Configuration Driven Design and Reuse: Present and Future

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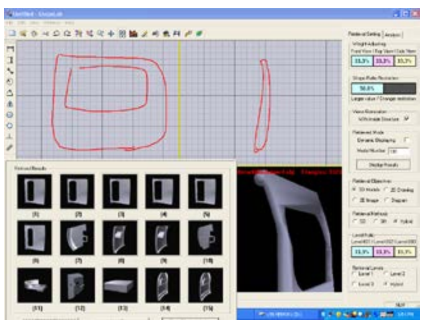
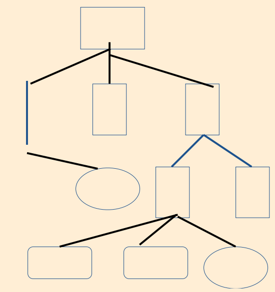
Research Overview

Shape Search

Ontology Search

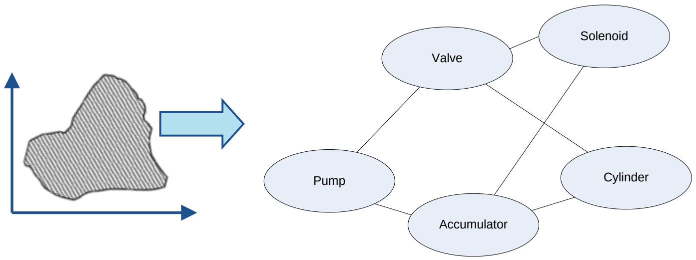


Search and Analysis
Of
High Dimensional Spaces

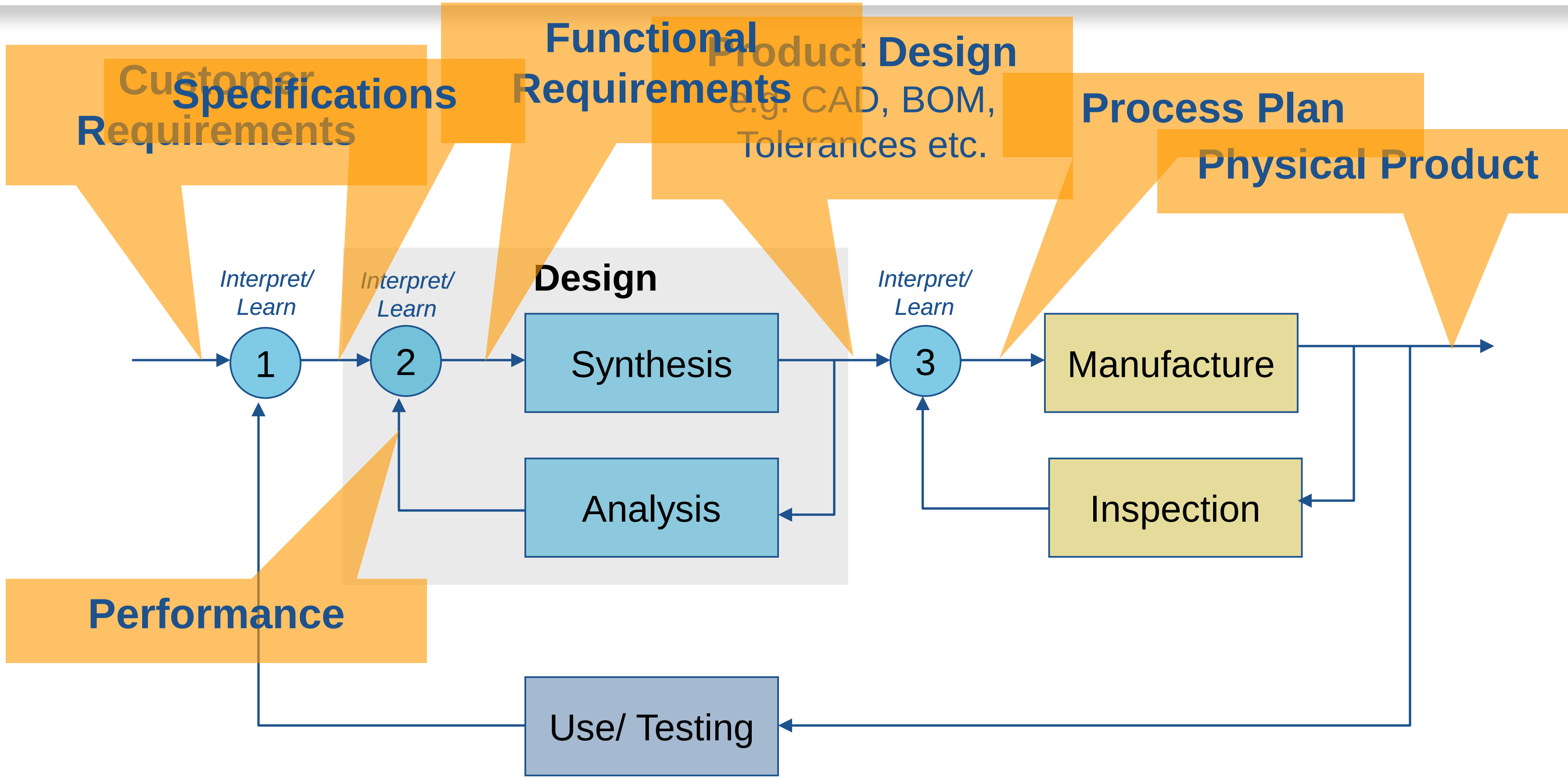


Domain Ontology Index

Design Space Search

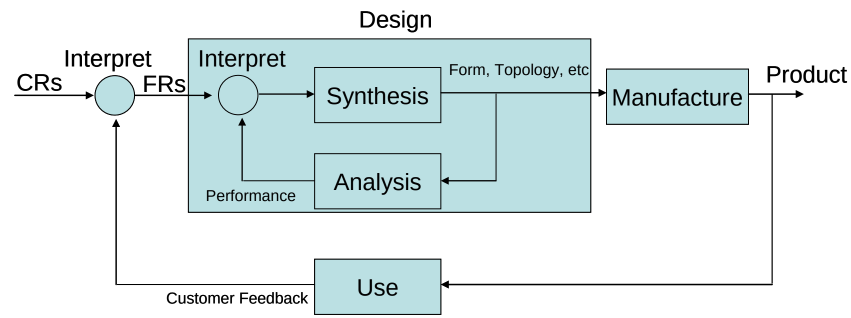


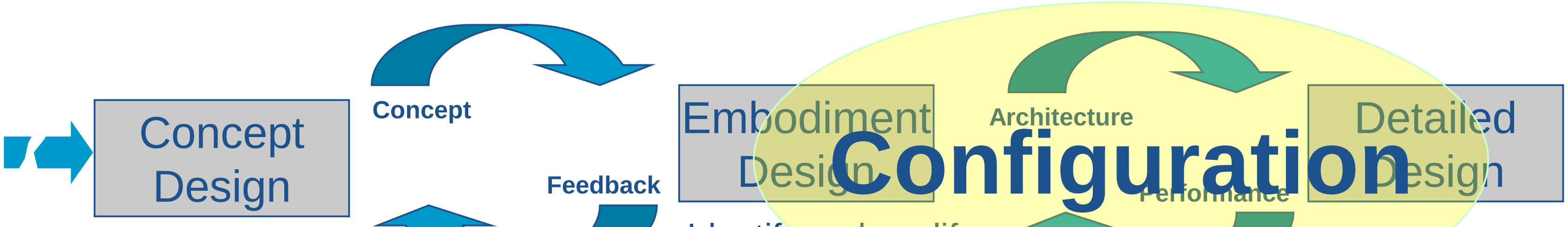
Basics - Product realization



Rationale

- Product Design:
  - Closed loop process
