CPS Synergy: Cyber Physical Infrastructure for Creative Design and Making

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State-of-the-art Infrastructure for Design and Make

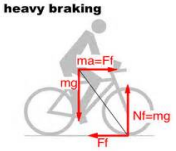


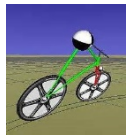








- Industrial Design
- Form Ideation

- User requirements
- Govt. regulations

Creation | Application

Make | Analysis

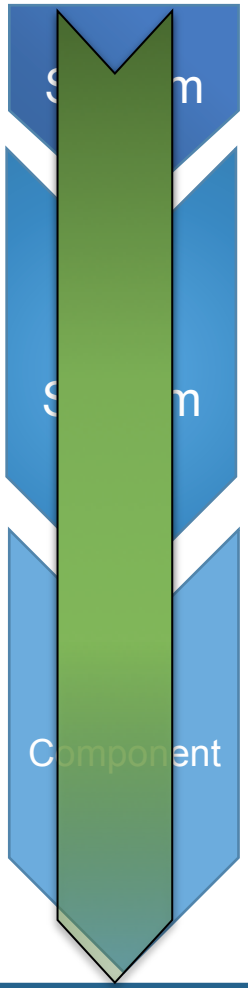
- Prototyping
- Testing

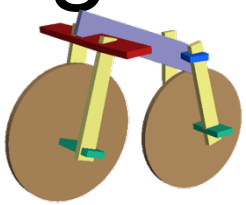
- Static Analysis
- Dynamic analysis

Current Infrastructure necessitates information and knowledge flow to achieve novel and optimal solutions

