Discovering Methodologies for Integrated Product Design

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- Multi-Agent Design System
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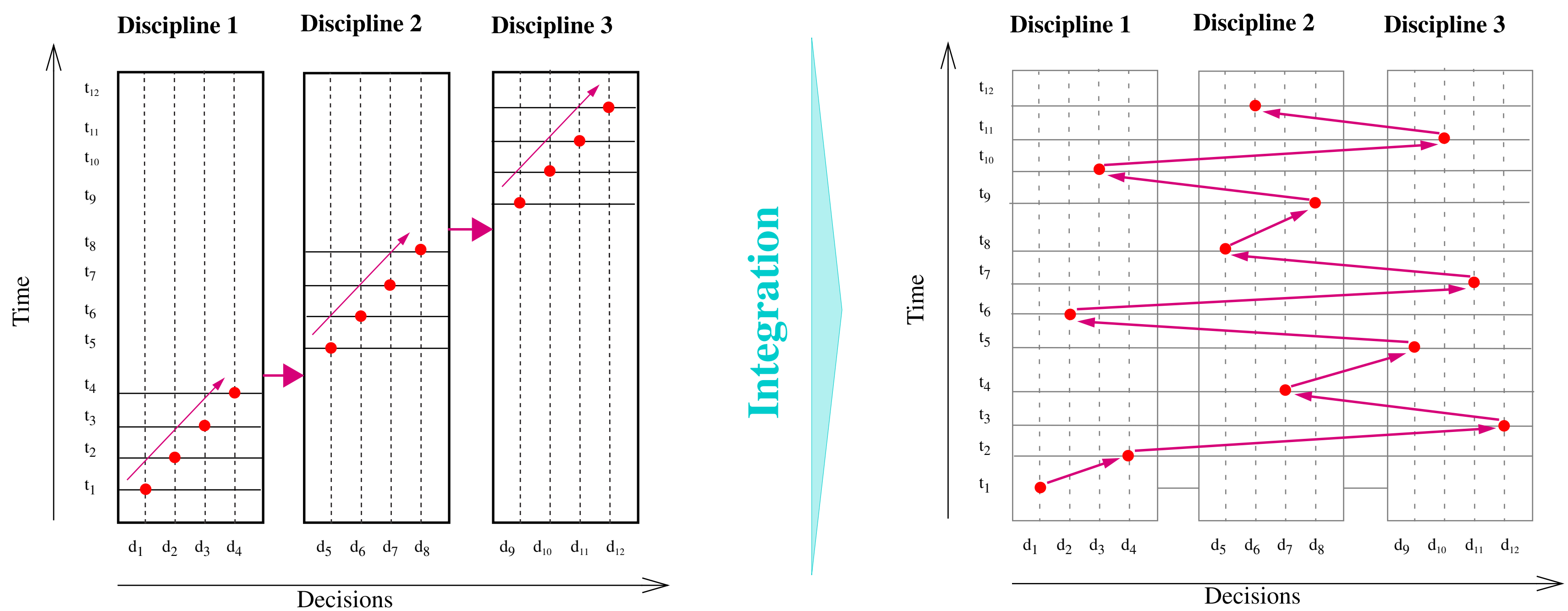
Introduction

- Motivation
  - Need for Integration, Collaboration, and Concurrency in Design Process
  - Examples: Automotive, Aerospace, Construction, ...
- Multi-disciplinary Product Design
- Integrated Product Design