  - Analysis models Use





•Generate “idea”

•Explain “what”

•Identify and qualify major components

•Characterize design parameters

•Assign performance targets

•Identify functional constraints

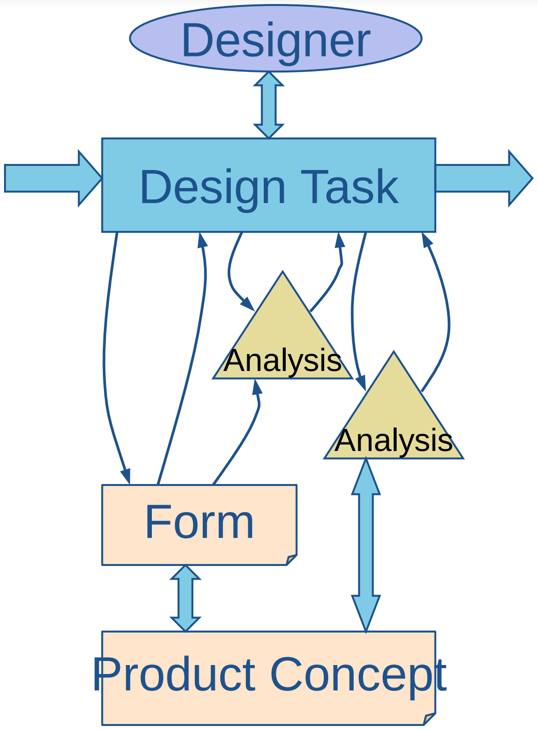
•Establish relationships between parameters

•Select values for various parameters

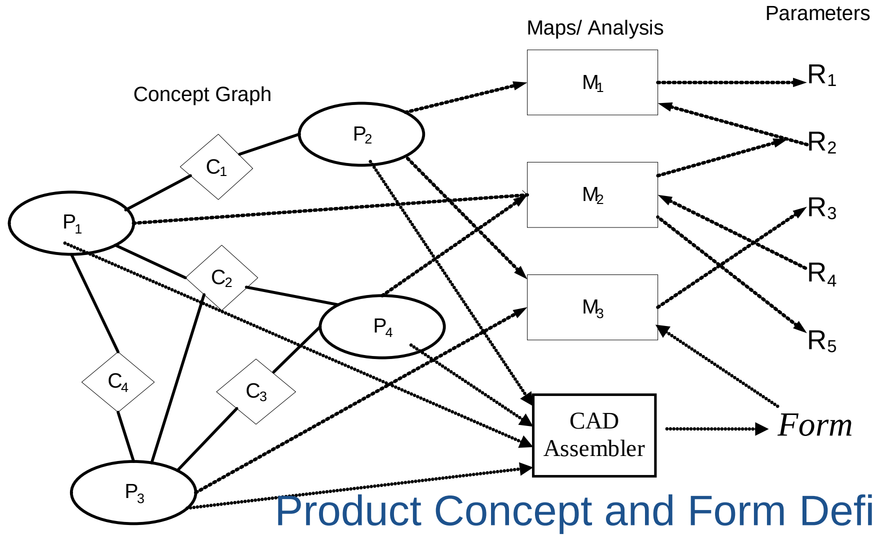
•Satisfy requirements and constraints

•Meet secondary objectives (e.g. cost)

Design task as a predicate



$$Task(Product\_Concept, Partial\_Instance, Analysis\_Tools, Designer) \rightarrow (Product\_Concept, Partial\_Instance)$$