Mass Manufacturing Infrastructure

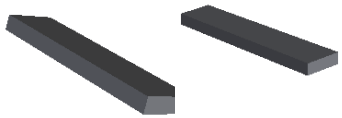
Information and knowledge Flow

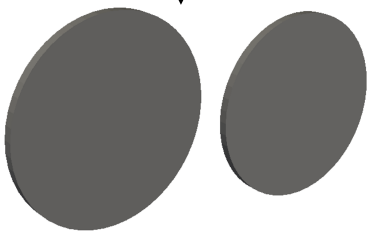




Customer

Original Equipment Manufacturer

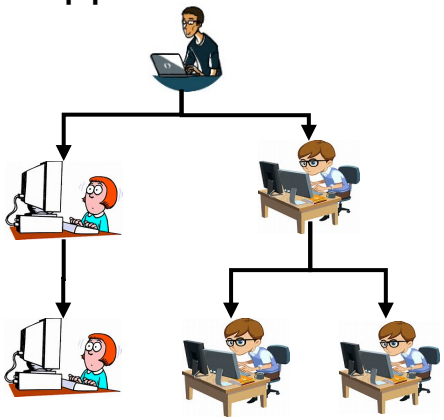


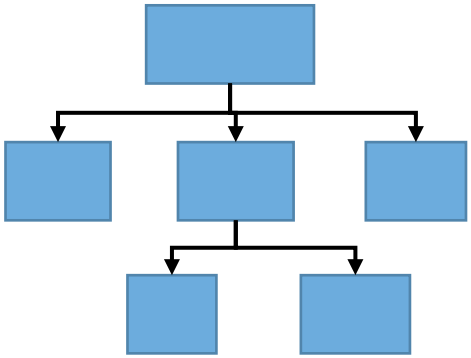


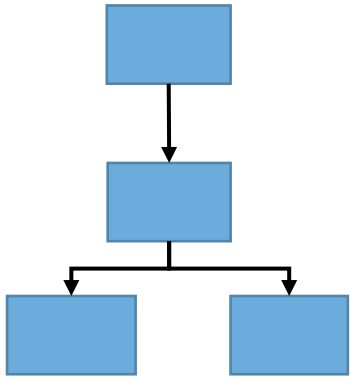
Supplier A: Frame

Supplier B: Axels

Supplier C: Tires

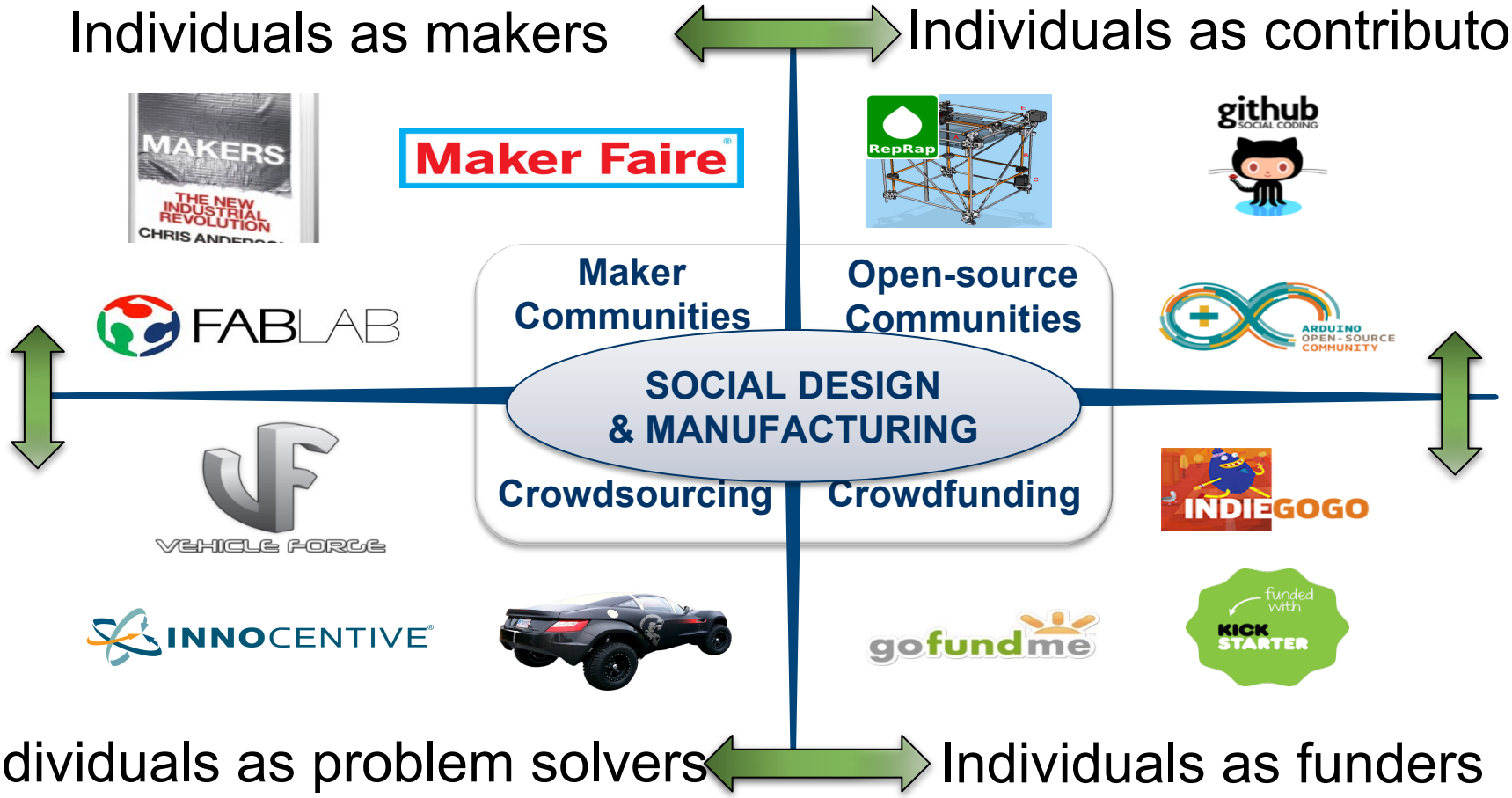






Inefficient flow of information and knowledge leads to missed opportunities and sub-optimal solutions

Emerging models of Innovation

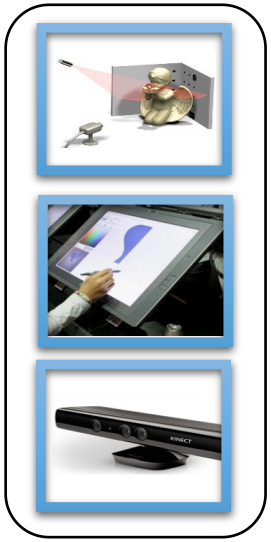


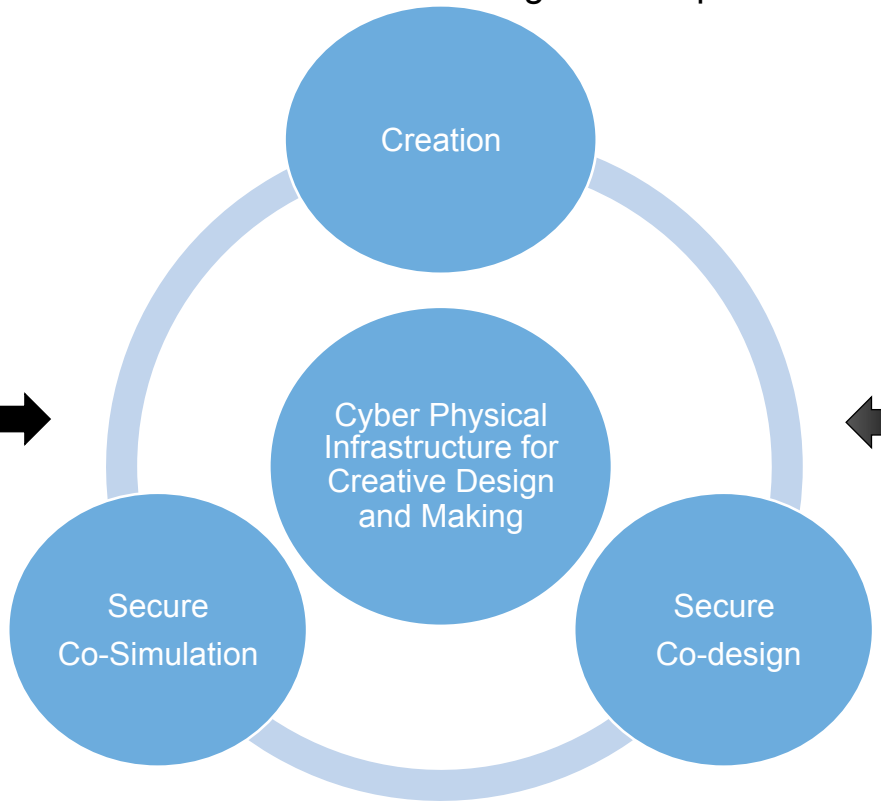
Democratization of design faces challenges related to information and knowledge flow
Need for intuitive interfaces for crowds to empower them

