Symbiotic Design for Cyber Physical Systems

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DESTION, CPS Week

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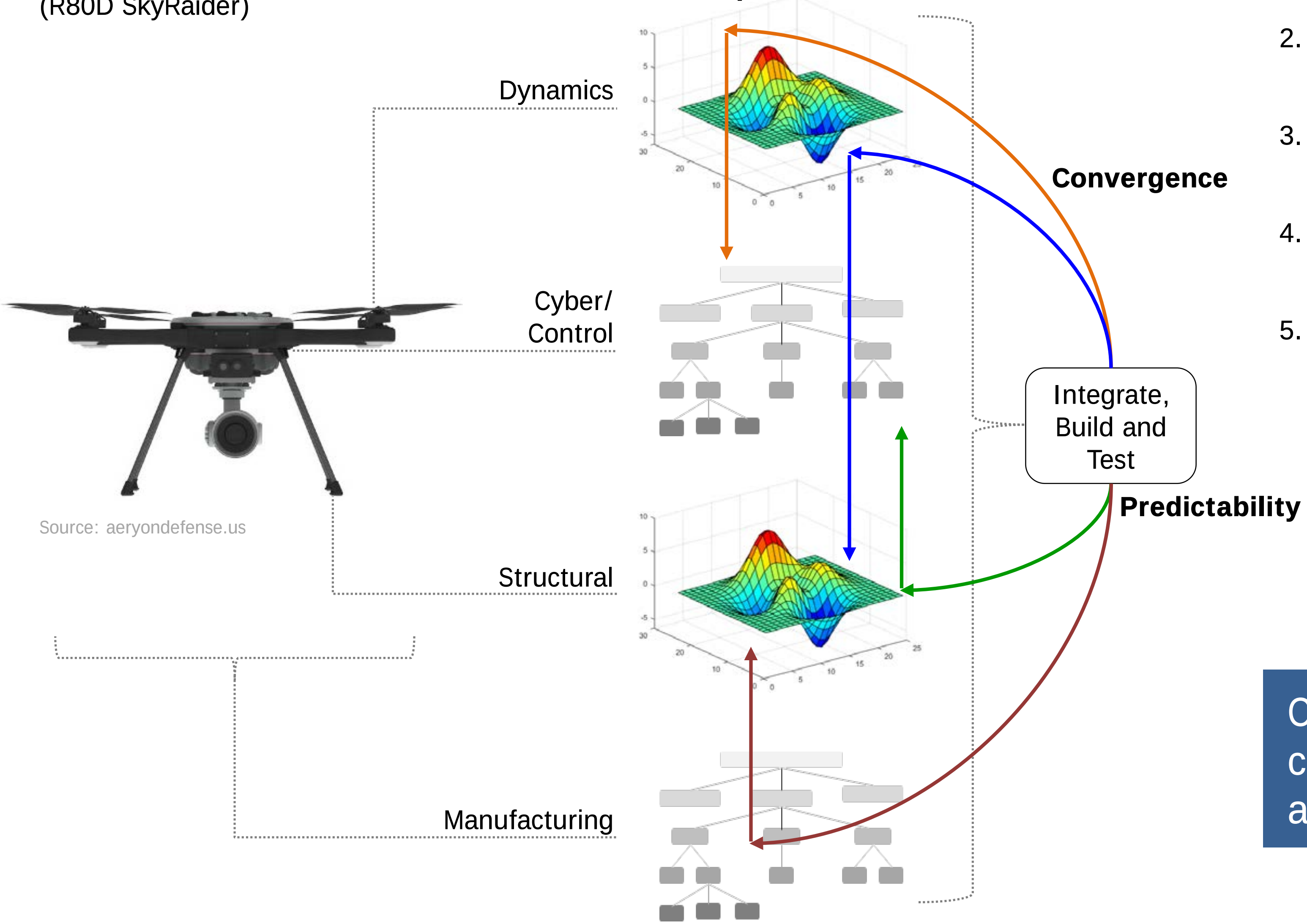
Innovation in Design – Creativity

Source: Netflix, AlphaGo Movie

Can AI creatively solve the kinds of problems that innovation requires?

How is design done today?