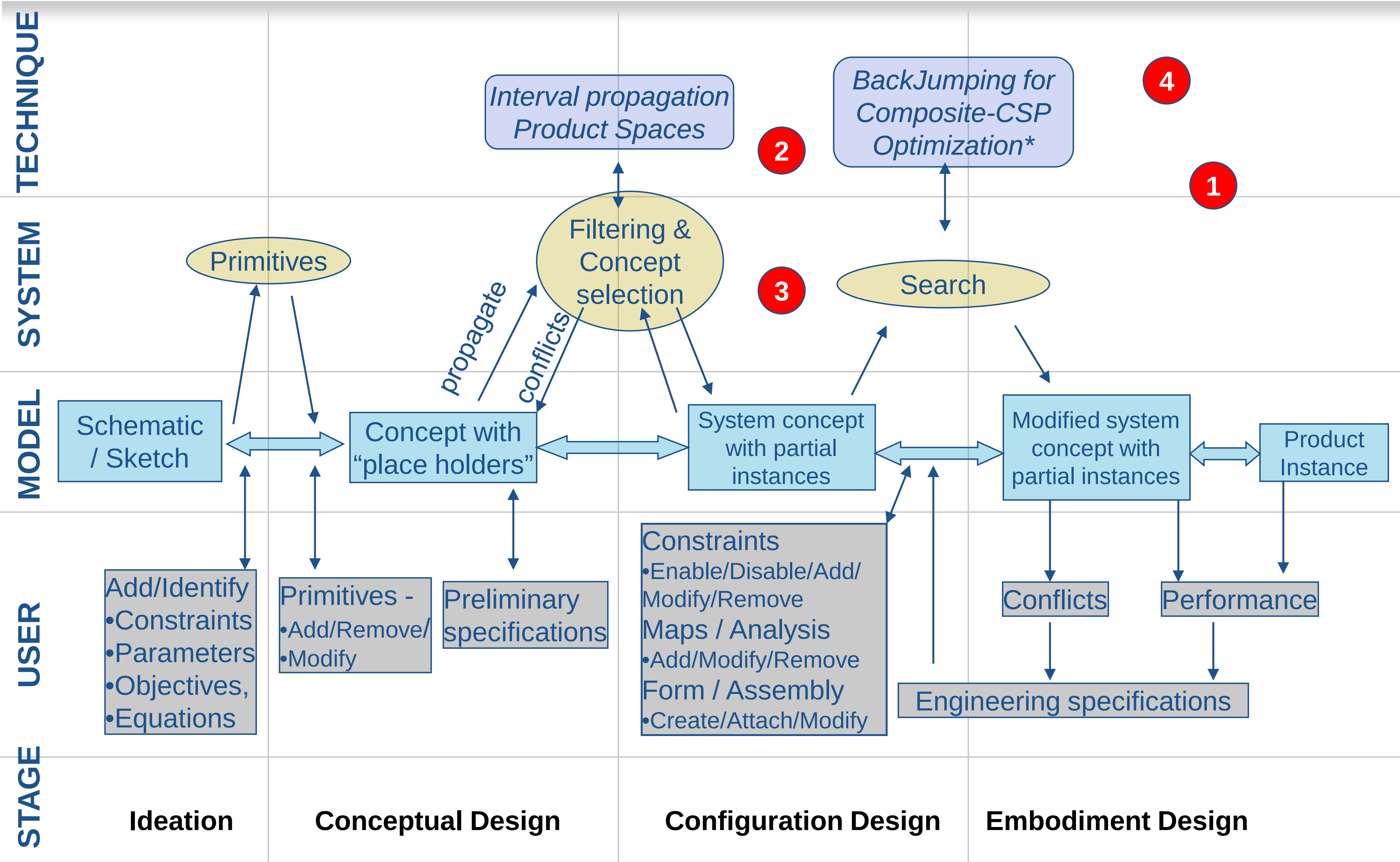


Product Concept and Form Definition[1]

- Concept definition encapsulates analysis representation
- Provides flexible representation for re-design thro' physics based configuration
- Mathematically captures interactions within product