Proposed Framework: Human-in - the loop Secure Co-Design (SCD)

Pen, touch, and gesture based NUI;
Incorporation of physical constraints;
Embedding physical objects;
Distributed handling of concepts.

Natural interfaces





Physical realization

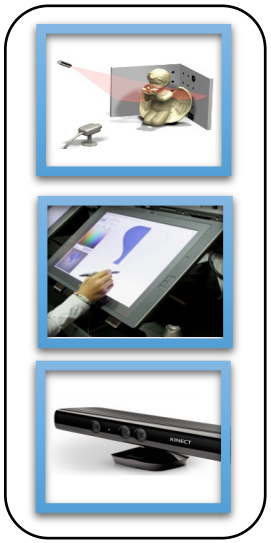
Design knowledge representations;
Real-time validation and guidance;
Model-based design coordination.

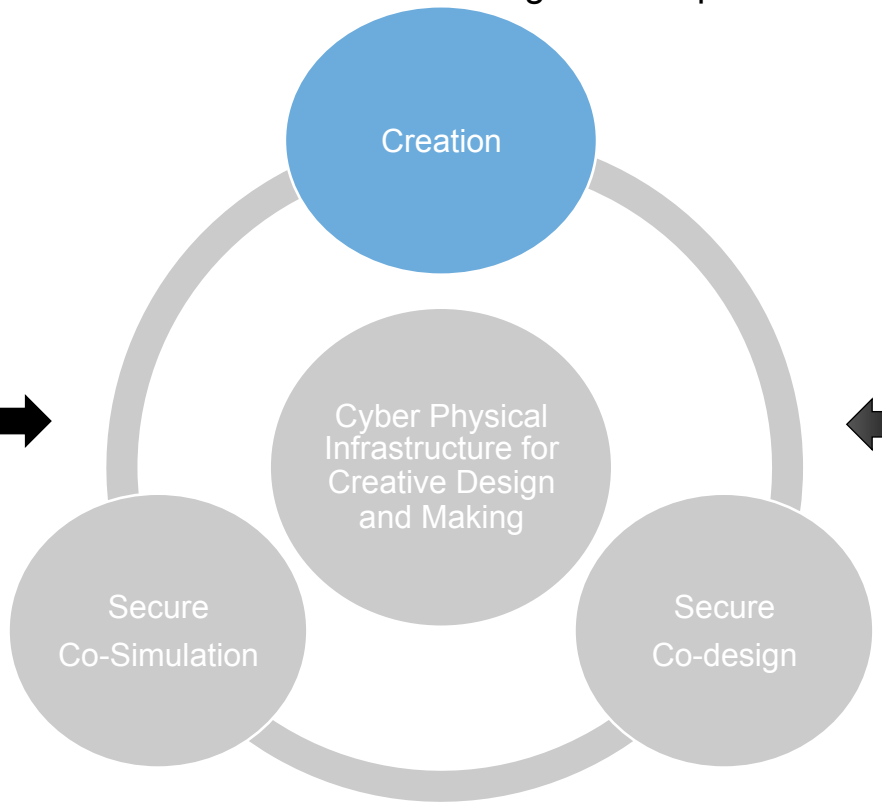
Minimum disclosure interactions;
Quality of inputs assurance;
Provenance and integrity;
Usage control

NUI-based Simulation- supported Design Framework

Pen, touch, and gesture based NUI;
Incorporation of physical constraints;
Embedding physical objects;
Distributed handling of concepts.

