# Creation of Design Spaces and Exploration through Visualization and Configuration


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# Introduction

- Design problems deal with constraints
- Constraints arise from
  - Specifications
  - Physical laws
  - Requirements
- Design process - currently “generate and test”

# Observation

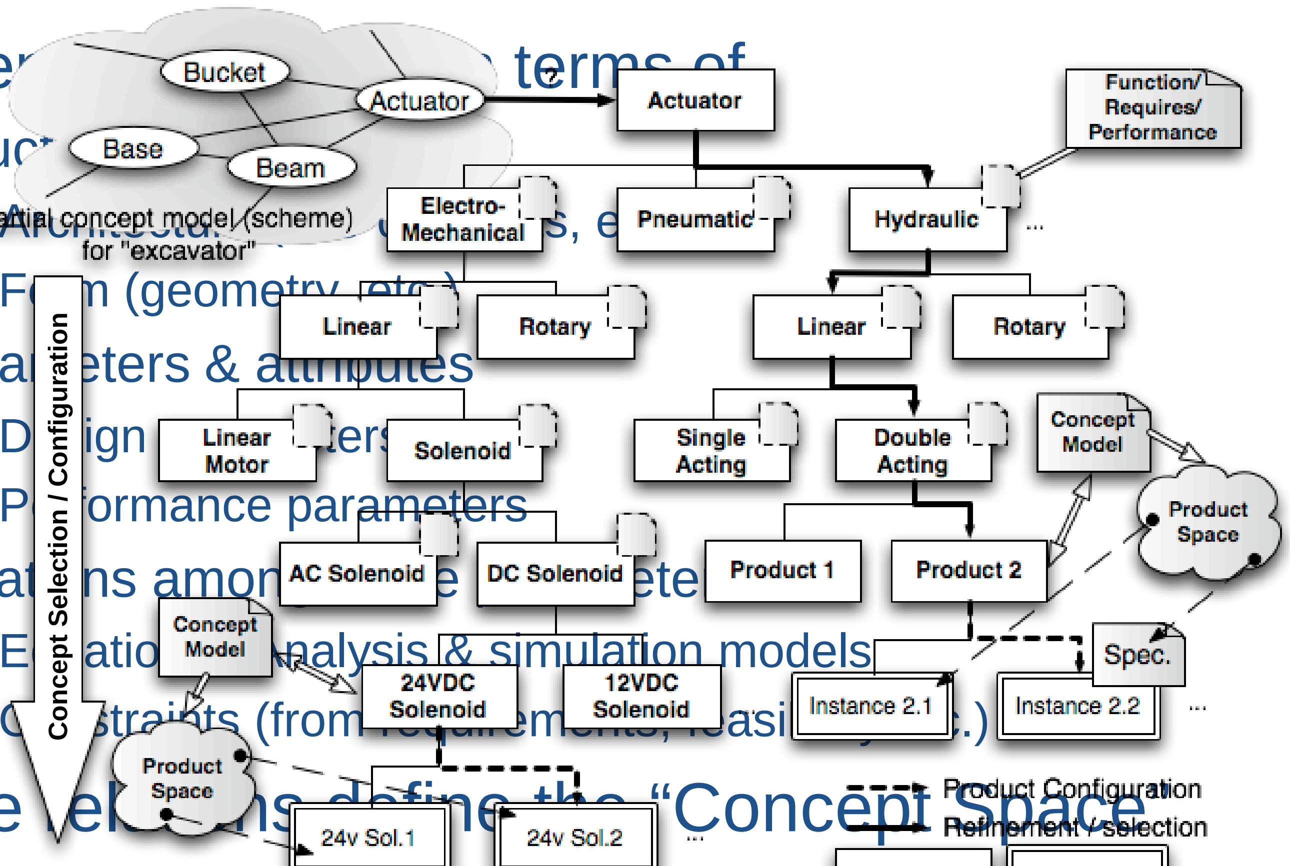
- Repeated analysis creation/run for
  - Small change in requirements / constraints / geometry / objectives
- Time consuming and redundant
  - Reason: Point based design (individual design)
  - Solution: Set based design (groups of designs)
  - Problem: No practical representation of design sets!