Integration in Multi-disciplinary Design



(a) Design Methods in Large Segments

(b) Cutting Methods into Pieces

Decision Points

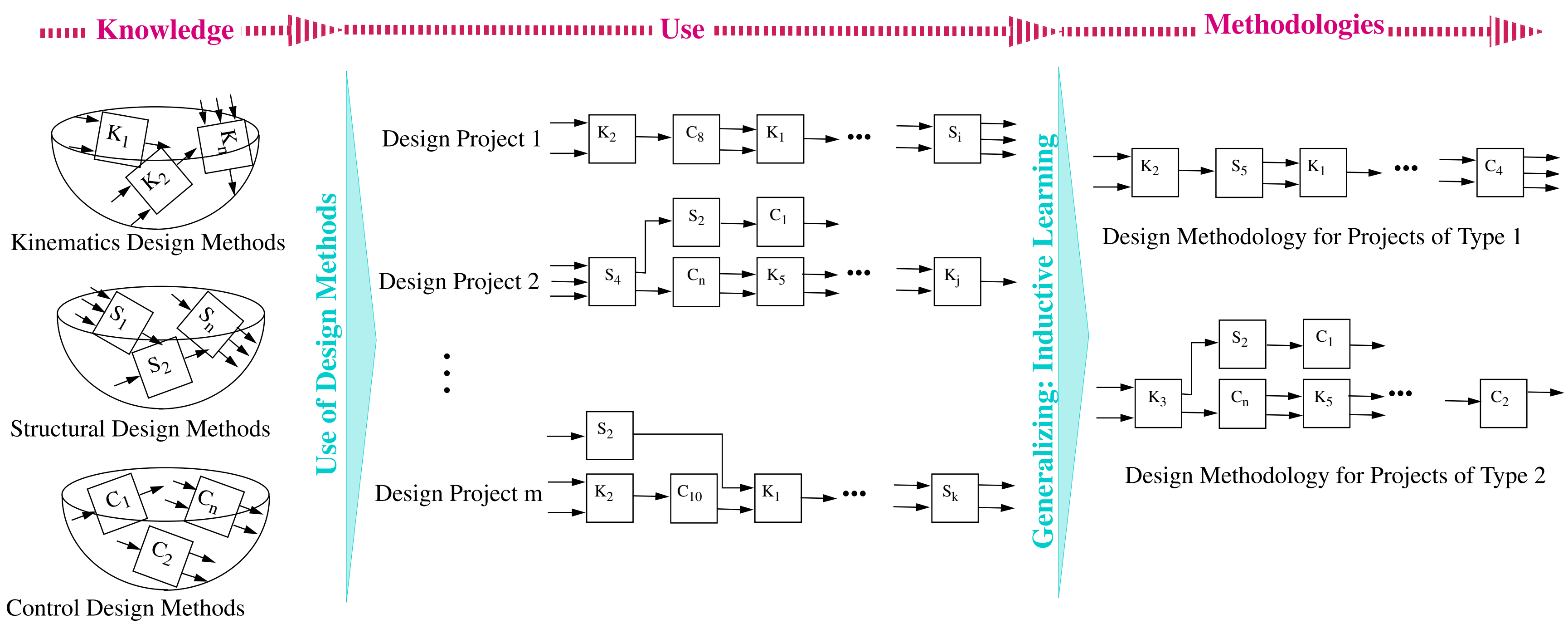
Design Methods

Problem Statement

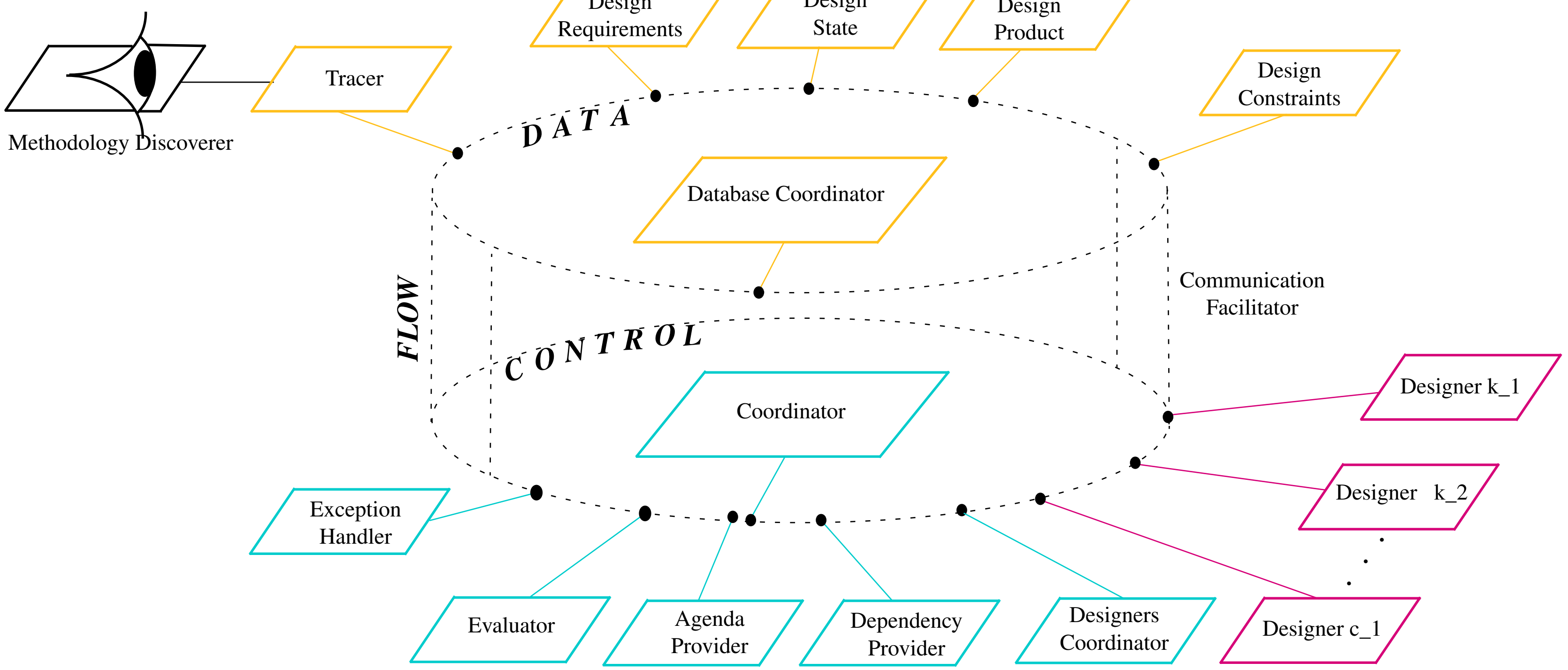
- Objective
  - To develop an approach for constructing superior methodologies for multi-disciplinary design
- Problem
  - Departmentalization/Compartmentalization
  - Built-in Disciplinary Goals
  - Disciplinary Design in Large Segments
- Strategies
  - Opportunistic Contribution
  - Cooperation
  - Least Commitment
  - Concurrency

