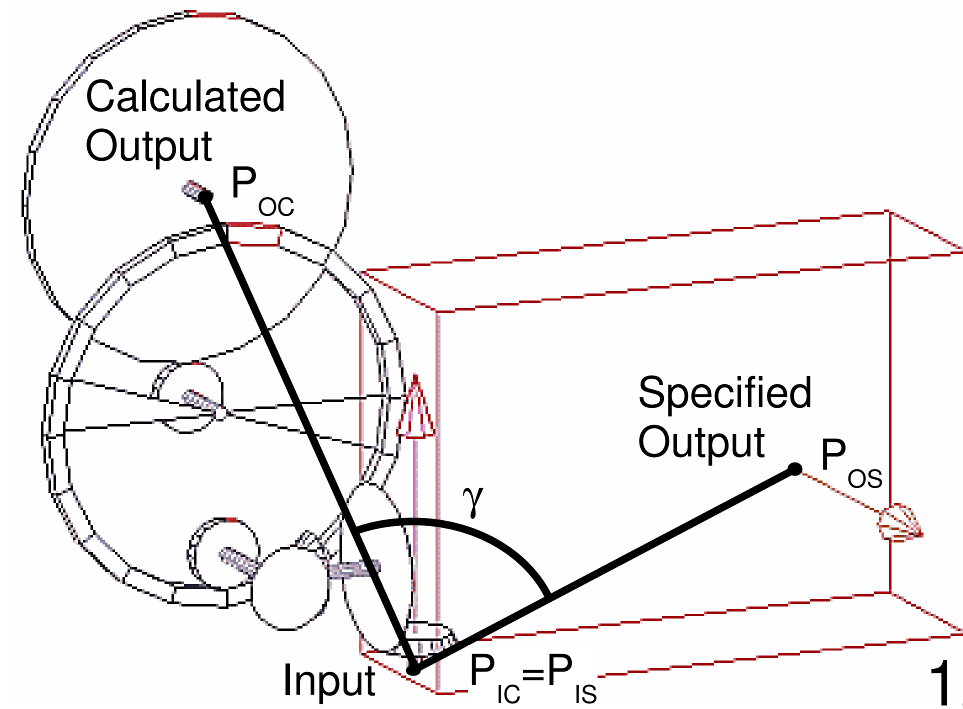
- The domain of configurations increases greatly
- Elimination rules can be refined
  - Limitation of the number of stages with orthogonal shafts
  - Good efficiency $\eta_C \geqslant \eta_S$ with $\eta_C = \prod_{i=1}^{N_{MaxS}} \eta_i$
  - Good speed ratio $U_S - \Delta_U \leqslant U_C \leqslant U_S + \Delta_U$ with $U_C = \prod_{i=1}^{N_{MaxS}} U_i$
  - Good rotation sense
  - Good absolute orientation of output shafts

    $\vec{Z}_{OC} = \vec{Z}_{OS}$ with $\vec{Z}_{OC} = \prod_{i=1}^{N_{MaxS}} \mathbb{R}_i \vec{Z}_{IC}$
  - Correct relative I/O locations

    $\gamma = \widehat{(\overrightarrow{P_{IC}P_{OC}}, \overrightarrow{P_{IS}P_{OS}})} < 90°$