Example: military-grade small unmanned aircraft system (R80D SkyRaider)



1. Goal: build a UAV with mission-specific performance objectives (e.g., range, endurance, speed, payload)

2. Decompose: the design problem into sub-problems (i.e., domains) and recruit a team to address each sub-problem

3. Design: Each team produces design artifacts from domain-specific design spaces

4. Integrate: them into an overall system-level design and build a prototype

5. Integration uncovers numerous issues triggering change
   a) Weight of system plus payload exceeds the lift
   b) Power requirements for propulsion and payload exceeds power available in the battery
   c) Acoustic coupling of motors induces high dynamic stress on the frame material
   d) Light weighting requires use of carbon composites which can not be manufactured in-house

CPS design today – constrained by challenges in predictability, convergence, and exploration – is *construct by correction*

Today vs. Future of CPS Design

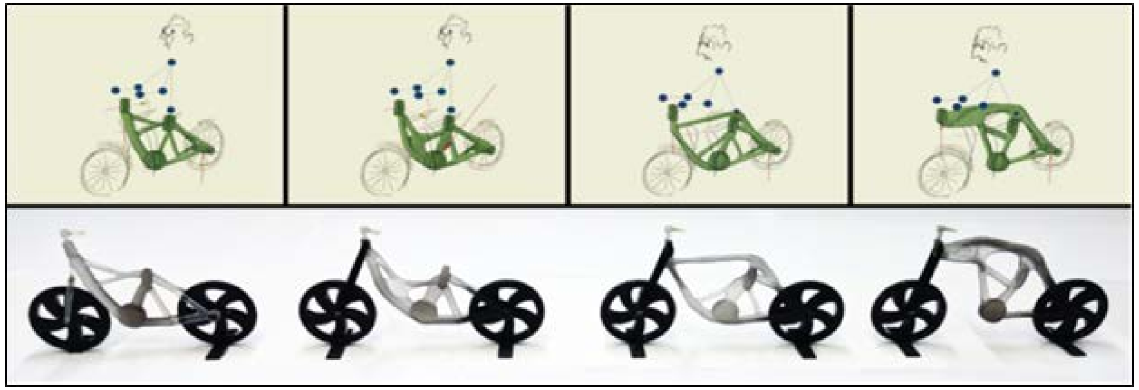
Challenge	Limiting Factors	State of the Practice	State of the Art		Symbiotic Design
		Model-based Design Tools	Commercial: Autodesk Dreamcatcher for CAD	DARPA: META Tools	
Predictability	Model construction (cost and fidelity)	Manual	Manual	Manual	**Automated**
Convergence	Model composition (intra-domain and cross-domain)	Manual	N/A	Partially automated	**Automated**
Exploration	Co-design (domains jointly explored)	Single	Single	Multiple	**Multiple**
	Designs explored	10's (manual)	1,000's (automated)	100's (partially automated)	**1,000,000's (automated)**
Cognitive Load	Interaction complexity	High	Medium	Medium	**Low**

State of the Art in CPS Design

Commercial

(Autodesk Dreamcatcher for CAD)

Manually specify baseline geometry and loading requirements



Source: Autodesk Dreamcatcher Project

Automatically evolve many variations of the baseline geometry satisfying loading requirements

Parametric topology optimization
Limited to single domain (geometry)

DARPA

(META Tools)

Manually construct component models

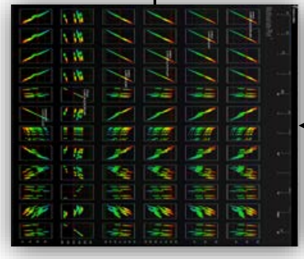
Multi-domain component models

Manually construct design space models

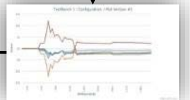
Design Space Models

Manually iterate over design space

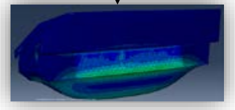
Automatically build analysis models



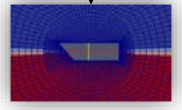
Trade-space visualization



Dynamics simulation



Stress analysis



CFD simulation

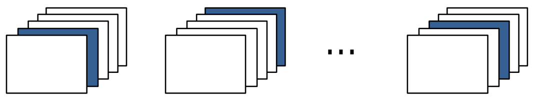
Source: Vanderbilt University

Rule-based model transformations
Manual design space construction and exploration

Challenges and Insights

Design Space Construction

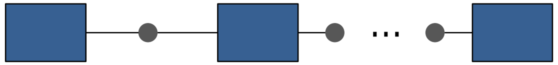
Predictability Challenge: Automate construction of design spaces