Natural interfaces





Physical realization

Design knowledge representations;
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Minimum disclosure interactions;
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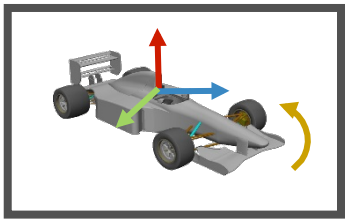
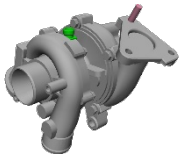
Enhanced Participation through NUIs

Current Technologies

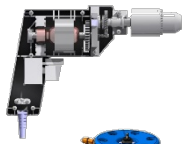


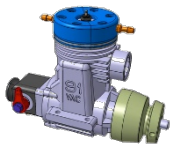
2D inputs for 3D design modeling



Limited support for early stage quick prototyping

Lack of intuitive interactions

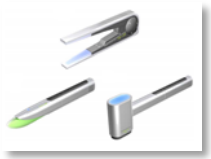


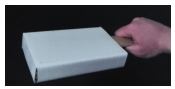


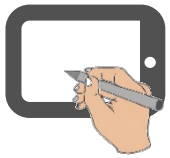
Knowledge & skill related barriers to novice users

Our Approach

Hand Gestures





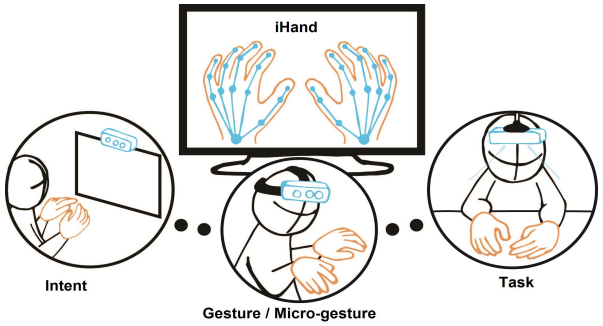


Tangible Tools and Proxies

Use of natural interactive modalities

Reduce barrier for 3D design expression

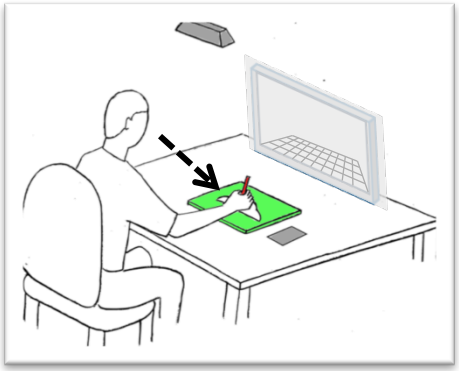
Facilitate early-stage design exploration in a virtual medium