    with $P_{OC} = \prod_{i=N_{MaxS}}^{1} \mathbb{C}_i P_{IC}$

C = Calculated
S = Specified

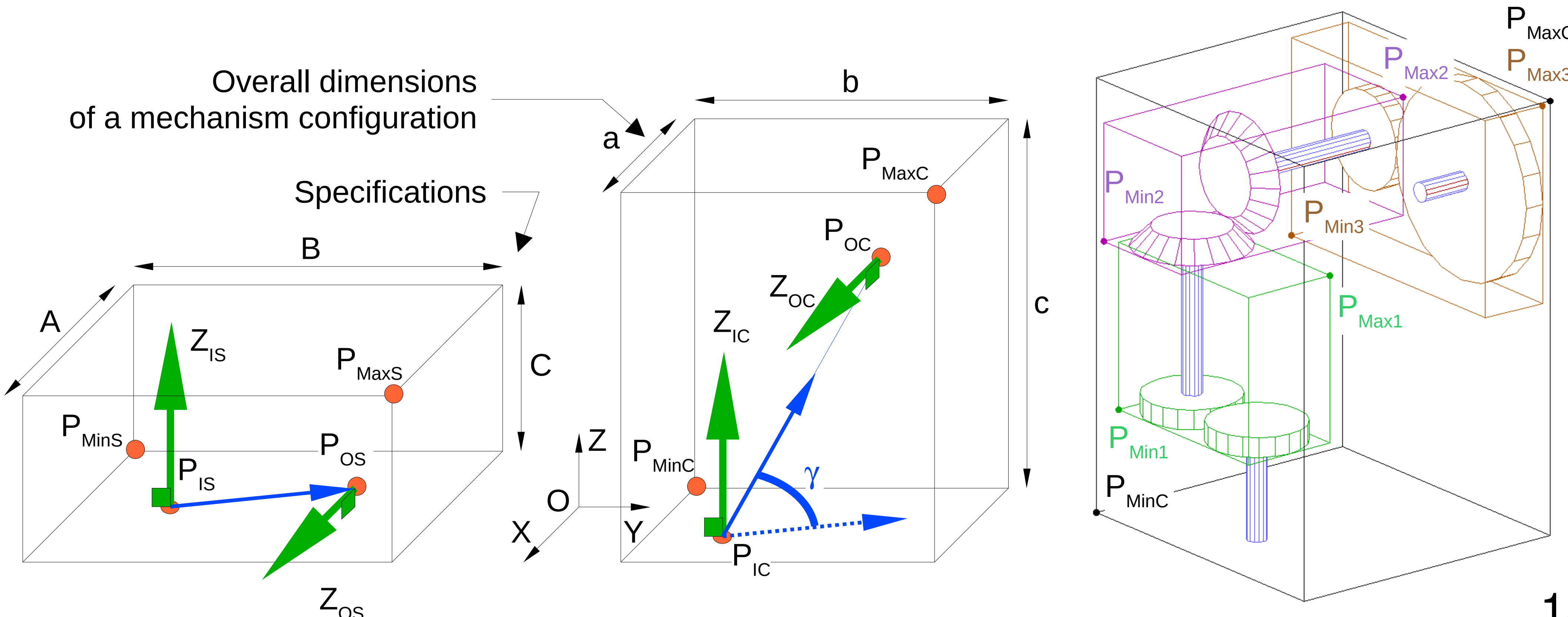


- Qualitative and non dimensional

Sorting Criteria (½1/2)

- Best configurations should be sorted first
- Five performance functions
  - Mechanism nature quality
    - Power transmission ability
    - Fabrication cost
    - Mounting cost
  - Overall proportion quality
    - From 0 (perfect fitting)
    - To infinity (infinite extension along one axis)

$$F_P = \left|\frac{a}{A} - \frac{b}{B}\right| + \left|\frac{b}{B} - \frac{c}{C}\right|$$



Sorting Criteria (½2/2)

- Five performance functions

Input location quality

$$F_I=(\ |NX_{IC}-NX_{IS}|+|NY_{IC}-NY_{IS}|+|NZ_{IC}-NZ_{IS}|\ )/3$$

with $NX_{IC}=\dfrac{X_{IC}-X_{MinC}}{X_{MaxC}-X_{MinC}}$ and $NX_{IS}=\dfrac{X_{IS}-X_{MinS}}{X_{MaxS}-X_{MinS}}$