New Insights:
- Novel machine learning approaches for mining large code corpora in DARPA MUSE program

Design Composition

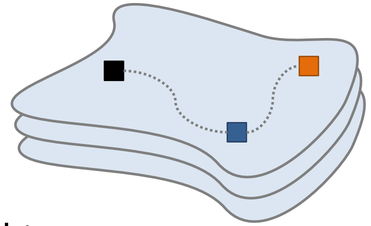
Convergence Challenge: Automate composition of partial designs



New Insights:
- Deductive model composition toolchains prototyped in DARPA META program
- Early results in combining deductive and inductive synthesis

Design Space Exploration

Exploration Challenge: Automate exploration of high-dimensional design spaces



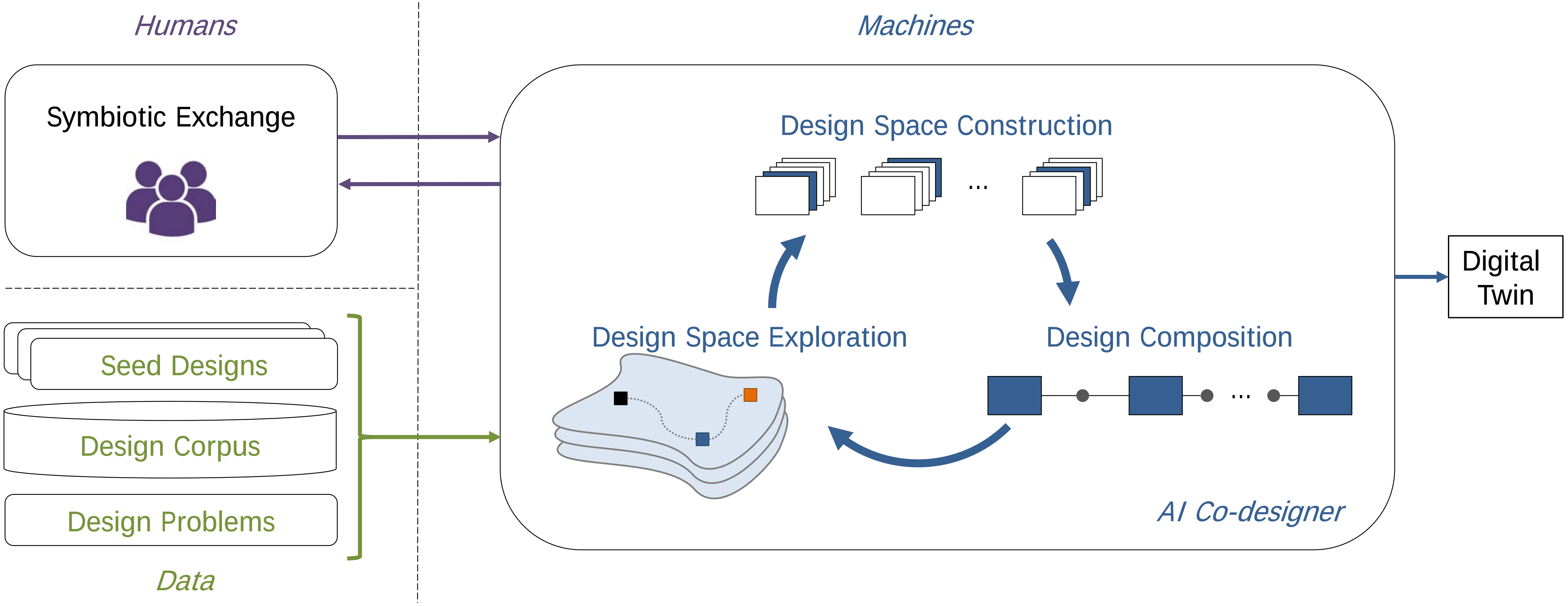
New Insights:
- Recent results in scalable design-space exploration using learning-based approaches
- AlphaGo inspired approaches for exploration

Symbiotic Exchange

Cognitive Load Challenge: Natural and anticipatory interfaces to enable effective human-machine partnership