# Proposal - revisited

- Move from point-based to volume / set based design
- Eliminate need to evaluate point-based solutions
- Design concepts implicitly define the design spaces.
- Pre-compute the design space to be used for
  - Exploration
  - Configuration design, etc.

# Basics - Design sets

- Design set is a collection of concepts
- Concep… terms of
  - Struc…
    - Architectu… s, e…
    - F… m (geometry, etc.)
  - Para… eters & attributes
    - D… ign … ters
    - P… formance parameters
  - Relat… ns amon… e … ete
    - E… atio… nalysis & simulation models
    - C… straints (from requirements, feasi… .)
- These … el… ns define the "Concept Space"
- Note the overlap with WKM presented earlier!



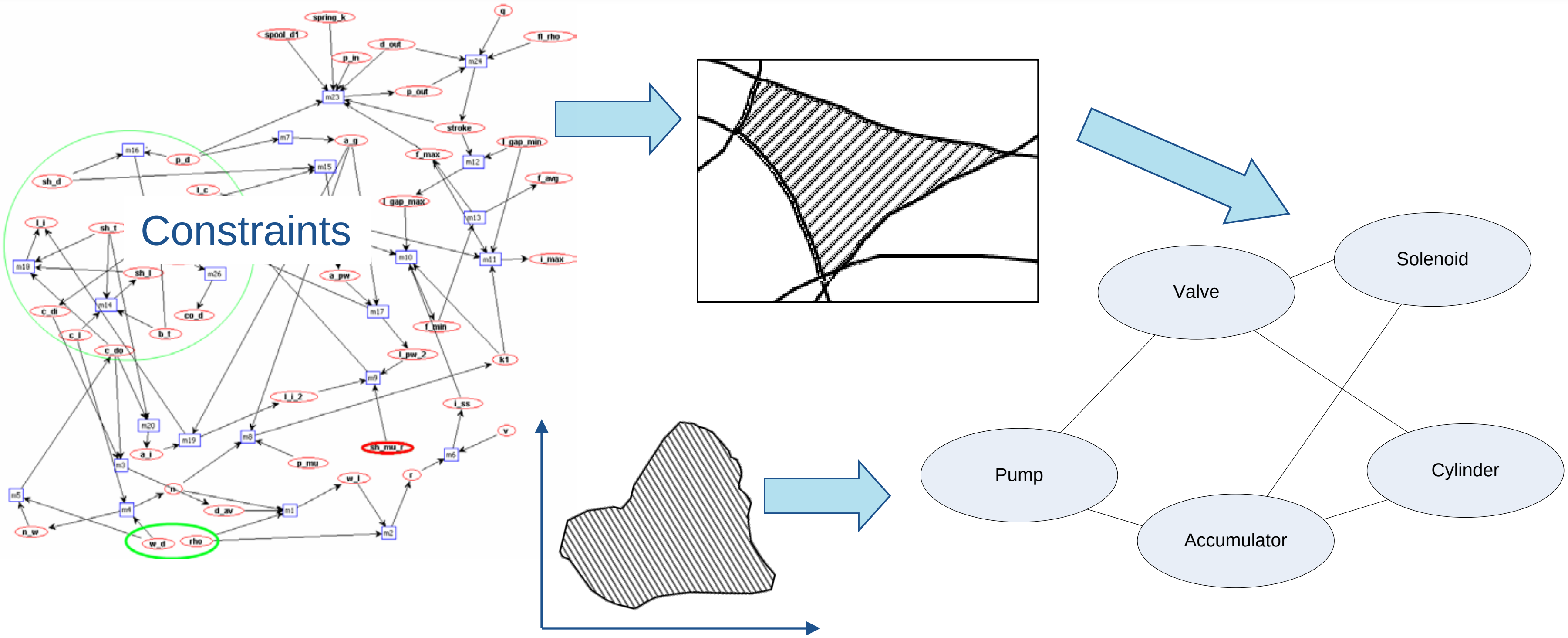
# Concept Space

- Consists of Design Space & Performance Space
  $D \times N \rightarrow P$, $C = D \cup N \cup P$