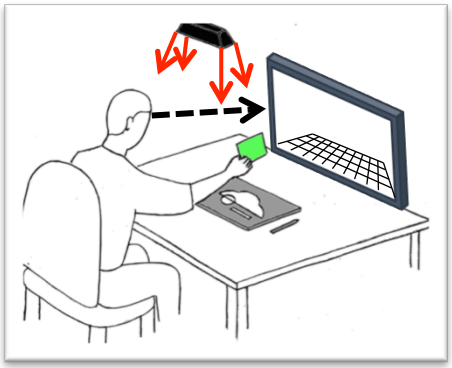
Multi-modal 2D-3D Design Interfaces

Proto-TAI: NUI for quick 3D design ideation

General Workflow



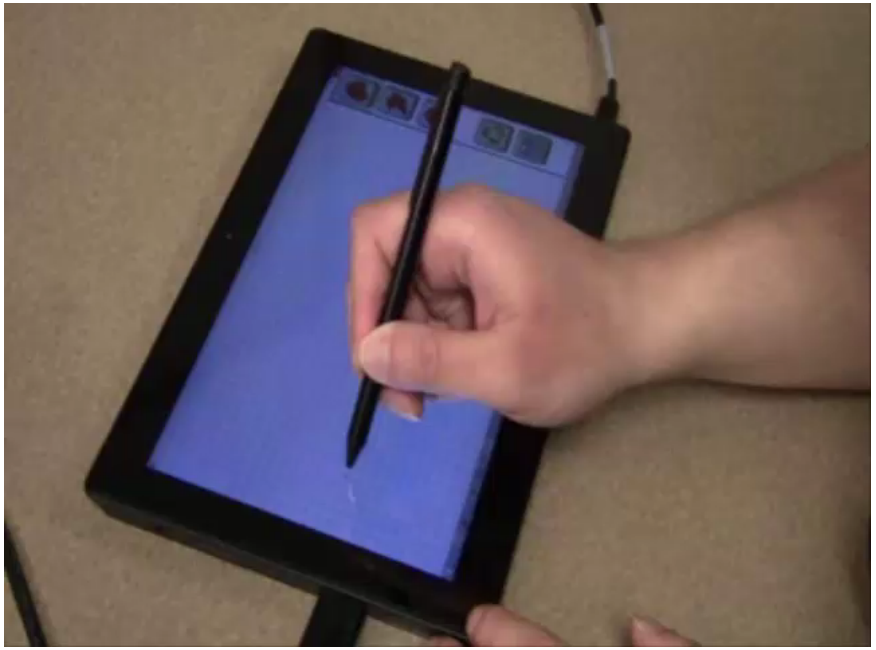
Sketching Planar Shapes



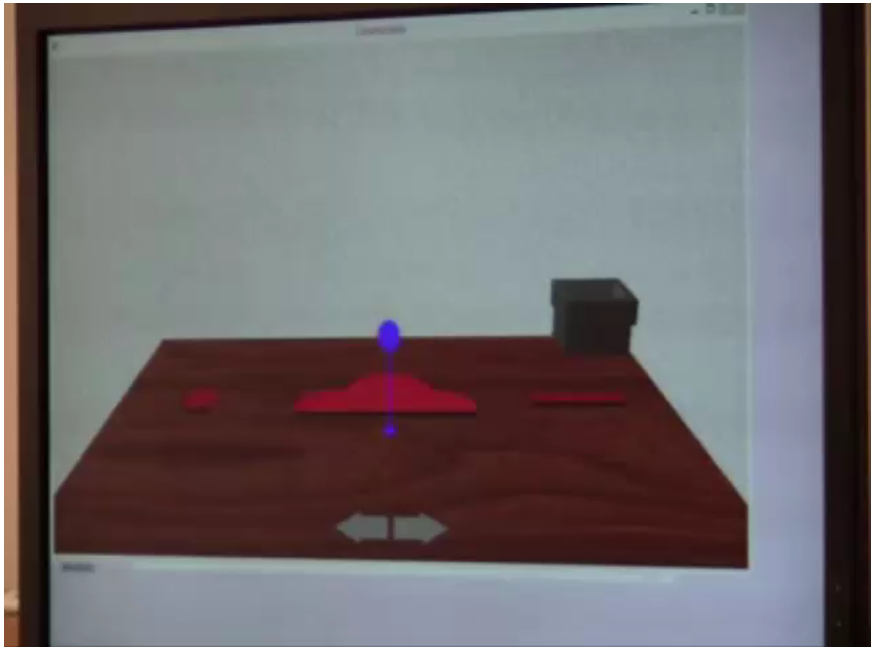
3D Assembly w/ Proxy

Simple Design Models

Sketching w/ Digital Pen

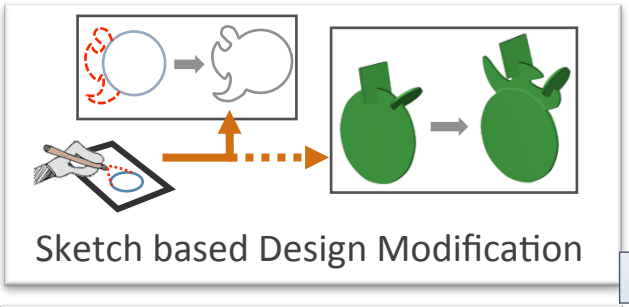


3D Assembly w/ Planar Proxy

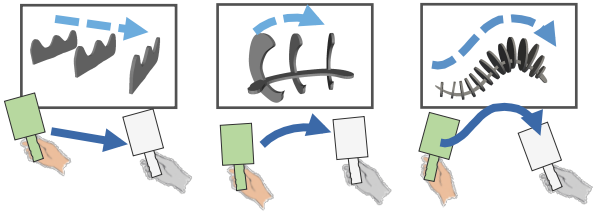


Proto-TAI: NUI for quick 3D design ideation

Advanced Operations using Simple Interactions



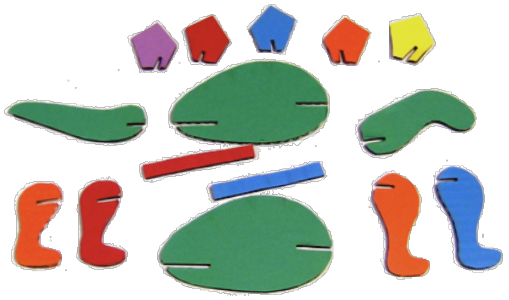
Sketch based Design Modification



Procedural Operations w/
Expressive Mid-air gestures

Detailed Design
Models

Fabrication



Laser Cut Parts

Physical Model

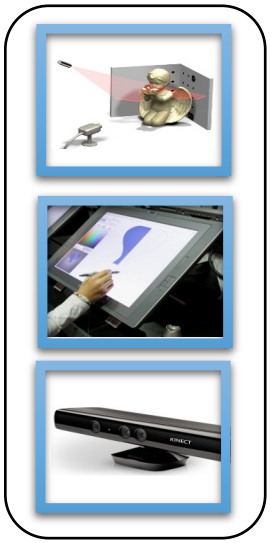
- Perform advanced modeling operations using the same intuitive modalities and interactions
- Retain simplicity of interface and input modalities.