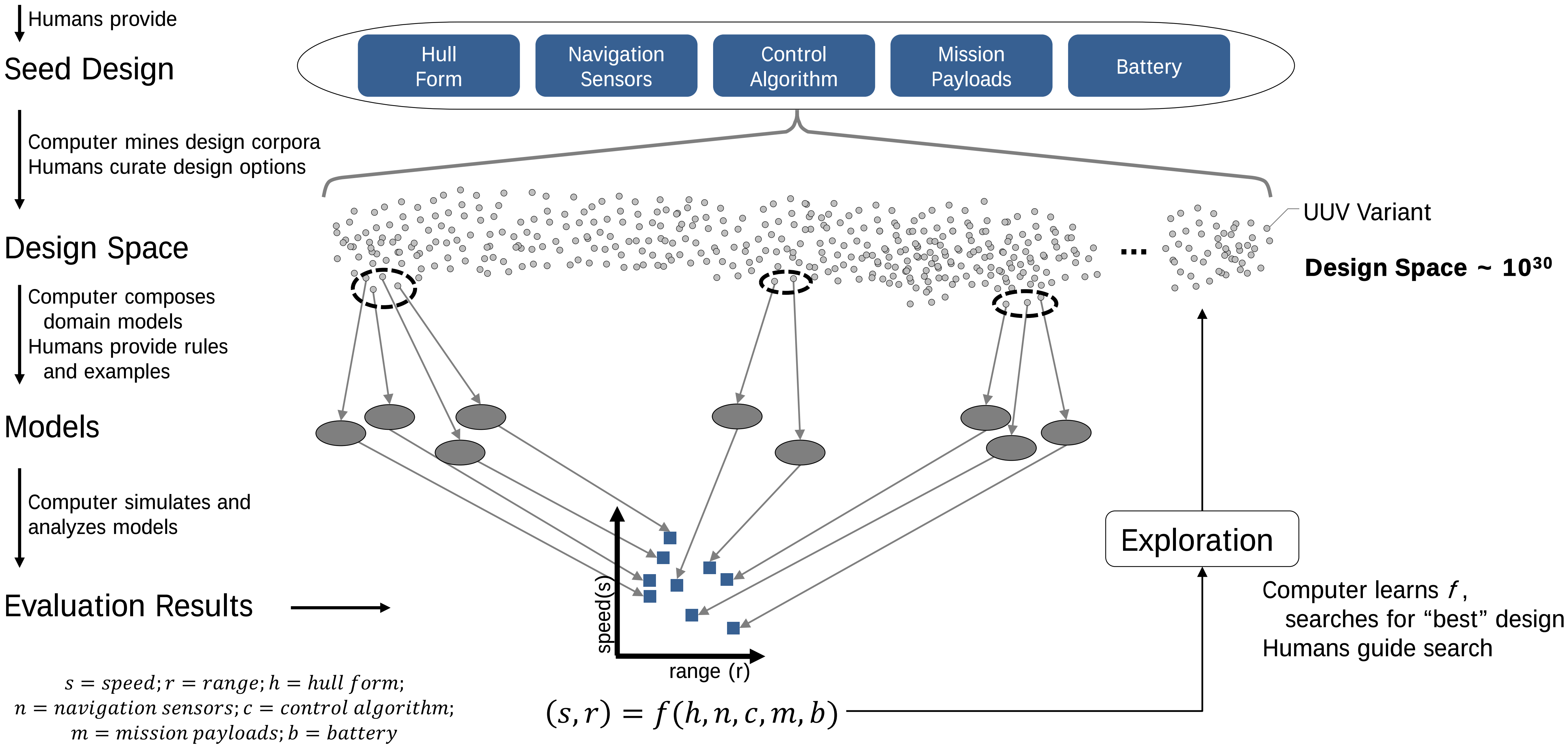
New Insights:
- Visualization and interpretation of high-dimensional data
- Cueing reinforcement learning by reward modeling
- Sketch-based interfaces