- Small Design Methods

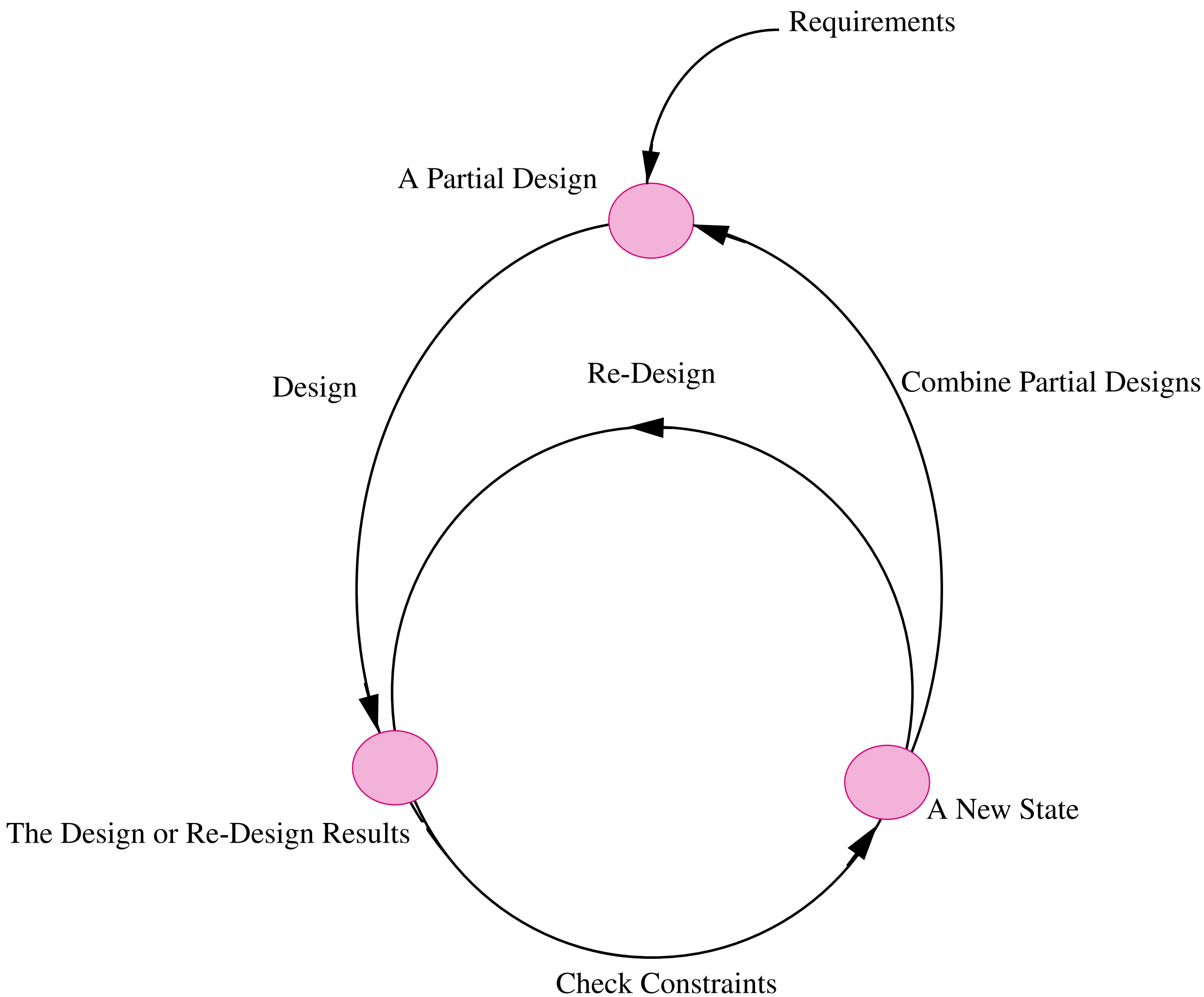
Knowledge-based Design Approach



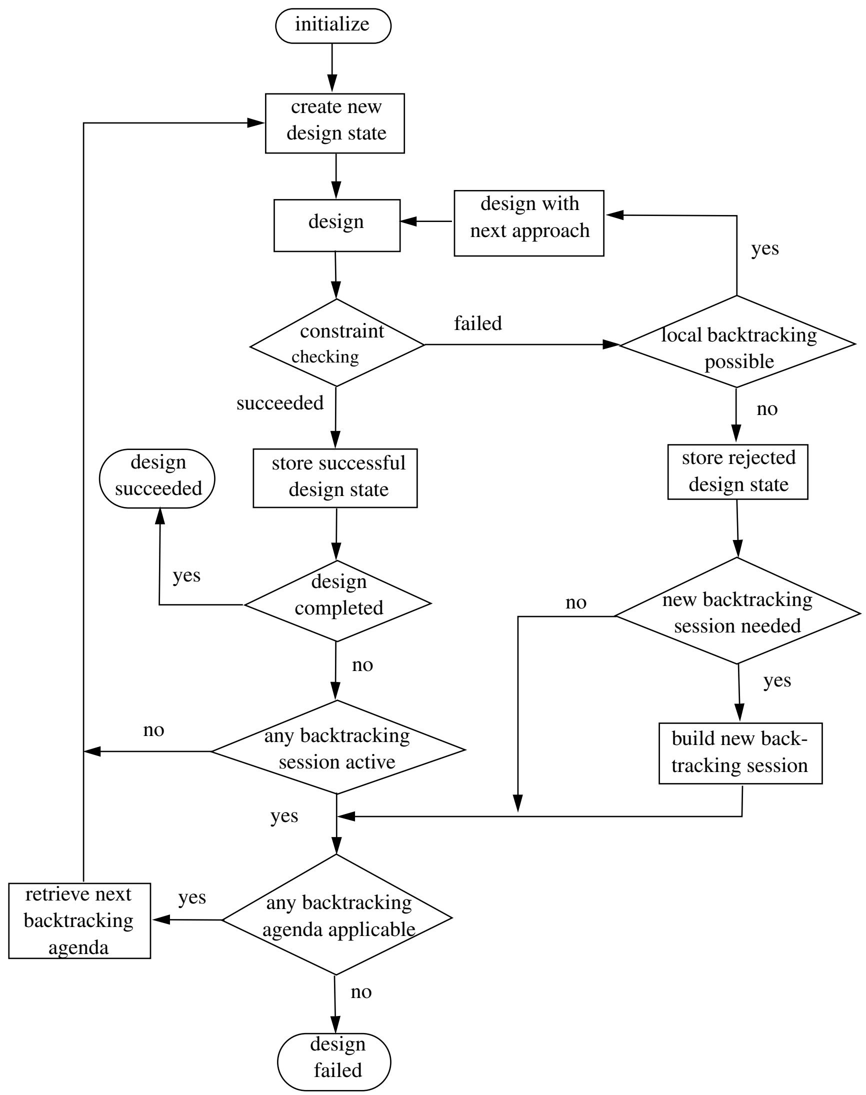
Multi-agent Design System



Flow of Design Process

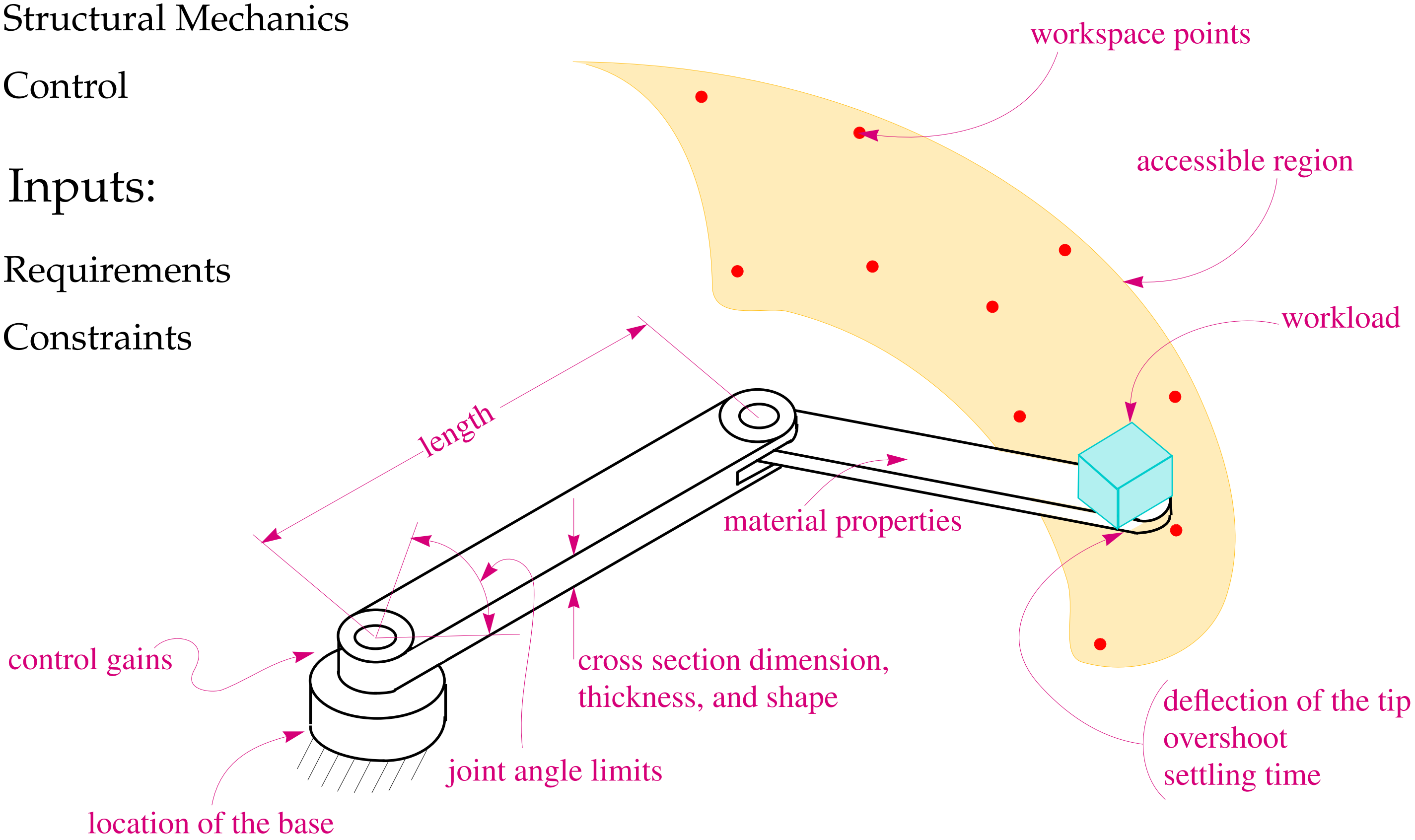


Flowchart of Design Process

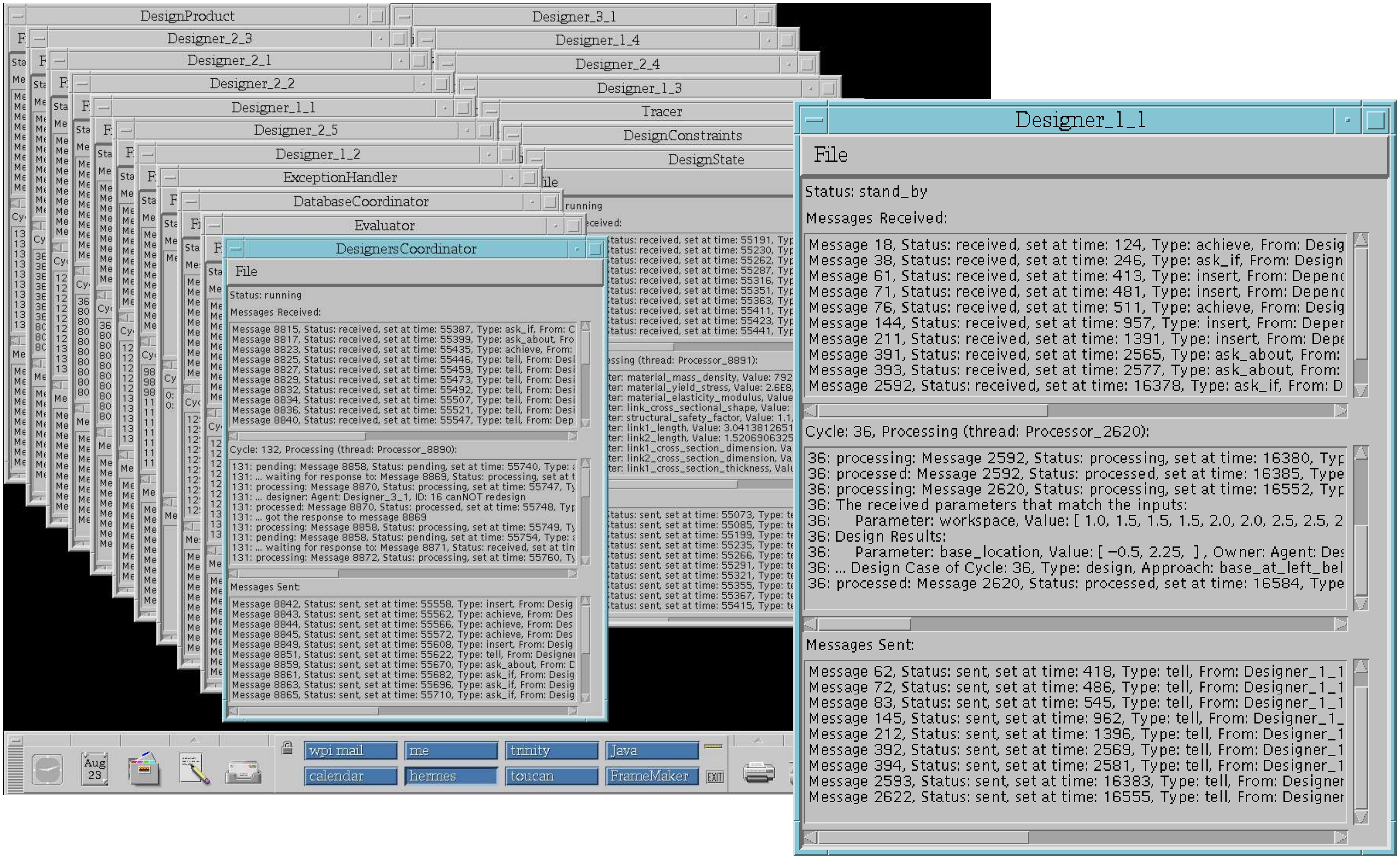


Design of a 2-DOF Robot

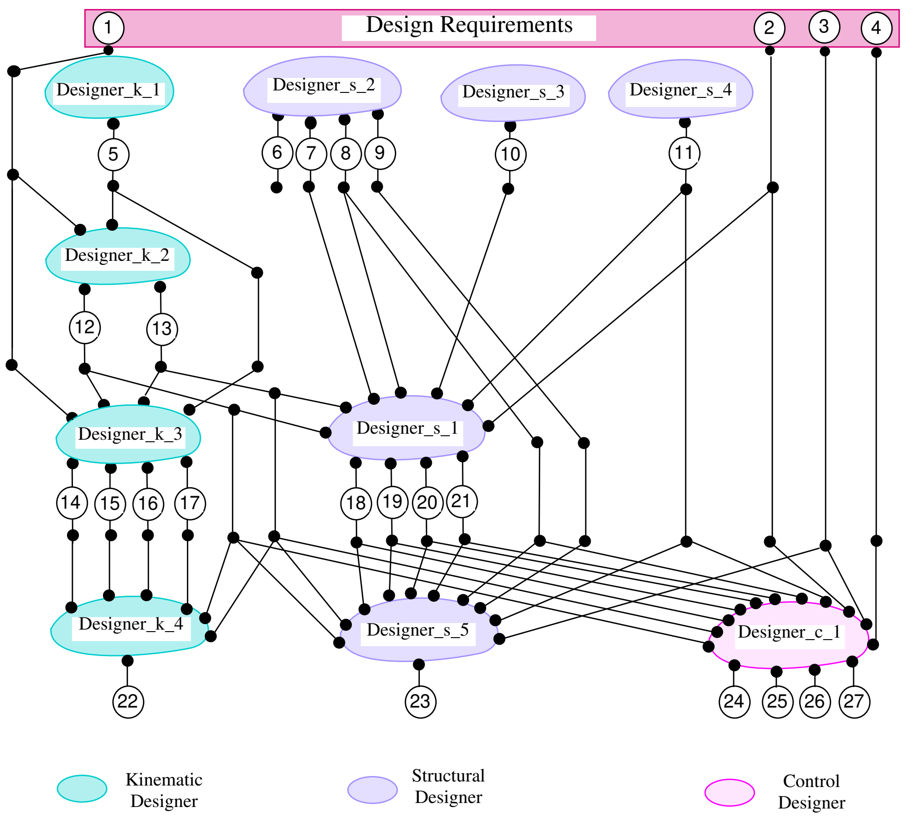
- Disciplinary Design Knowledge
  - Kinematic
  - Structural Mechanics
  - Control
- User's Inputs:
  - Requirements
  - Constraints



System in Action



Discovering Dependencies



Design Parameters:

1. workspace
2. workload
3. settling_time
4. maximum_overshoot
5. base_location
6. material_name
7. material_mass_density
8. material_yield_stress
9. material_elasticity_modulus
10. structural_safety_factor
11. link_cross_sectional_shape
12. link1_length
13. link2_length
14. theta1_min
15. theta1_max
16. theta2_min
17. theta2_max
18. link1_cross_section_dimension
19. link2_cross_section_dimension
20. link1_cross_section_thickness
21. link2_cross_section_thickness
22. accessible_region_area
23. tip_deflection
24. proportional_gain1
25. derivative_gain1
26. proportional_gain2
27. derivative_gain2