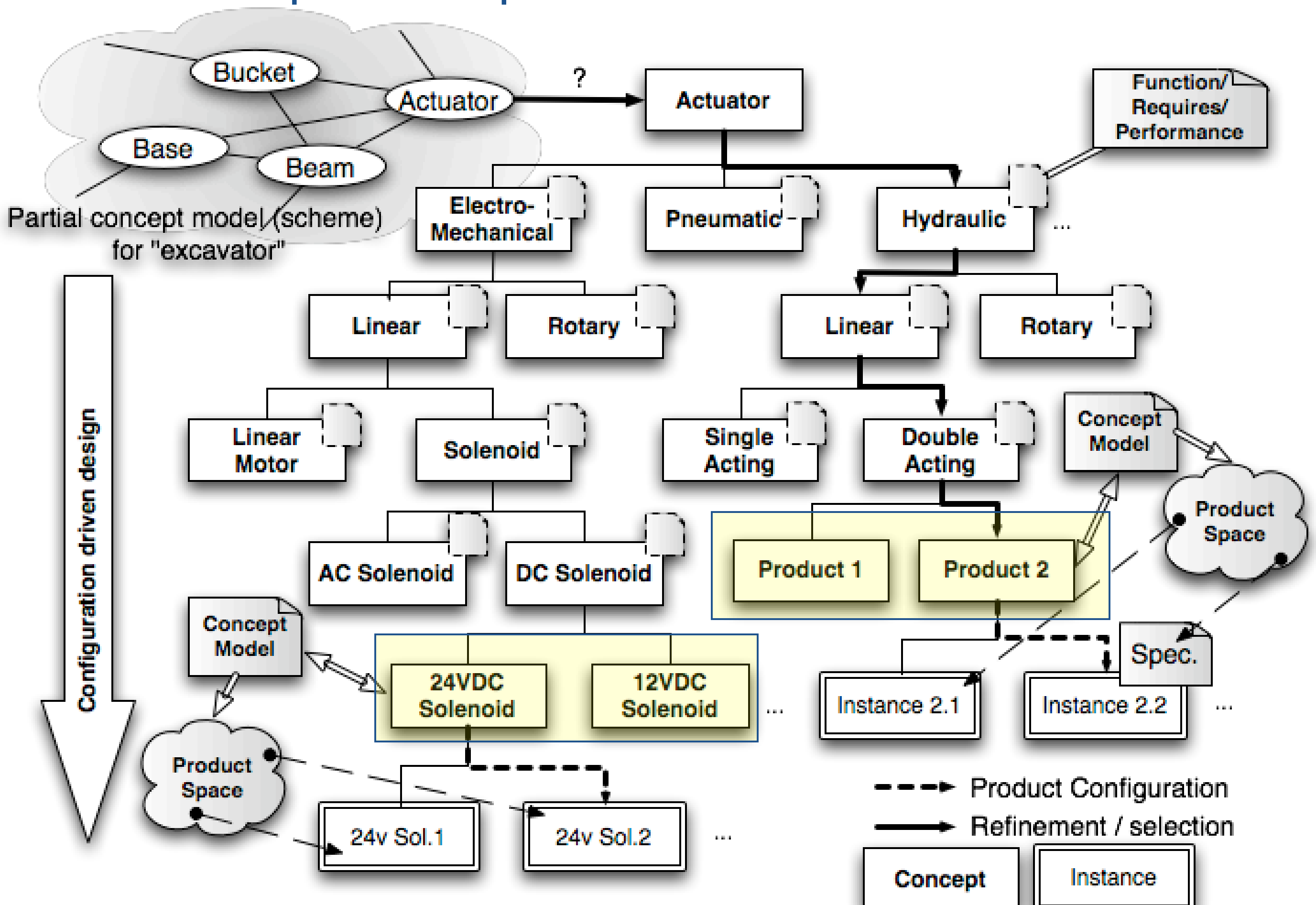
[1] Devanathan et al., 2005

Vision – Configuration driven design



Configuration driven design

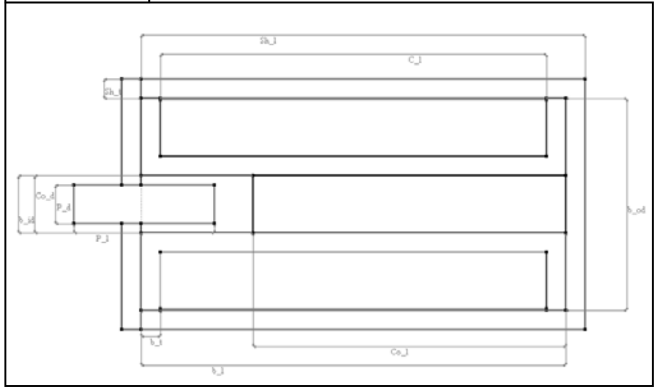
- The domain for each concept is hierarchical
- Each product associated with model that mathematically describes variants in the product space



Example – Solenoid

S.No	Meta Variable	Variable Name	Variable Symbol	Type	Data Type	Unit
1	Bobbin	Bobbin Inner Diameter	b_id	geometric	real	mm
2		Bobbin Length	b_l	geometric	real	mm
3		Bobbin Outer Diameter	b_od	geometric	real	mm
4		Bobbin Thickness	b_t	geometric	real	mm
5	Coil	Coil Average Diameter	d_av		real	mm
6		Coil Inner Diameter	d_in	geometric	real	mm
7		Coil Length	c_l	geometric	real	mm
8		Coil No of Turns	n		integer	
9		Coil No of Windings	n_w		integer	
10		Coil Outer Diameter	d_out	geometric	real	mm
11		Coil Resistance	r		real	ohm
12	Core	Core Diameter	co_d	geometric	real	mm
13		Core Length	co_l	geometric	real	mm
14	Plunger	Plunger Diameter	p_d	geometric	real	mm
15		Plunger Flux Area	a_pw		real	mm2
16		Plunger Flux Path Length	l_i		real	mm
17		Plunger flux path length eqv	l_i_2		real	
18		Plunger Permeability	p_mu		real	
19		Plunger Wall Gap	l_pw	geometric	real	mm
20		Plunger Length	p_l	geometric	real	mm
21		Plunger Wall Gap eqv	l_pw_2		real	
22	Shell	Shell Diameter	sh_d	geometric	real	mm
23		Shell Relative Permeability	sh_mu_r		real	
24		Shell Thickness	sh_t	geometric	real	mm
25		Shell Length	sh_l	geometric	real	mm
26		Shell Average area	a_i		real	mm2
27	Wire	Wire Diameter	w_d		real	mm
28		Wire Length	w_l		real	mm
29		Wire Resistance per length	rho		real	ohm/m
30		Average Force	f_avg		real	N
31		Cross-section Gap Area	a_g		real	mm
32		Force coefficient	k1		real	
33		Length	l		real	mm
34		Maximum Current	i_max		real	A
35		Maximum Force	f_max		real	N
36		Maximum Gap Length	l_gap_max		real	mm
37		Minimum Force	f_min		real	N
38		Minimum Gap Length	l_gap_min		real	mm
39		Operating Voltage	v		real	V
40		Steady State current	i_ss		real	A
41		Stroke	stroke		real	mm

Sectional View



```
[w_l := n * rho * PI * d_av / 2.0
[r := rho * w_l
[d_av := (d_in + d_out ) / 2.0
[n_w := n * w_d / c_l
[d_out := n_w * w_d
[i_ss := v / r
[a_g := 0.25 * PI * p_d^2
[k1 := 0.5 * p_mu * a_g * (n^2);
[l_c := l_pw_2 +l_i_2 / sh_mu_r
[f_min = k1 * (i_ss^2) /( (l_gap_max + l_c))
[i_max := sqrt(f_max *(l_gap_min + l_c) / k1)
[l_gap_max := l_gap_min + stroke
[f_avg := 0.5 * (f_min + f_max)
[l := c_l + 2*sh_t + b_t
[a_pw := PI * sh_d * sh_t
[l_pw := 0.5 * (sh_d - p_d)
[l_pw_2 := l_pw * a_g / a_pw
[l_i := sh_l + sh_t + d_out
[l_i_2 := l_i * a_g / a_i
[a_i := 2 * PI * d_out * sh_t
```

Configuration design problem

- Modeled as a composite-CSP
  - Hierarchical domain, dynamic, meta-CSP
  - Collection of meta-problems $\{\langle \Phi, X, D, C, F\rangle_i\}$

Minimize $F = F(\phi) = \{F_i(X)\},\ i = \{1, 2, \ldots m_1\}$ such that

$C = \{G, H\}$, the set of constraints is satisfied, where,

$\Phi = \Phi(\phi) = \{\phi_j\},\ j = \{1, 2, \ldots m_2\}$, the set of *m2* meta-variables (or sub-concepts);

$X = X(\phi) = P \cup \left(\bigcup X(\phi_j)\right),\ X \in D$, the design variables;

$D = D(\phi) = D(P) \cup \left(\bigcup D\left(X(\phi_j)\right)\right)$, the set of domains for the design variables;

$G = G(\phi) = \{g_k(X) \le 0\},\ k = \{1, 2, \ldots m_3\}$, the set of inequality constraint;