- Design Space ***D***: The set valid designs of the concept described using design parameters
- Performance Space ***P***: The dependent set of evaluated performances at each point in ***D***.
- Noise Space ***N***: Set of possible designs described using noise variables

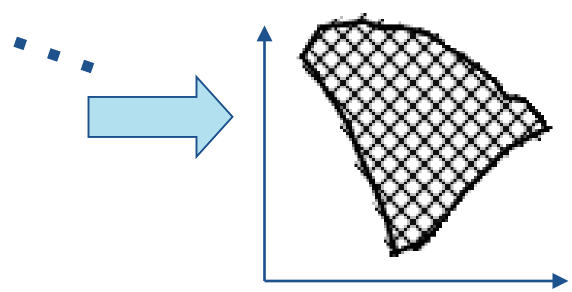
# Research Issues

- How to <u>represent</u> the space?
- How to <u>create</u> it? Point based don't work, 2k trees inefficient, boxes too inaccurate.
  - Methods motivated by algebraic geometry
    - Most elegant and simplest form
    - Has been forgotten in engineering (Abhyankar!)
    - New computational methods can work quickly and efficiently by exploiting properties
- How to perform <u>operations</u> on it?
  - Entire design space reasoning can be done geometrically
  - Algorithms from computational geometry and constraint processing

# Design space creation




How to do the same in high dimensions?