Symbiotic Design: Achieving correct-by-construction at scale



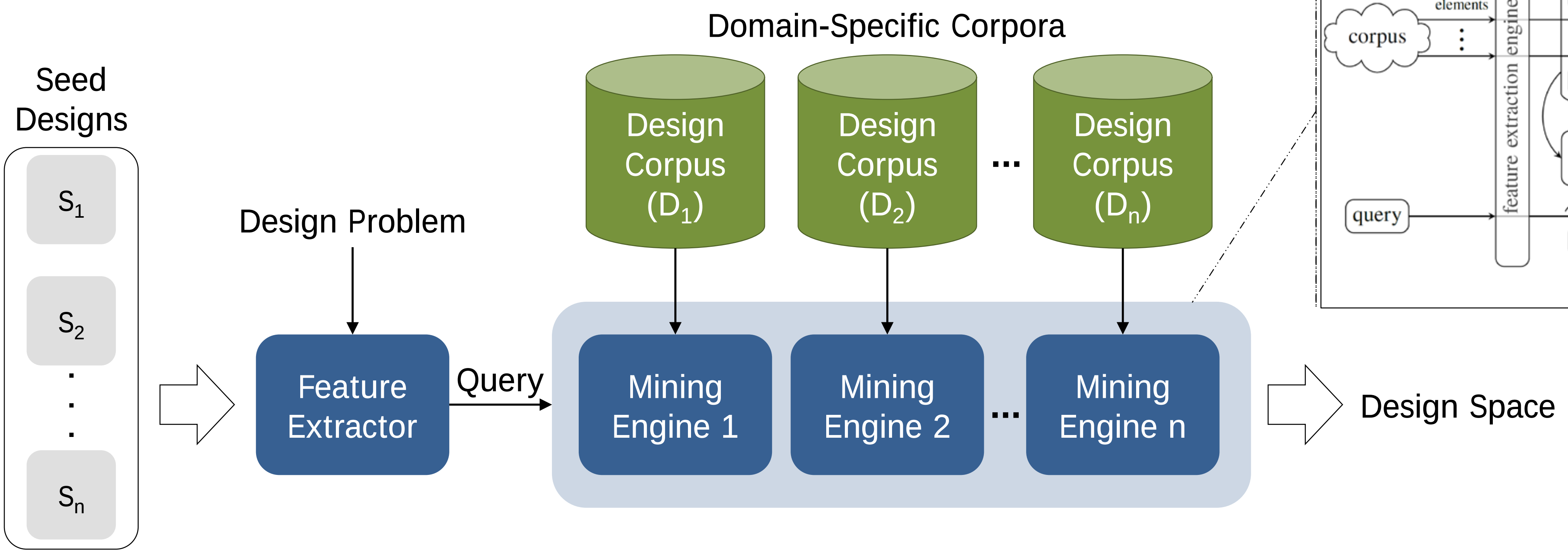
Develop symbiotic AI-based technologies for correct-by-construction design of military-relevant CPS in order to reduce the time from inception to deployment from years to months, and increase innovation

An Example of Symbiotic Design flow

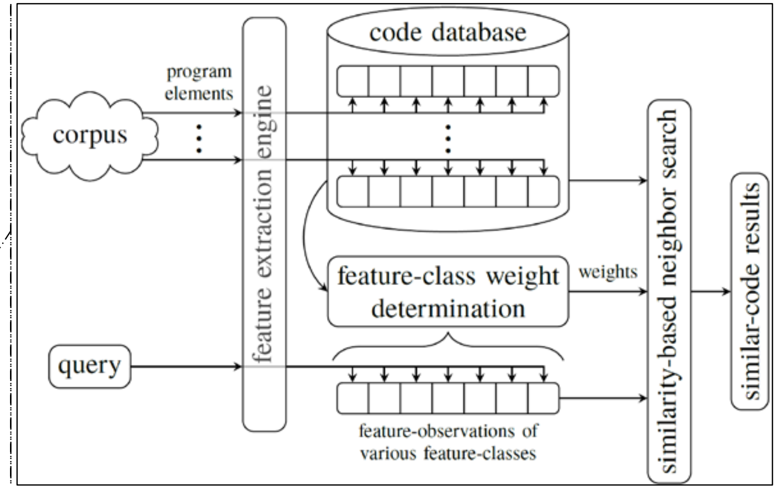


Design Space Construction

Goal: Develop technologies to automatically and incrementally construct design space for a given specification and seed designs



From DARPA MUSE



[Kashyap et al, 2017]