$H = H(\phi) = \{h_l(X) = 0\},\ l = \{1, 2, \ldots m_4\}$, the set of equality constraints;

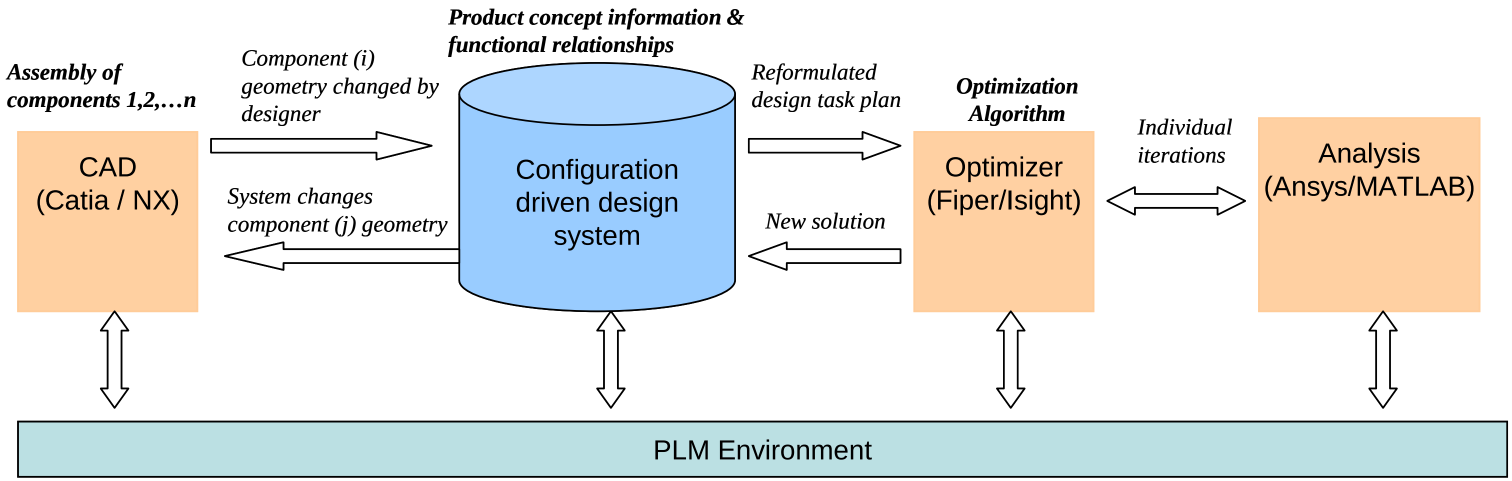
$P = P(\phi) = \{p_s\},\ s = \{1, 2, \ldots m_5\},\ p_s \in D(p_s)$, the parameters of the meta-variable;

m_1, m_2, m_3, m_4 and m_5 are constants.

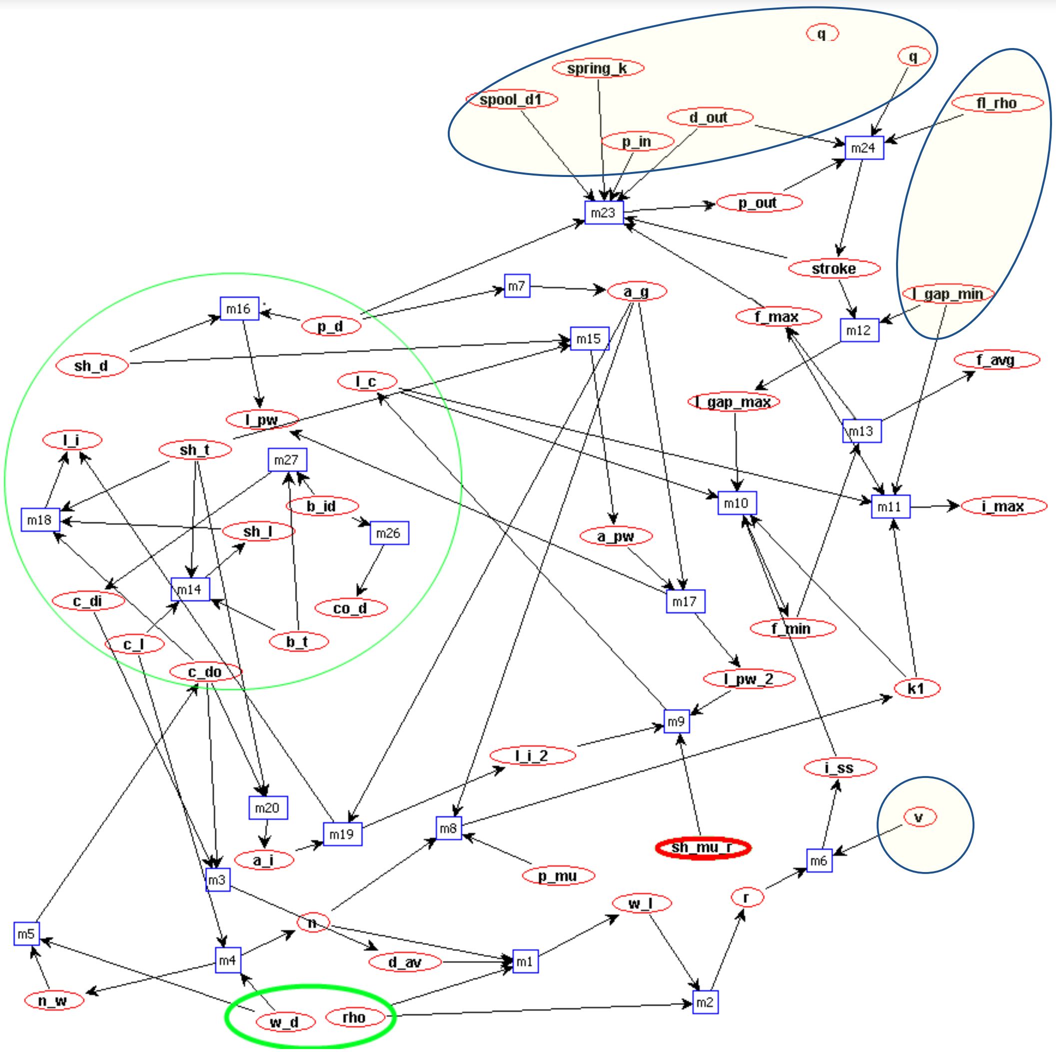
  - Domain for meta-variables (concepts) is hierarchical
  - Reduces to a continuous CSP or an Optimization problem under restrictions.