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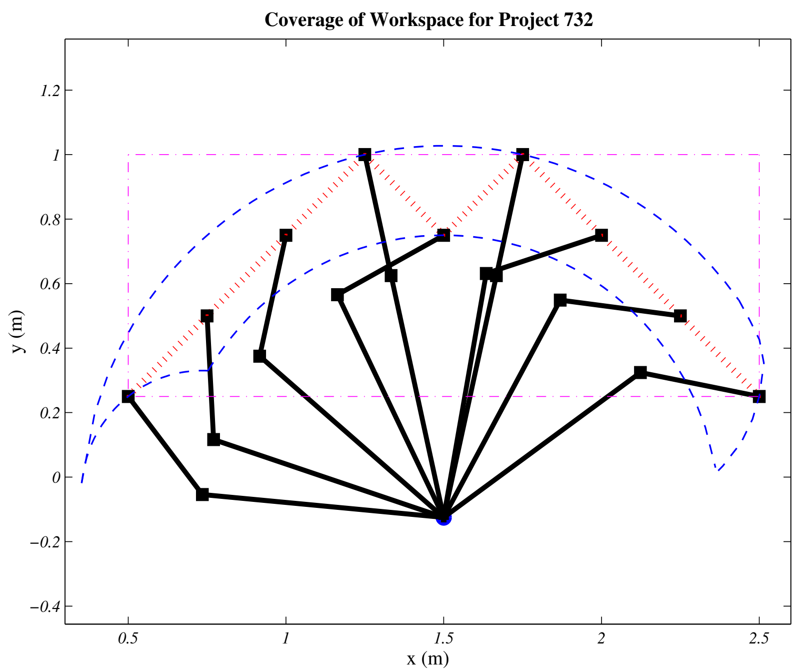
Example: Project 732

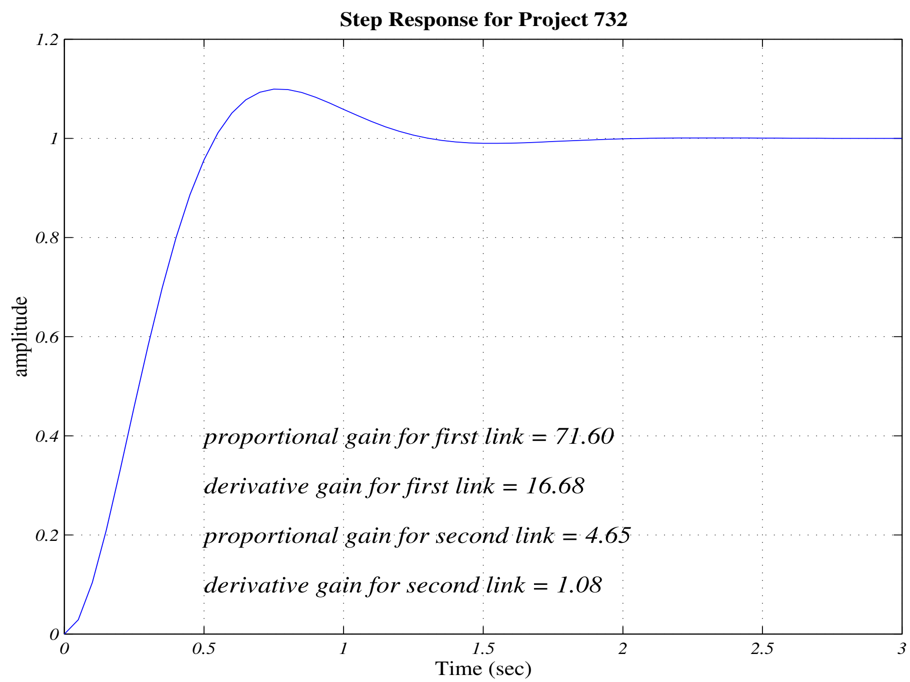
Constraints:

0 < link1_length < workspace_rectangle_length
0 < link2_length < link1_length
0 < link1_cross_section_dimension < 0.1 * link1_length
0 < tip_deflection < 0.001 * (sum of link lengths)
0 < accessible_region_area < 1.0 * workspace_rectangle_area
0 < proportional_gain1 < 100
0.05 * section_dimension < link1_cross_section_thickness < 0.25 * section_dimension
...

Requirements:

workspace = {(0.5, 0.25), (0.75, 0.5), (1.0, 0.75), (1.25, 1.0), (1.5, 0.75), (1.75, 1.0), (2.0, 0.75), (2.25, 0.5), (2.5, 0.25)} m
workload = 1.0 kg
settling_time = 1.0 sec
maximum_overshoot = 10%