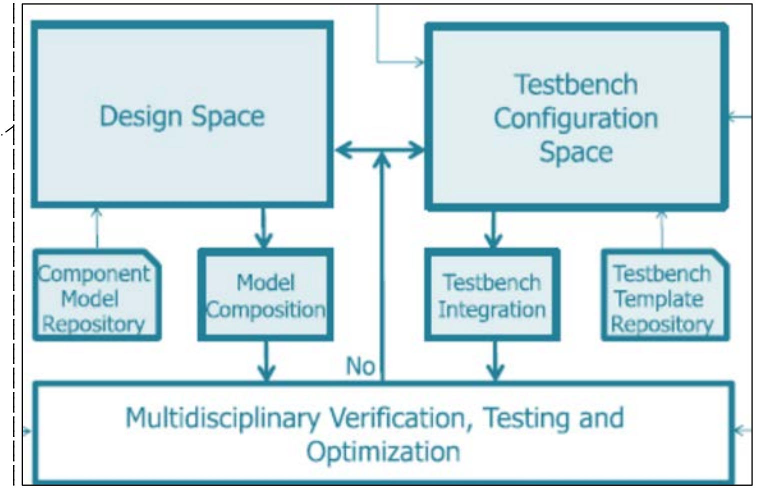
Challenges

- Query generation from seed designs and design problem
- Mining heterogeneous model-based design artifacts
- Incremental construction of design space

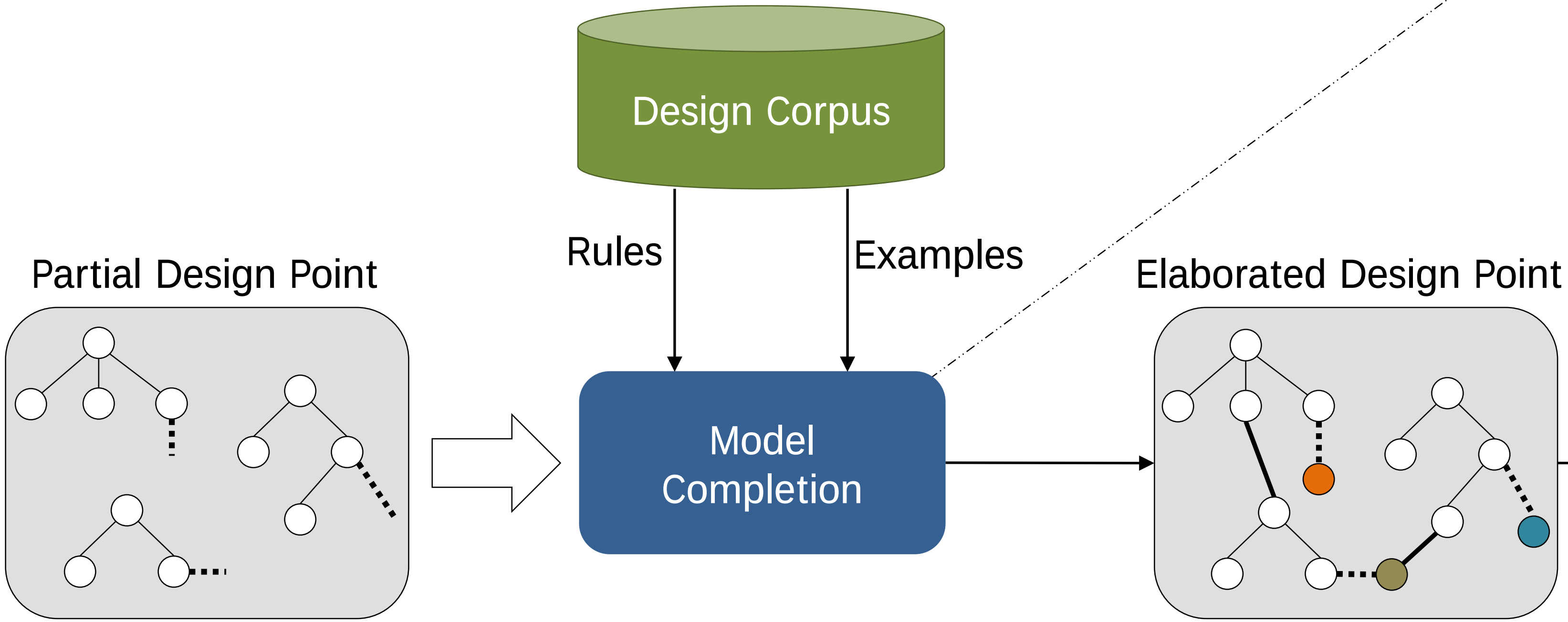
Design Composition

Goal: Develop technologies to automatically compose and evaluate a design point

From DARPA META



[Sztipanovits et al, 2018]