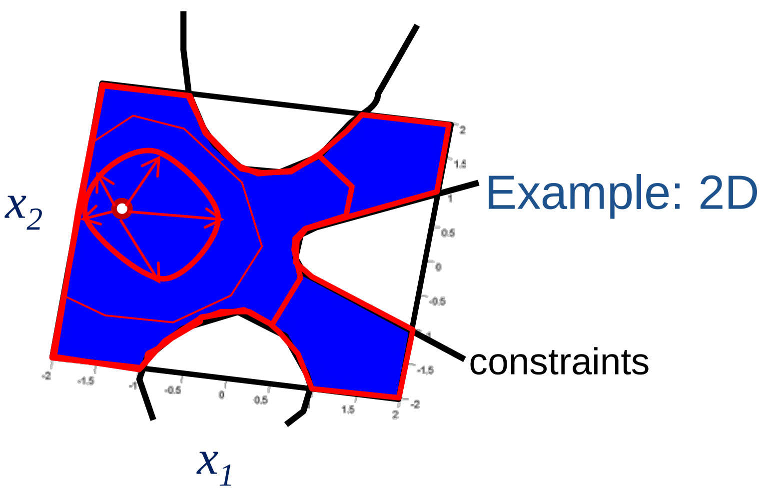


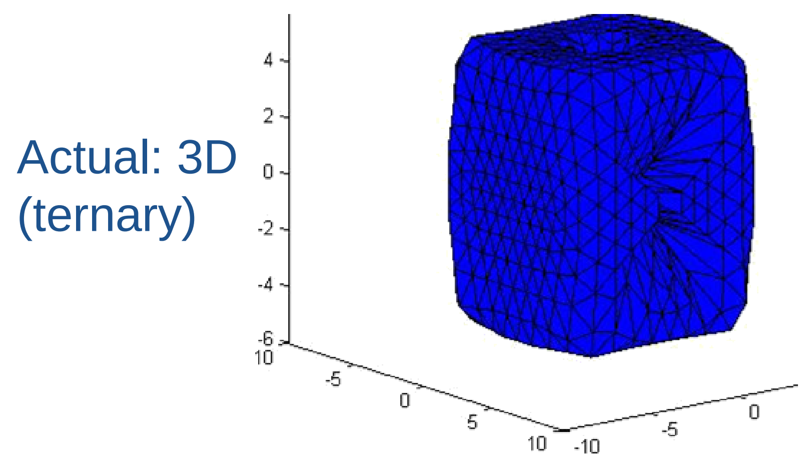
# Creating concept space - steps

1. Pre-process
   - Identify design parameters
   - Project the constraints and relationships onto the space of design parameters
     - Using Quantifier Elimination form algebraic geometry
2. Convert to ternary constraints
   - Involve only 3 variables at a time