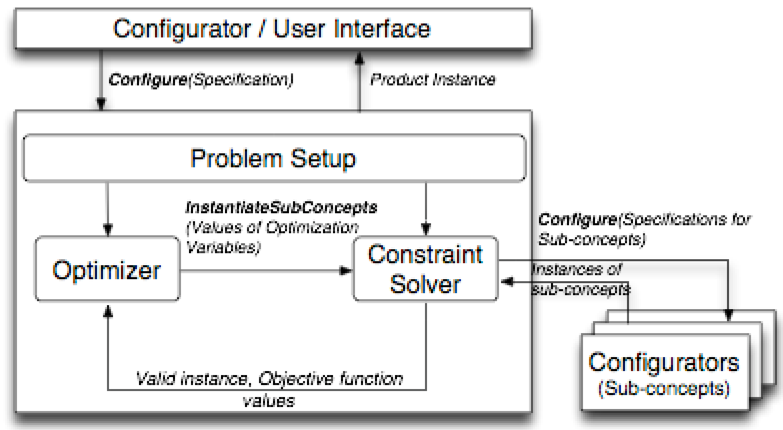
Completed System Example

- Configuration driven design
  - Reuse product and analysis models in new designs
  - Automatically maintain consistency among sub-systems



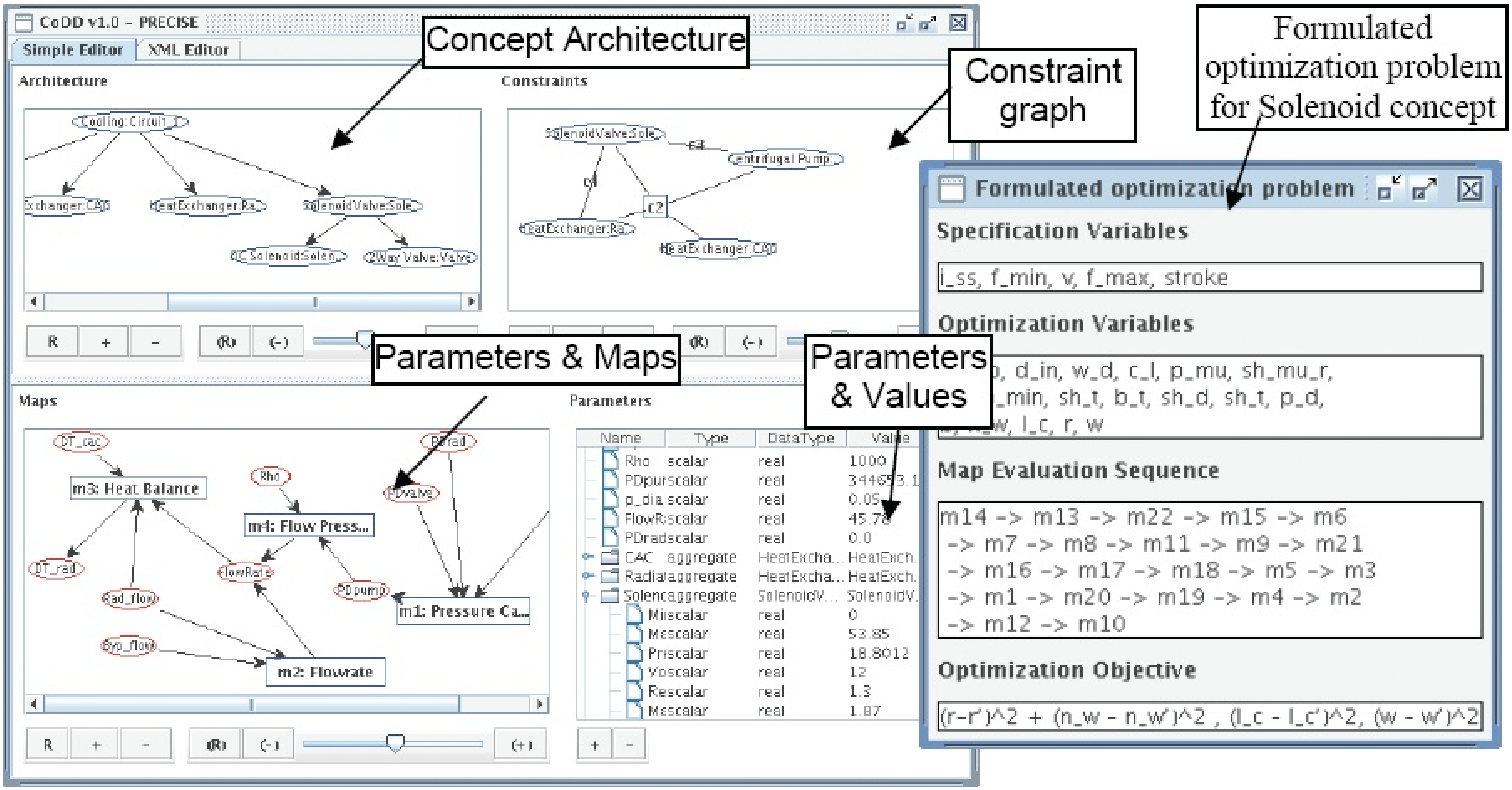
Constraint network (solenoid valve)





- Automatically formulate optimization problem
- Use Constraint solver for consistency maintenance