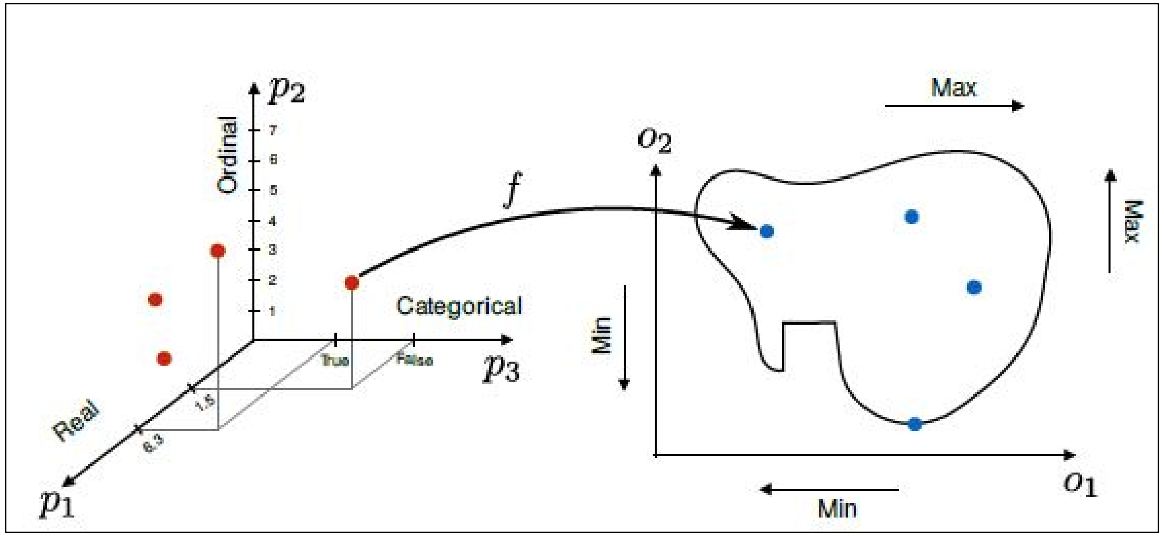


Challenges:

- Automated model completion in heterogeneous domains
- Automated cross domain reasoning and model learning
- Accelerated design analysis and simulation

Design Space Exploration

Goal: Develop technologies to explore high-dimensional multi-domain combinatorial design spaces



[Nardi et al, 2018]

Evaluation Results

Design Space

→ Performance Prediction Model | Exploration Strategies →

Next Design Point

Challenges:

- High-dimensionality of the space
- Heterogeneous domain models
- Objective functions defined over multiple abstraction layers

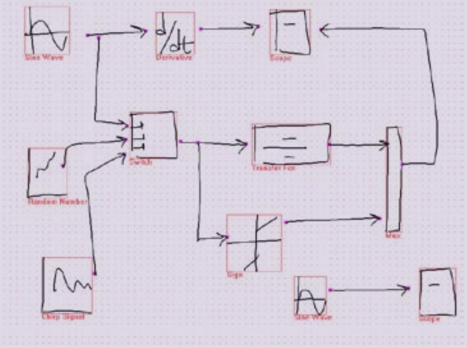
Symbiotic Exchange

Goal: Develop technologies to enable effective partnership between human and machines to solve complex design problems