     - Can leverage standard computational geometry algorithms
   - Introduces new variables to capture actual geometry of design space

# Creating concept space - steps

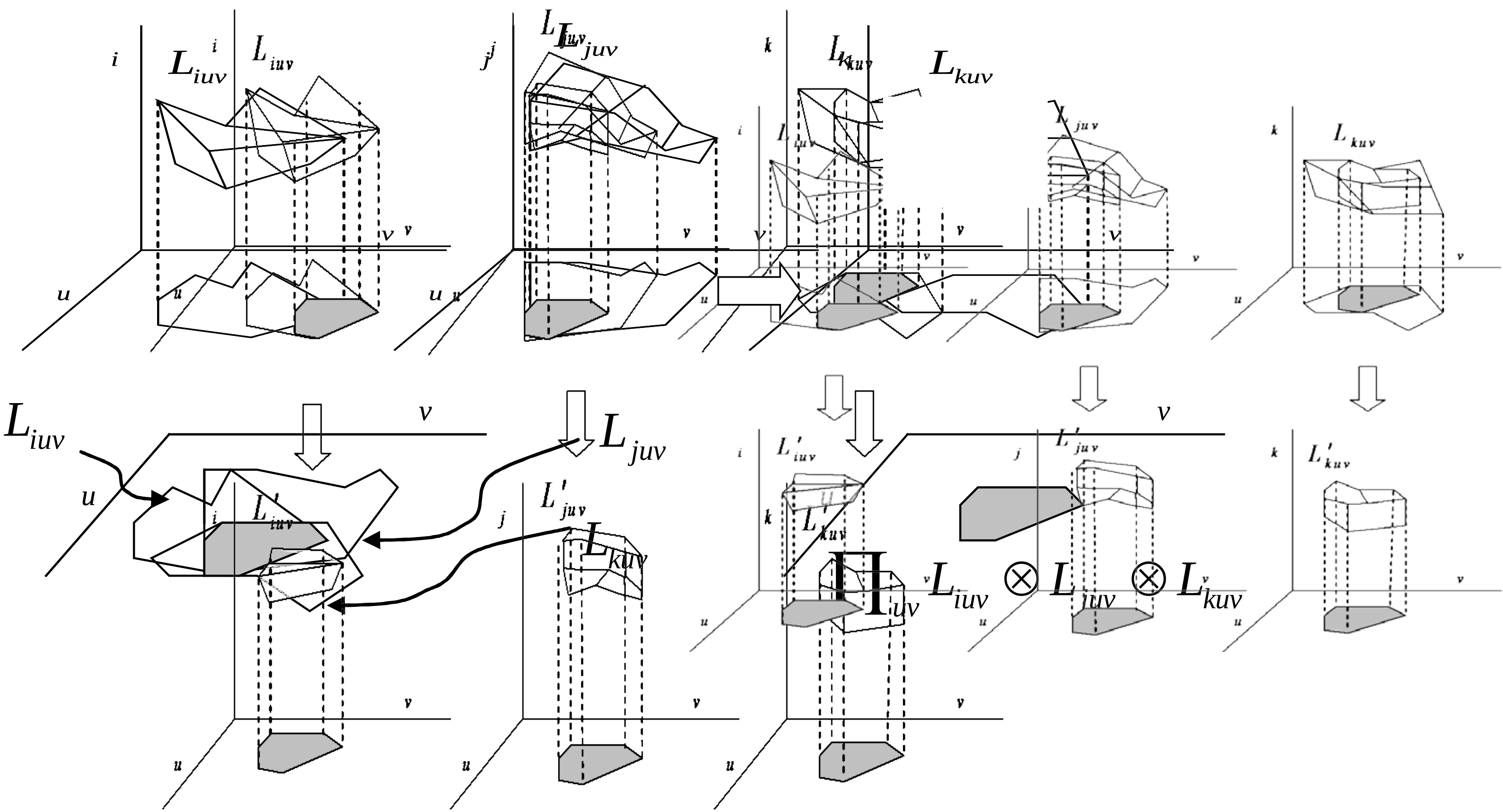
3. Representation – polytope/polyhedra based data structure (NEF – polyhedra)
4. Create individual polyhedron
   - For each ternary constraint
   - Use “filling” algorithm with a “seed” point