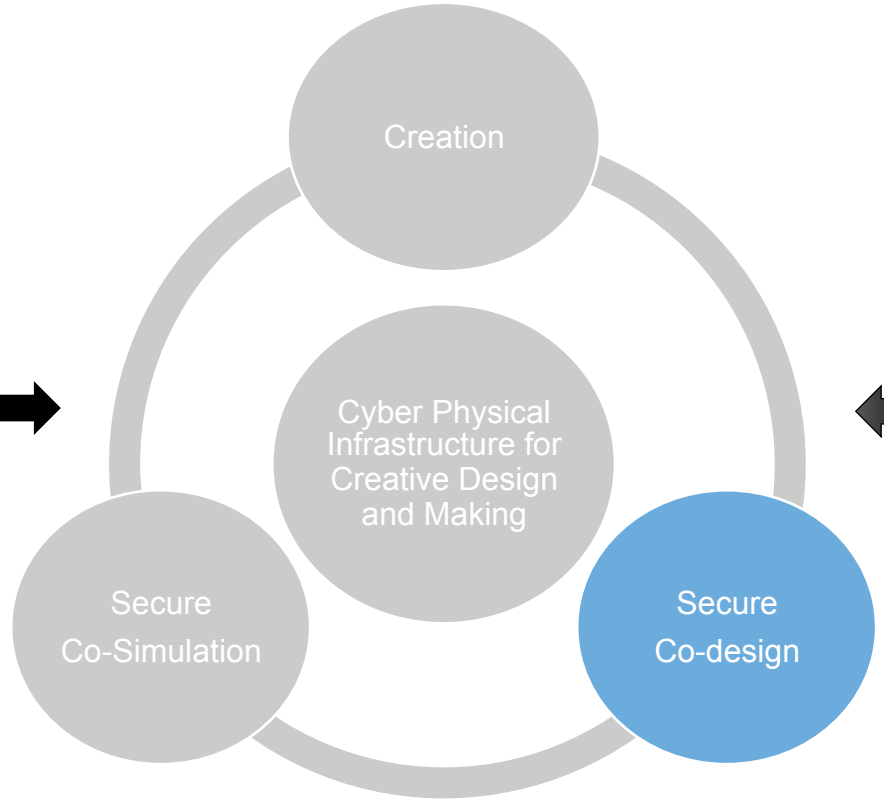
- Use quick fabrication to produce physical model for testing and design evaluation.
- Produce functional objects for practical use.

Secure co-design Framework

Pen, touch, and gesture based NUI;
Incorporation of physical constraints;
Embedding physical objects;
Distributed handling of concepts.

Natural interfaces





Physical realization

Design knowledge representations;
Real-time validation and guidance;
Model-based design coordination.

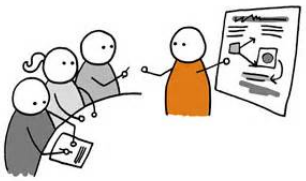
Minimum disclosure interactions;
Quality of inputs assurance;
Provenance and integrity;
Usage control

Why do we need security in collaboration?

- Today's Collaborator is Tomorrow's competitor

- Perfect copies of CAD + Physics models can be made: more knowledge is becoming digital

Sources of information leakage

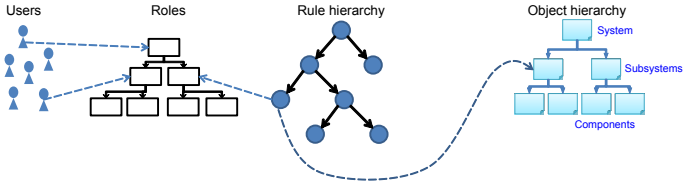


Problem description

Decisions analysis

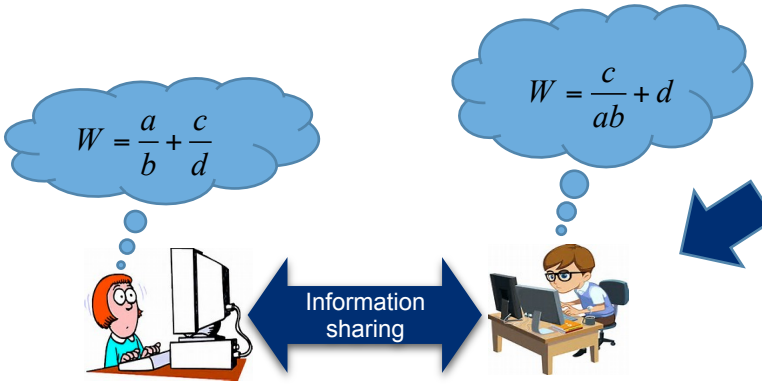
Security of information exchange is a barrier for collaboration in design

What is Security in Collaboration?



Authorization and Authentication

Integrity



Purpose control

Computation Time

Non-repudiation

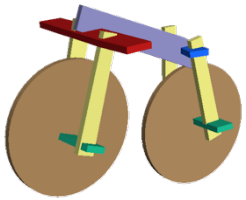
How to preserve confidentiality of designer's information in a collaboration?