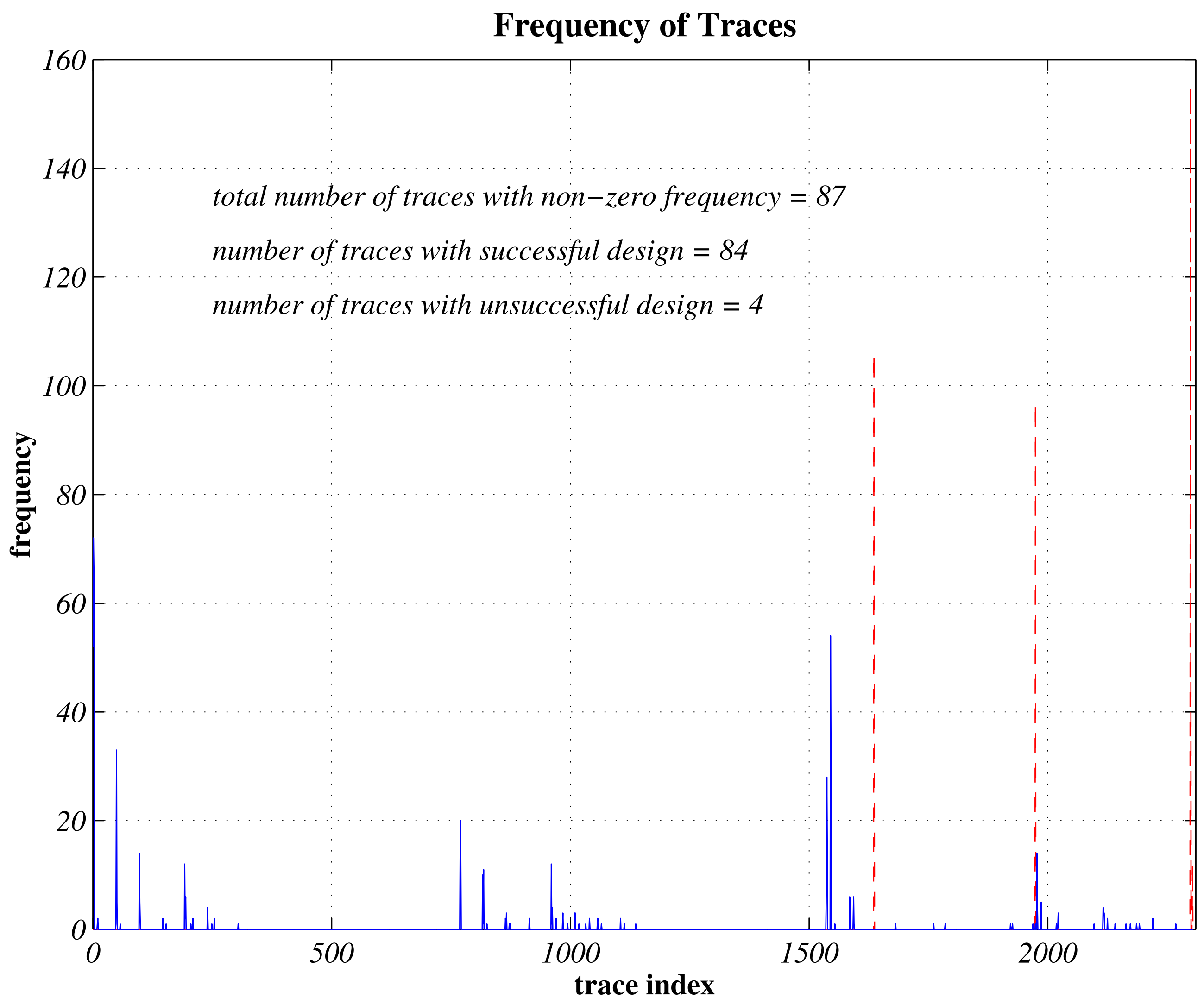
Trace: Project 732

Table 1: Design Approaches

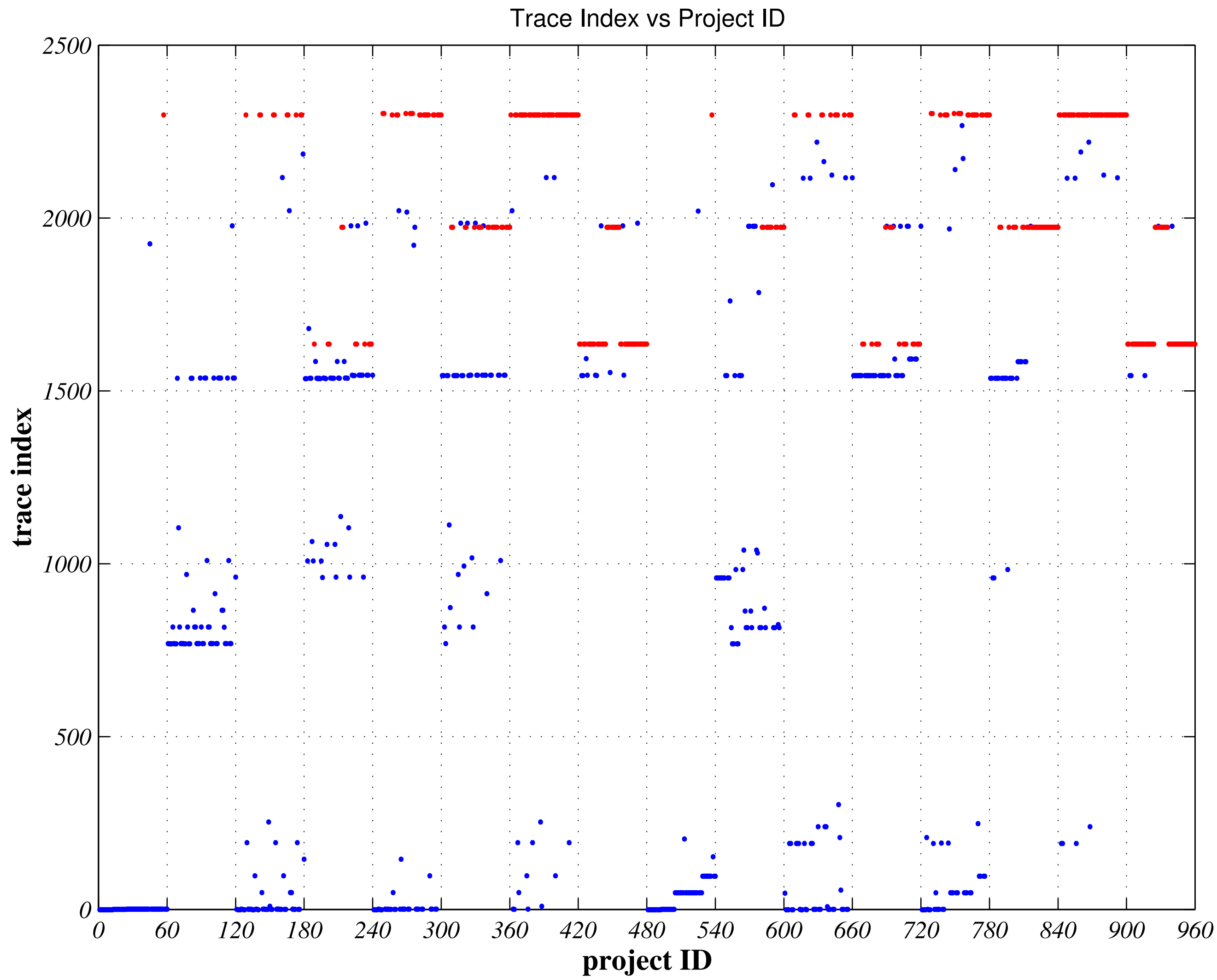
Design Agent	Design Approach	Approach Index
Designer_k_1	base_at_left_below_midway_workspace_length	1
Designer_k_2	link_lengths_ratio_0.5	1
Designer_k_3	theta1_is_alpha1_minus_alpha2	1
Designer_k_4	default	1
Designer_s_1	dimention_min_ratio_3	2
Designer_s_2	steel_stainless_AISI_302_annealed	1
Designer_s_3	safety_factor_3	1
Designer_s_4	hollow_round	1
Designer_s_5	default	1
Designer_c_1	default	1