Example Screenshot



Publications

- Devanathan, S., and Ramani, K., (2007), "Combining constraint satisfaction and non-linear optimization to enable configuration driven design", Sixteenth International Conference on Engineering Design, Paris, France, August 28 - 31, 2007
- Titus, N., O'Sullivan, B., and Ramani, K., (2007), "ConfigLab: A Conceptual Design Tool with Corrective Explanations Supported by Sketch-Based Design Reuse" Sixteenth International Conference on Engineering Design, Paris, France, August 28 - 31, 2007
- Titus, N., Schunn, C., Walthall, C., Chiu, G., Ramani, K. (2008), "What Design Processes Predict Better Design Outcomes? The Case of Robotics Design Teams", Seventh International Symposium on Tools and Methods of Competitive Engineering, Izmir, Turkey, 2008
- Devanatha, S., Murugappan, S., Sellamani, S., Ramani, K., (2008), "An interactive constraint based multimodal early-design support system", Artificial Intelligence for Engineering Design and Manufacture, (in preparation)

Contributions

- Integration of geometric, engineering constraints and configuration solvers
- Modeling of the early design problem to identify hidden structures within it eg: motor
- Identified minimal knowledge to allow reuse of design concepts
- Discovered that point-based ideas lead to inefficient solution evaluations (trashing) => leading to hyper-volume based ideas for concept evaluation

Exploring Design Spaces through Algebraic Geometry-based Methods

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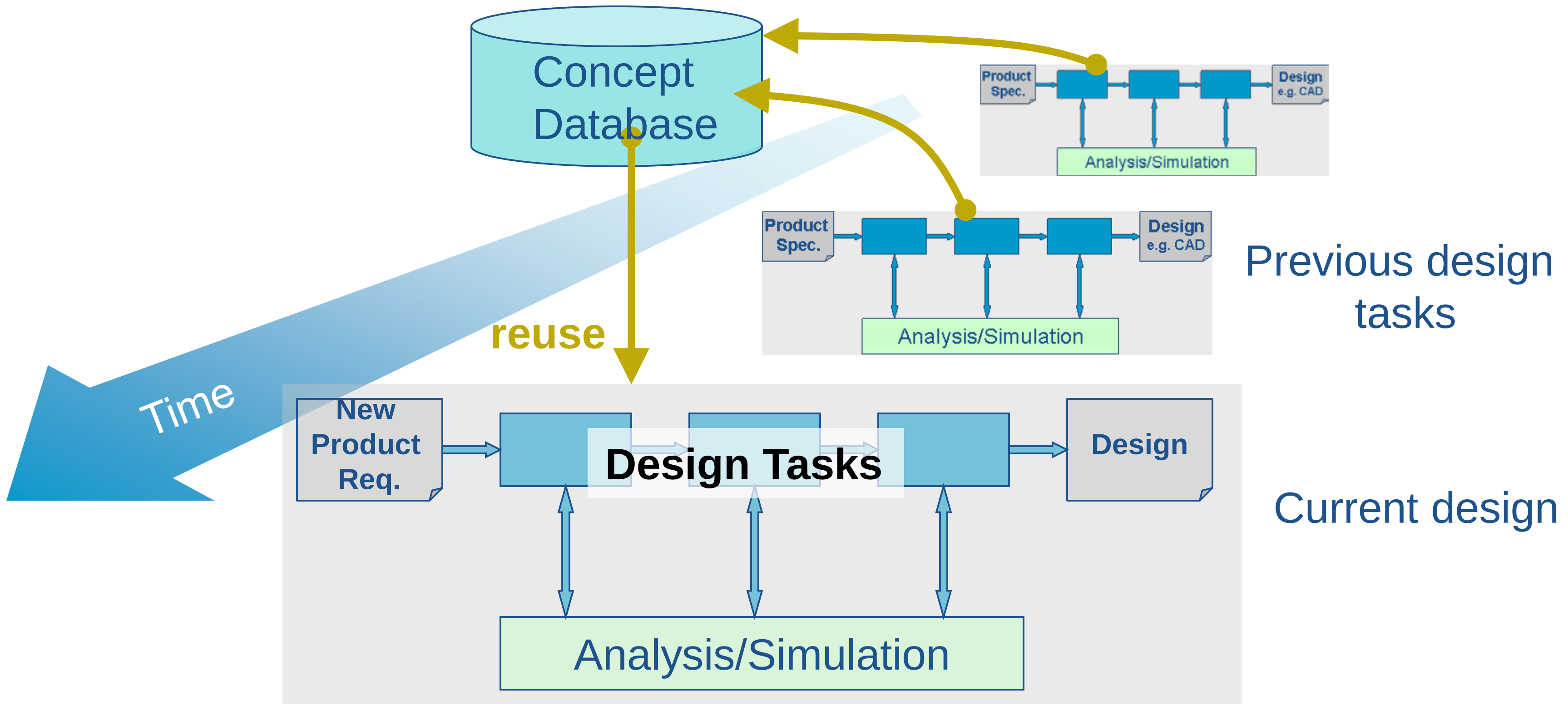
Shape of Design

- Today in most cases the design stage where decisions can influence the product concept is usually DONE “before” simulation, analysis, configuration etc happen.
- So what you hear about design integration with other tools appear to be false.

Data to Knowledge Gap



<u>The data generated during these runs are discarded as there are no ways to utilize them currently.</u>

The solution to this high dimensional exploration problem is not simple.

Observation => New Idea

- Repeated analysis creation/run for
  - Single point is obtained as a solution => entire problem is solved again when design is changed
  - Change in requirements, constraints and objectives
  - Small changes requires rerun
  - Decision making and selection
- Time consuming and redundant
- Data to knowledge gap!