Example

System

Sub-System

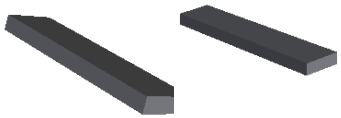
Component



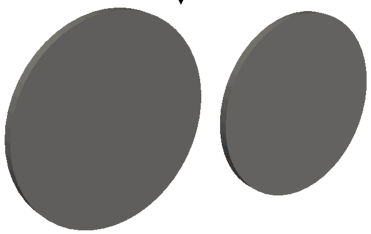
Original Equipment Manufacturer

Customer

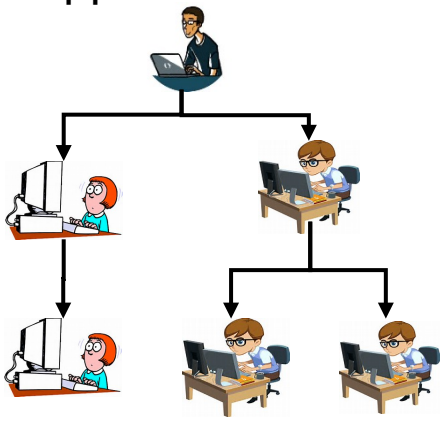
Supplier A: Frame

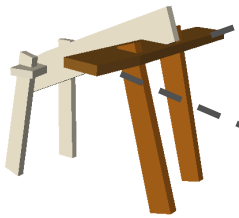


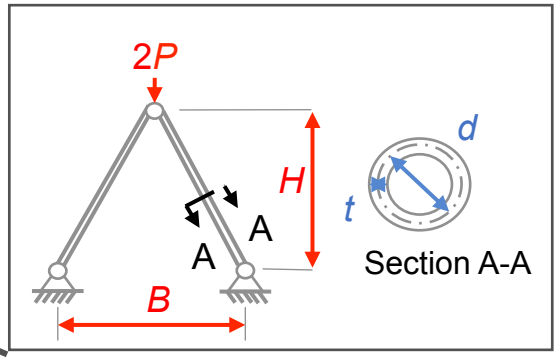
Supplier B: Axels



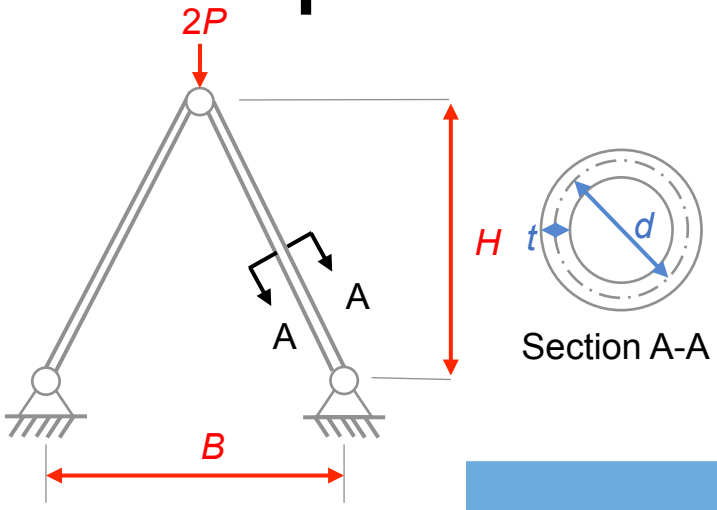
Supplier C: Tires







Example contd…



Section A-A

Alice
Structural Designer
Constraint: Minimize Weight

Bob
Material Designer
Constraint: Avoid failure

Assumption: Mathematical model is known to both designers

	Alice Structural Designer	Bob Material Designer
Internal Constraint	$W = 2\sqrt{2}\pi dt\rho B \geq W_0$	$\frac{P\sqrt{2}B}{\pi s_f dH\sigma_o} \leq d$
Design Parameters	W	d
Private Parameters	H, B, P, W_0	s_f, ρ, σ

Secure co-design (SCD) framework

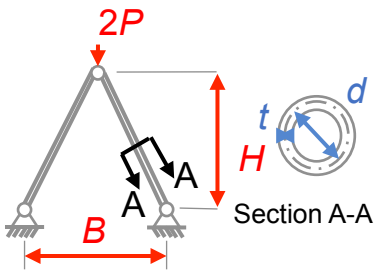
SCD framework enables designers to share private information as if there is no sharing!

Application : Co-design Scenario

Alice
Structural Designer
Constraint: Minimize Weight (W)

Bob
Material Designer
Constraint: Avoid failure

	Alice Structural Designer	Bob Material Designer
Internal Constraint	$W = 2\sqrt{2}\pi dt\rho B \geq W_0$	$\frac{P\sqrt{2}B}{\pi s_f dH\sigma_o} \leq d$
Design Parameters	W	d
Private Parameters	H, B, P, W_0	t, ρ, σ