Trace Index: 1

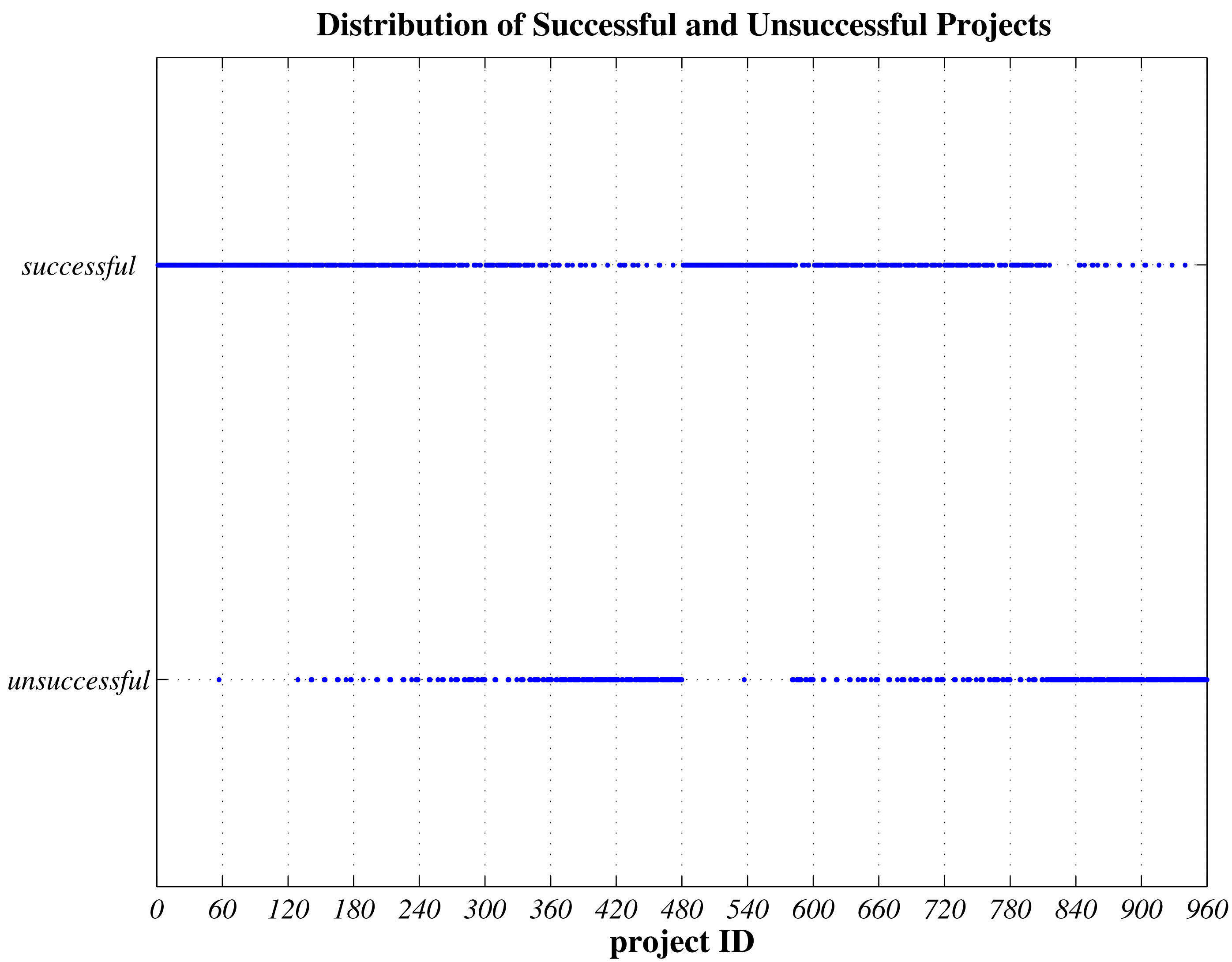
Frequency of Traces



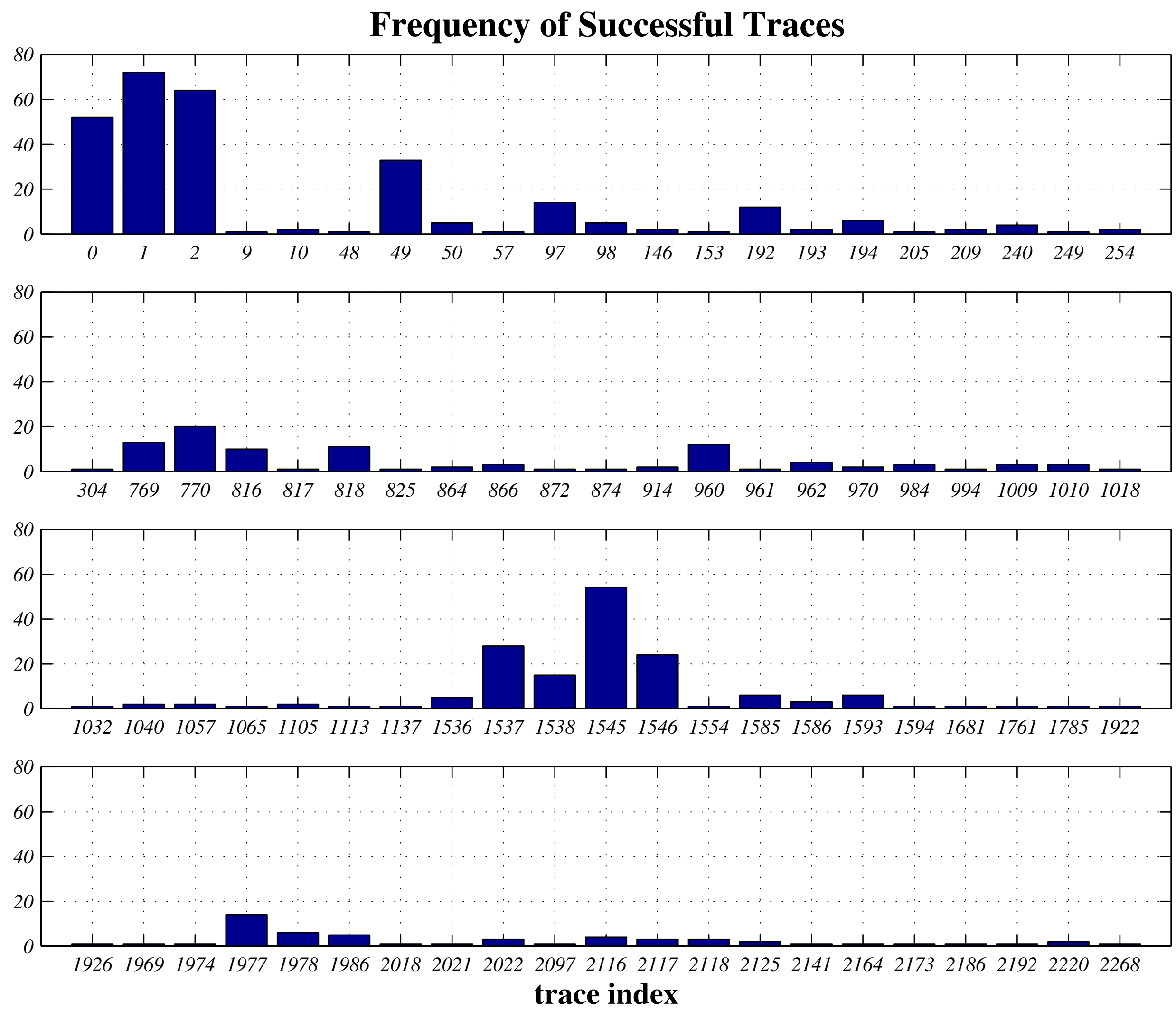
Distribution of Traces versus Projects



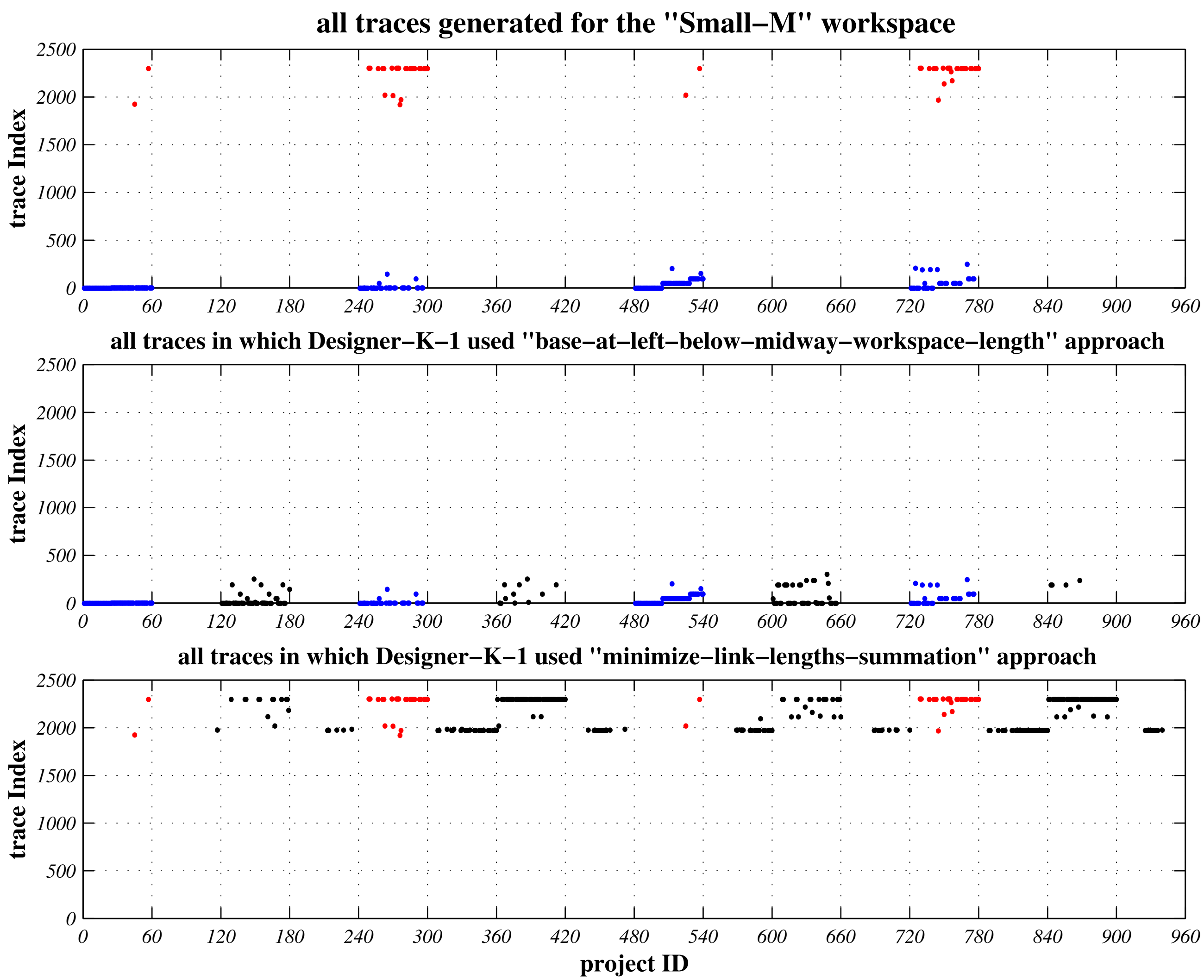
Successful and Unsuccessful Projects



Frequency of Successful Projects



Correlation between Requirements and Approaches



A Sample Design Methodology

- IF workspace is "small-M" and requirements on settling time and maximum overshoot are not very tight but the constraint on deflection of the tip is tight,
- THEN:

1

- put the base of the robot at "left or below midway of the workspace length"
- for material choose "steel stainless AISI 302 annealed"
- select a "hollow round" shape for cross section of the link and a safety factor of 3
    - do the design and proceed to the next step

2

- choose the second link to be "half of the first link" in length