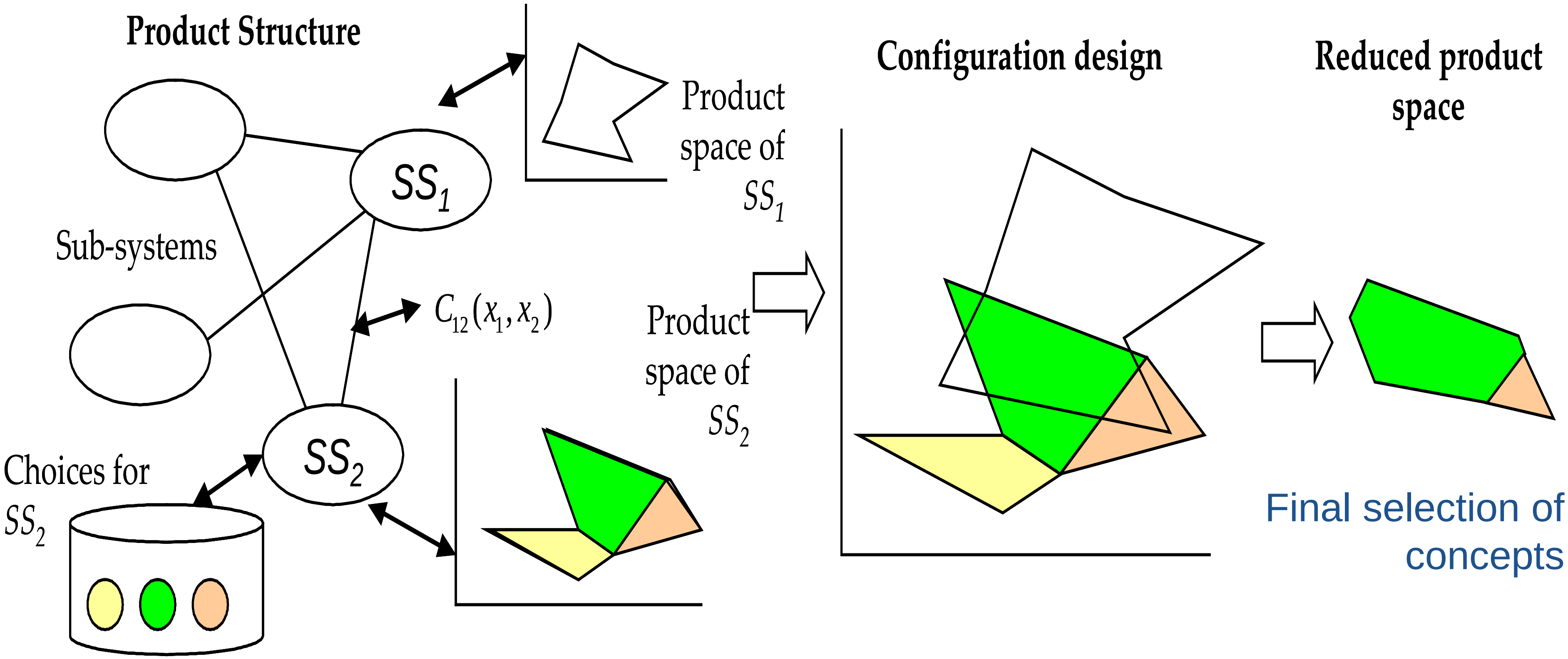
# Creating concept space - steps

5. Maintain consistency between constraint spaces
   - Example: 3 constraints (i,u,v), (j,u,v), (k,u,v)



# Application1: Configuration & Concept Selection

Future work



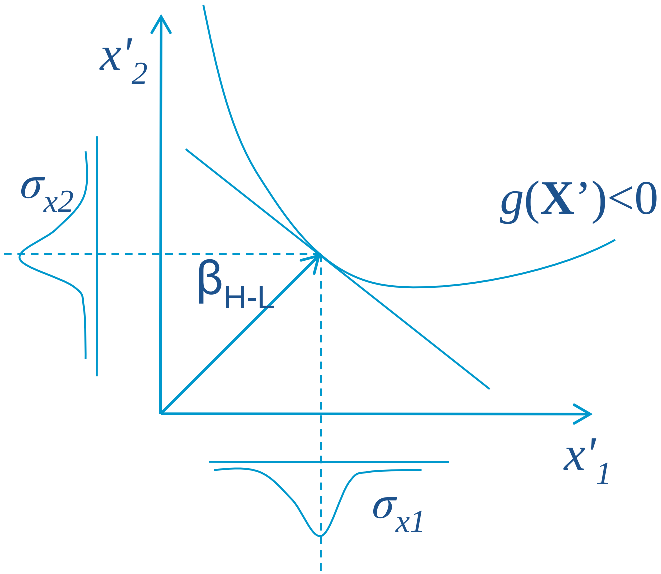

Final selection of concepts

- Design operations transformed into geometric operations on design spaces

# Application 2: Reliability based design

- Background – First order reliability (Hasofer-Lind)
- $x_i$ – design variable
- $\sigma_{xi}$ – standard deviation of $x_i$
- $\mu_{xi}$ – mean value of $x_i$