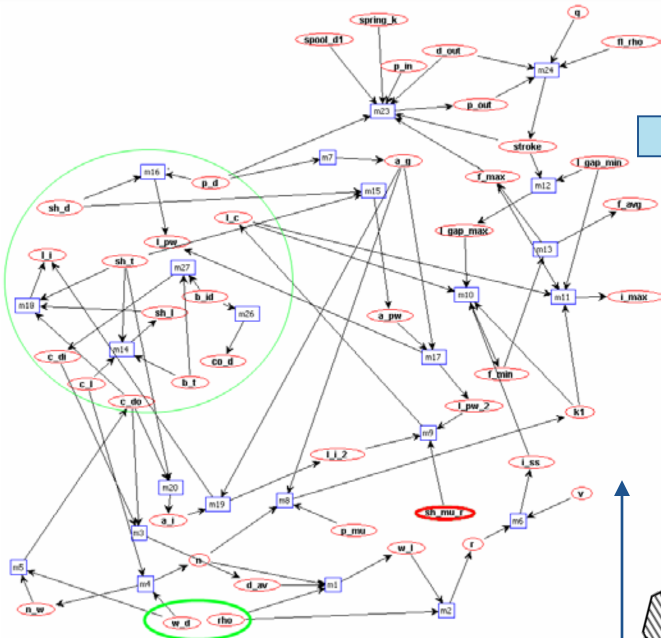
Proposed new research

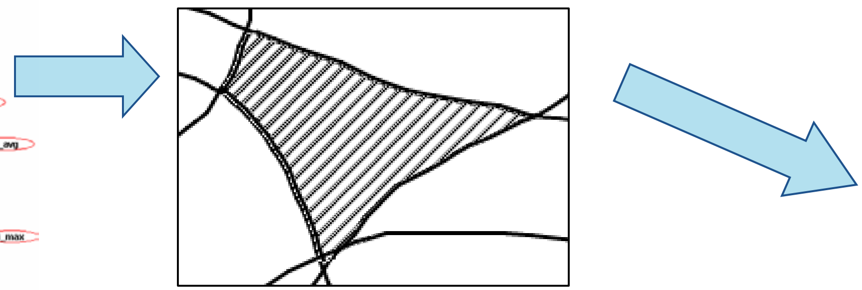
- Design Space: The n-dimensional space of valid designs; Performance space: space of performance parameters
- Pre-compute the design and performance space
  - Allow exploration of the entire design space
  - Store the design space efficiently
  - Search the space for a valid design based on new “CONCEPT” (NOT POINT BASED!!)

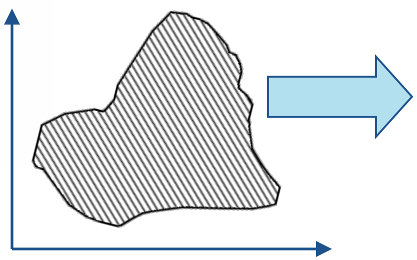
Concept selection using Product Spaces

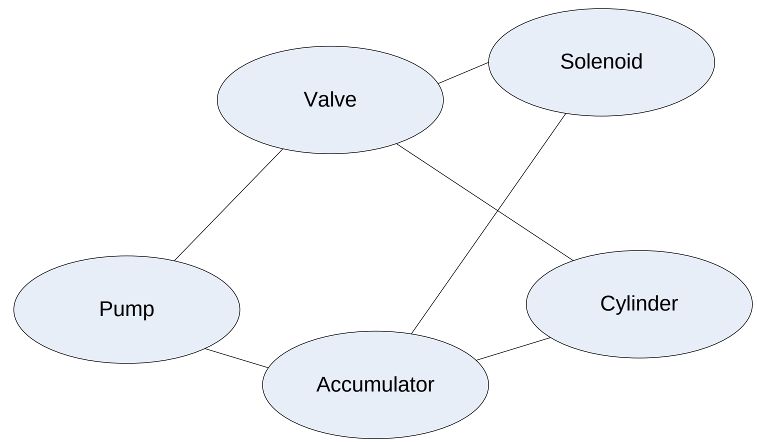
- Given a concept definition, in terms of parameters and constraints, quickly answer
  - Is a design concept feasible?
  - Can we find instances of two concepts that will function together?
- We attempt to use product spaces for such questions
- Product Space = {Design Space, Performance Space}

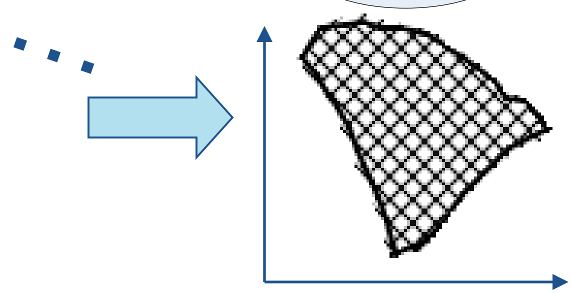
Design space creation and exploration











Question: How do we want to compute with a high dimensional design space?

Design Spaces Issues

- How to represent the space?
  - How to create it? Point based don't work, 2k trees inefficient, boxes too in accurate.
  - 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
    - Handles high dimensionality and captures knowledge in data
- How to perform operations on it?
  - Entire design space reasoning can be done

Changes Engineering Design

- *Porting standard point-based design methods such as reliability-based design, robust design, uncertainty management, tolerance design, surrogate models and optimizations to **higher dimensional volume-based reasoning involves complete re-thinking in terms of solution algorithms**, based on geometry and topology.*
- 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.
- Enables design innovation! This is a key to the U.S. economy.

Summary

- Past work was completed beyond original goals
- New proposals to NSF (CreativeIT $200 K submitted leverages this work)
- Another proposal directly leverages this work and new PLM08 Proposals = NSF CI positioning ($50 -$250 Million over 2008-12)
- Highly cited paper award (CAD), 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) 2007.

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) fully committed and working on the project proposal.

Cyber-Enabled Discovery & Innovation (CDI)

"Broaden the Nation's capability for innovation by developing a new generation of computationally based discovery concepts and tools to deal with complex, data-rich, and interacting systems."

- ENG broadly supports research in advanced cyber-enabled engineering throughout all its divisions.
- CDI investments areas include:
  - Complex interactions
  - Computational experimentation
  - Knowledge extraction
  - Virtual environments
  - Education in computational discovery
- Budgets -

	2008	2009	2010	2011	2012
Budgets	$51.98m	$100m	$150m	$200m	$250m

Proposed research

- Massively parallel algorithms for pre-computing design spaces
  - Utilize high performance computing to explore the space defined by the model
  - Efficient data structures for indexing and reasoning with design spaces
- Transfer of constraints, parameters, boundary conditions, loads from previous design (geometry) to current geometry
  - Extension from 2D to 3D

Value Proposition (Business)

- Cut design time drastically by
  - Reusing analysis data for new designs by leveraging high performance computing infrastructure
  - Reusing analysis models by reformulation
  - Reuse analysis setup by transferring boundary constraints and loading between designs