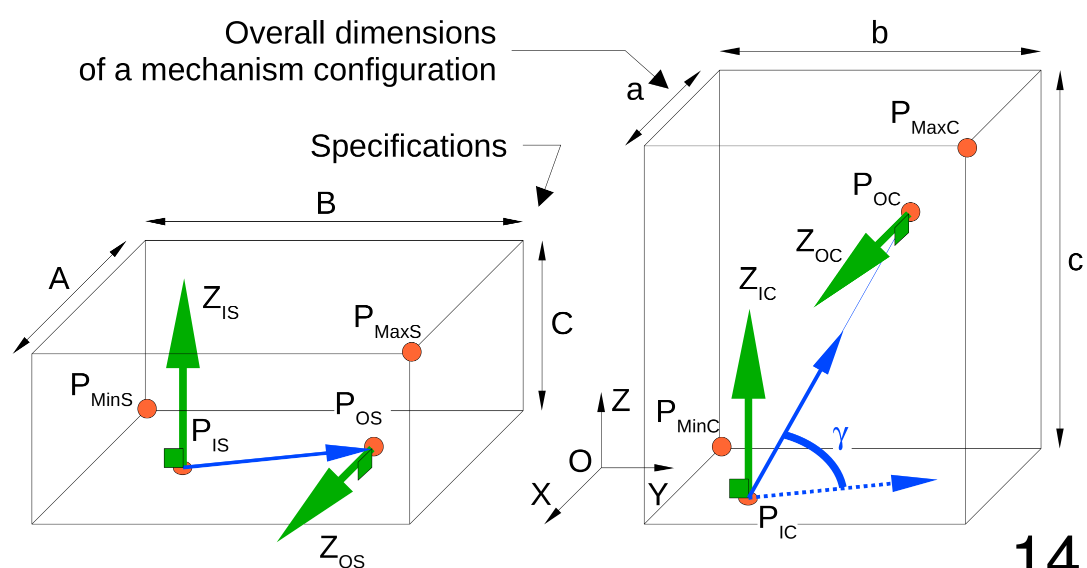
- NX_{IC} represent the non dimensional position in % of P_{IC} along the specification box
- F_I = 0 for an input perfectly fitting specifications
- F_I = 1 for an input diagonally opposed to requirements

Output location quality

Relative I/O location quality

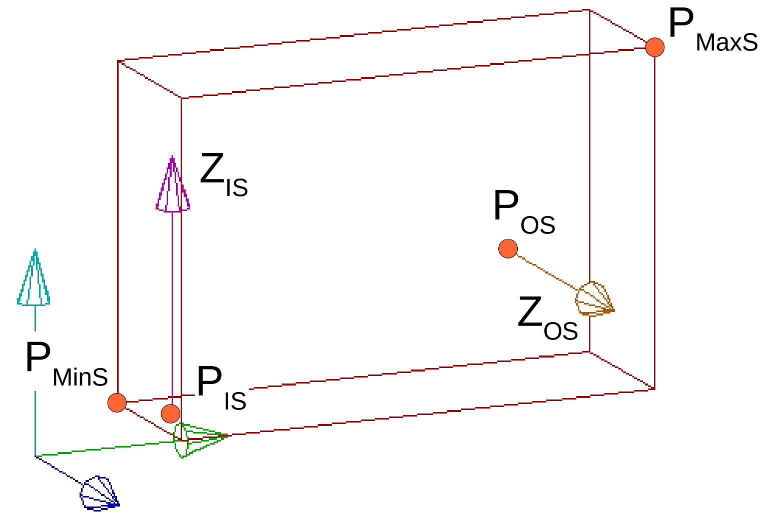
$$F_{IO}=1-\cos(\gamma)$$

- F_{IO} = 0 when relative I/O location perfectly fit specifications
- F_I = 1 when I/O is very far from expected



Example

- Design of the following mechanism :
  - Orthogonal I/O shafts
  - Efficiency > 90%
  - Speed ratio around 47
  - Reversing sense
  - No more than 4 stages