$$x_i' = \frac{x_i - \mu_{x_i}}{\sigma_{x_i}}$$



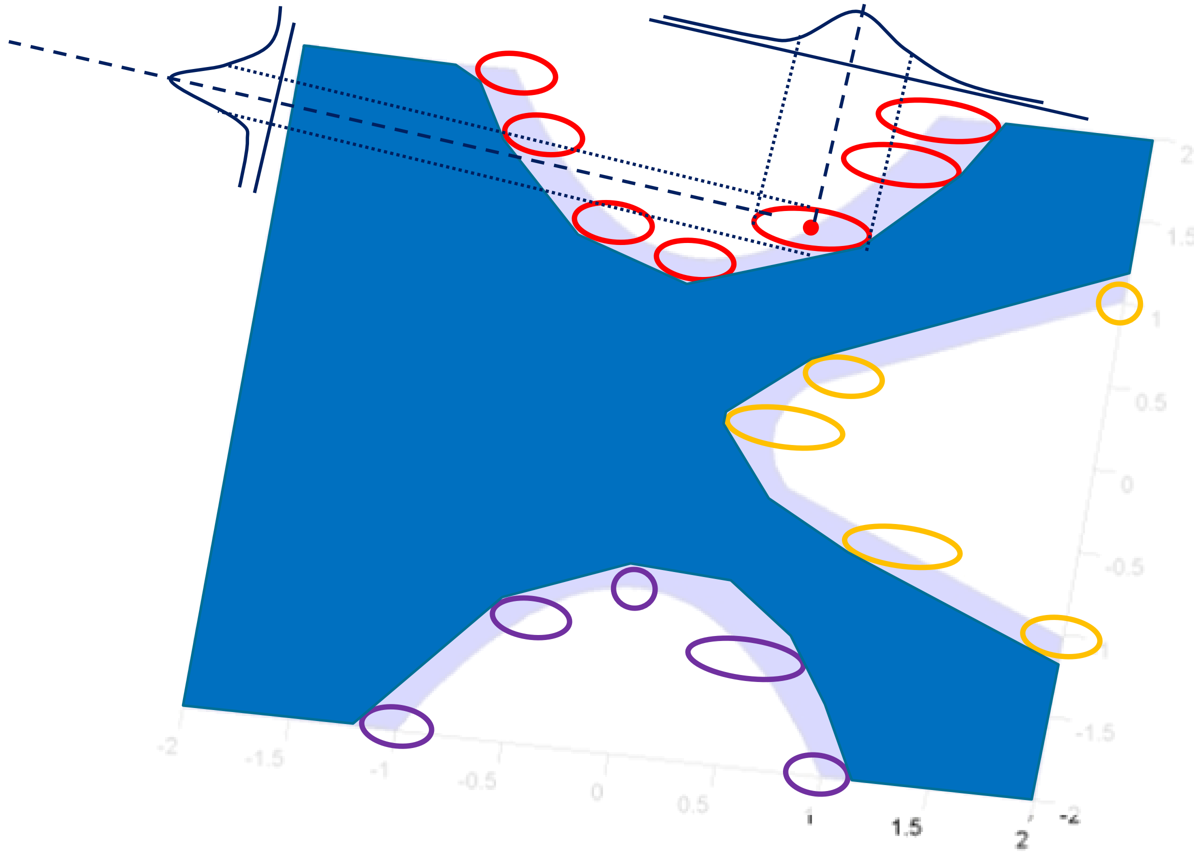

- Probability of failure

$$p_f = 1 - \Phi(\beta_{H-L})$$

- Reliability = 1-$p_f$
- Question: *Given a minimum reliability requirement, how does the new design space look like?*

# RBD using design spaces

- Geometric meaning



- Again, design operations are transformed into geometric operations!

# Conclusion

- Porting to **higher dimensional volume-based reasoning involves complete re-thinking in terms of solution algorithms**, based on geometry and topology.
  - reliability-based design (showed FORM)
  - robust design,
  - uncertainty management,
  - tolerance design,
  - surrogate models and optimizations
- Today, legacy designs deter engineering teams from trying out new concepts since it involves a complete reengineering which is too difficult and hence not considered in the light of time and cost constraints for products.

# Summary

- Past work was completed beyond original goals
- New proposals to NSF (SciSCP $250 K submitted leverages this work)
- Another proposal directly leverages this work and new PLM08 Proposals = NSF CI positioning ($50 -$250 Million over 2008-12)
- U.S. Chair PLM08 - Korea, Engineering Research Excellence Award 2007, NSF Engineering Adcom Subcommittee (3 year), Invited Plenary Speaker CAD 08 (Florida), Invited Plenary Speaker CAE (Madras – India)

# Leverage

- Two Ph.D. students who are well past their course work and have real design experiences in industry, sufficient computational and information science backgrounds including (Algorithms (CS580), Computer Graphics (CS535 ), and Database Systems (CS541)).
- University fellowships to the student, TA ship, and the University Faculty Award to the PI
- Past 3 years of 2 students work was funded
- Engineous and Alcoa student internships.

# Leverage

- Sabbatical that directly relates to the proposed work and extension (cost and time share)
- Fellow Institute of Pure and Applied Maths (2007): NSF Institute Cost Share at UCLA
- Co-PI: on new proposal – Professor Abhyankar (Marshall Distinguished Professor). New class offered at graduate level on algebra for algebraic geometry.