    - do the design and proceed to the next step

3

- pick either the "left-hand" or "right-hand" configuration for the robot
- select the dimension of the cross section of the link not smaller than "0.15 of the length of the link"
    - do the design and finish the process with the rest of designers

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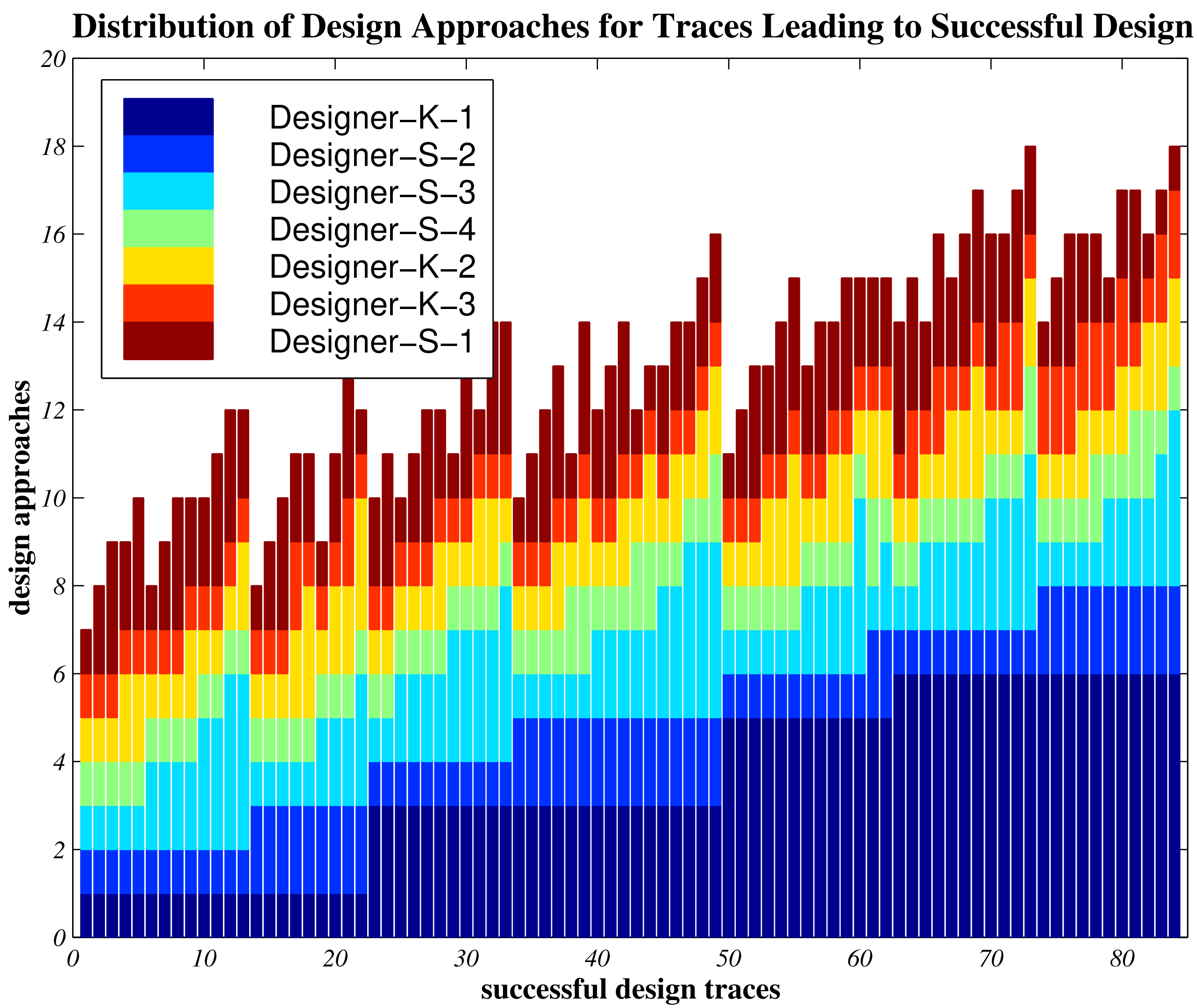
Distribution of Design Approaches



Conclusions

- Problem: Integration in Multi-disciplinary Design
- Approach: Knowledge-based Design
- Implementation: Multi-agent System
- Domain: Robot Design
- Results: promising in discovering better methodologies
- Difficulty: building the design system
- Extensions:
  - Methodologies for "Design for X"
  - Supply-Demand Chain Management
  - Shop Floor Job Scheduling