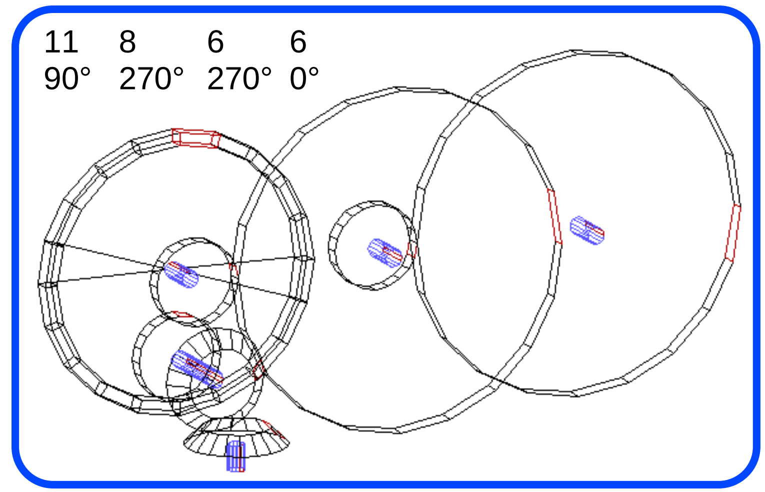


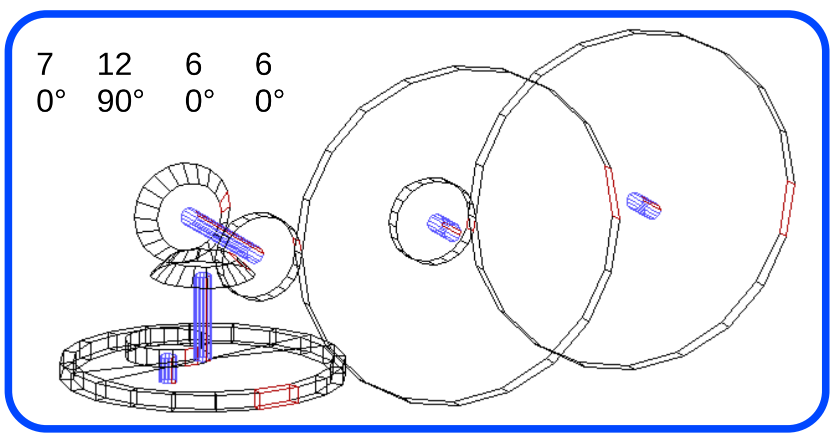
- Results :
  - 10 240 000 combinations
  - Less than 5 seconds on a PIII 650 Mhz
  - No solutions with $\Delta U = 0$
  - 5723 solutions with $\Delta U = 1$ (space reduced by a factor 2000)
  - Most of time spent in Exploration and Elimination phases
  - High efficiency of **qsort** method (average running time N.log(N))

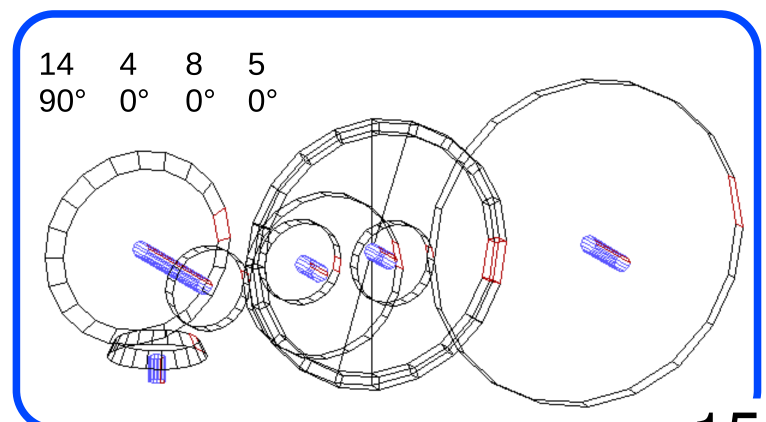
    Example : 10^6 combinations sorted in 10 seconds
  - Time may be cut down by changing elimination rule order

    Example : Orientation rule from first to last place

    Computing time from 45 to 4 seconds







Conclusion

- A new method for designing transmission mechanisms with **standard components** and **standard orientations**

- Advantages
  - Standard components : more precise and **realistic** particularly for transmission ratio and efficiency
  - Solutions are **better defined** with more qualitative information
  - Realistic diameters and part orientations
  - **Compact** mechanisms are exhibited
  - Divides by **several thousands** the initial combination space

- To be Improved
  - Elimination rules may be refined
  - Sorting criteria may be refined
  - Faster computations with large databases

- An efficient tool for **suggesting ideas** to designer with exhaustivity