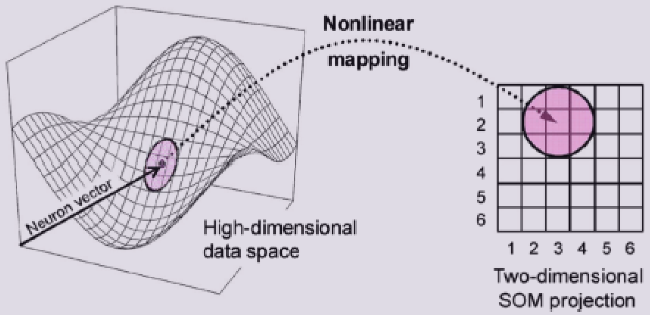
Evaluation Results

Design Space

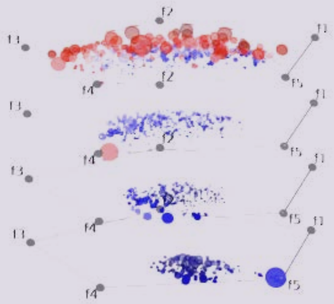
Collaborate



Visualize



Analyze



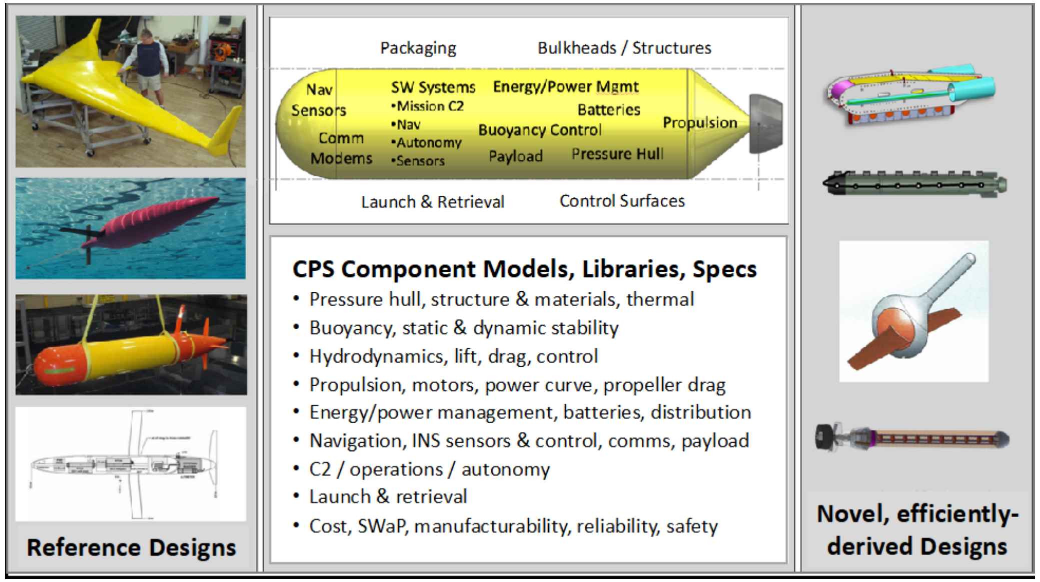
Exploration guidance

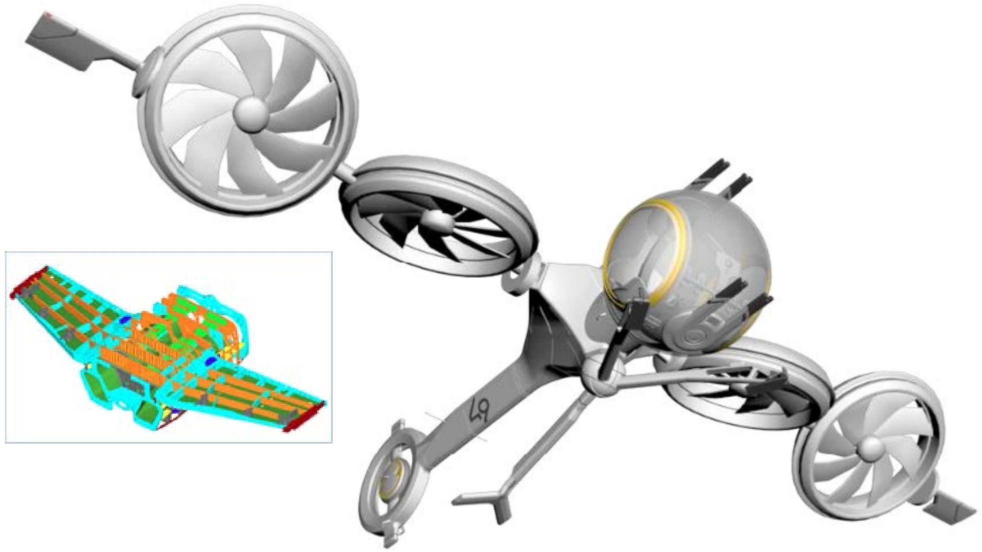
Challenges

- Visualization and understanding of high-dimensional design spaces
- Shaping and guiding exploration
- Interaction complexity of engineering design tools

Concluding Remarks

- CPS Design is complex, highly manual, and iterative
- Novel AI-based approaches combining automated design mining, composition, and scalable exploration offer promise
- Symbiotic Design program geared to explore and demonstrate the potential of AI-based approaches for revolutionizing CPS design in DoD applications





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