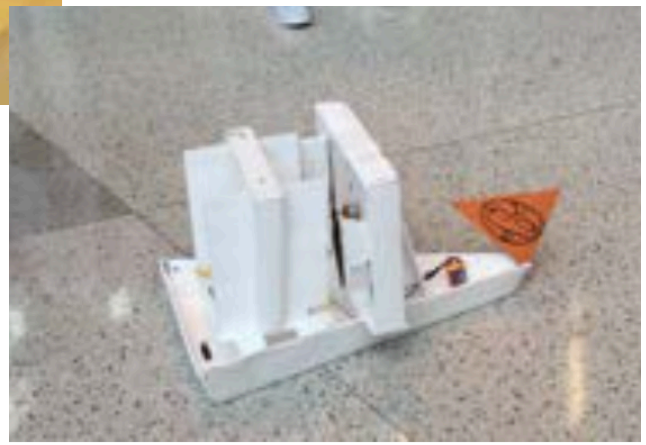
Leader Follower

Pareto Co-operation

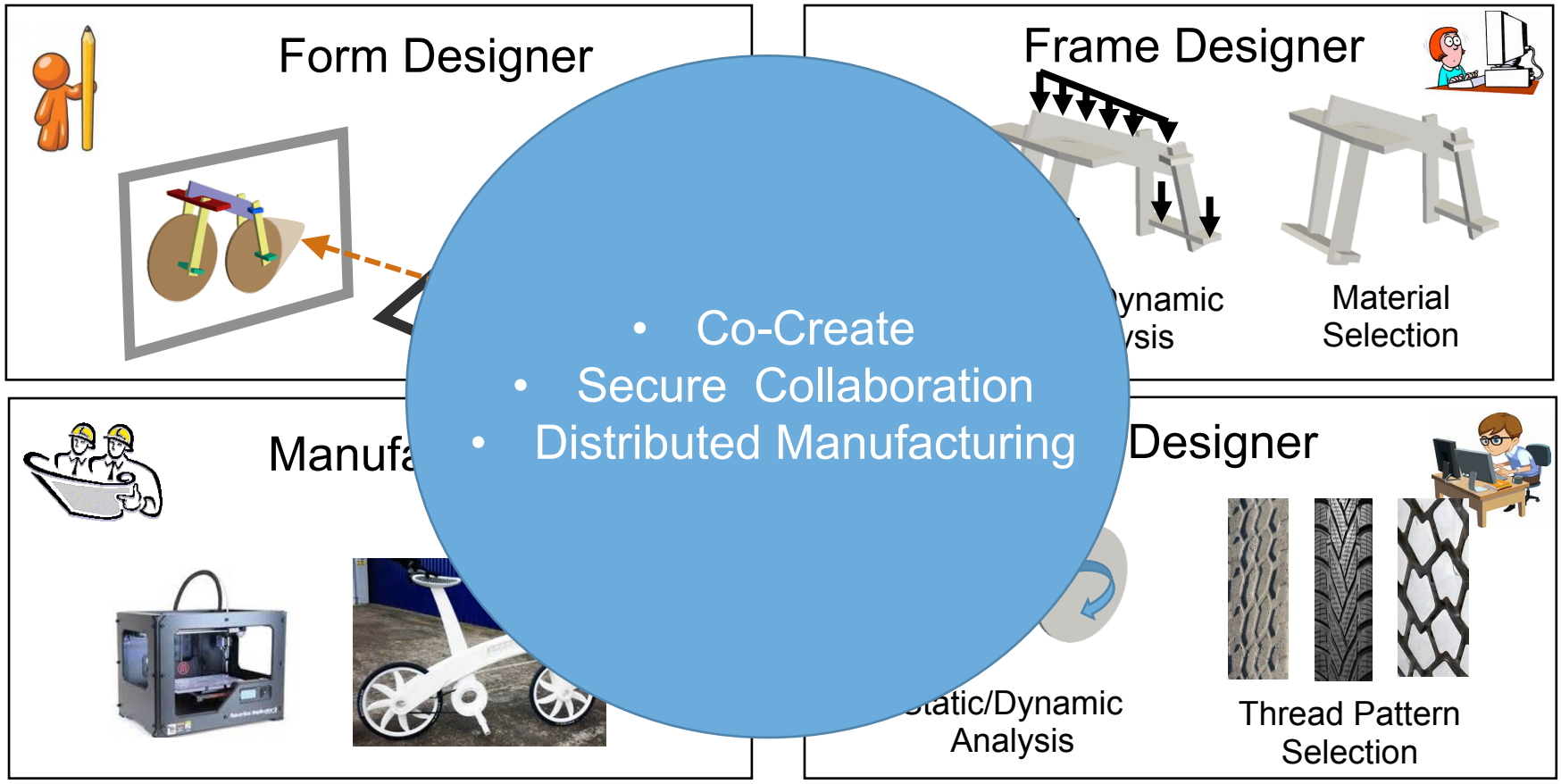
Nash Non-Cooperation

Conventional	Bob may have to reveal his private information (t, ρ, σ)	Both Alice and Bob have to reveal their private parameters	No optimal solution but both designers do not reveal
SCD Framework	Implemented and validated to achieve optimal solutions while preserving confidentiality of the private parameters of both designers		

Toy Design Outreach

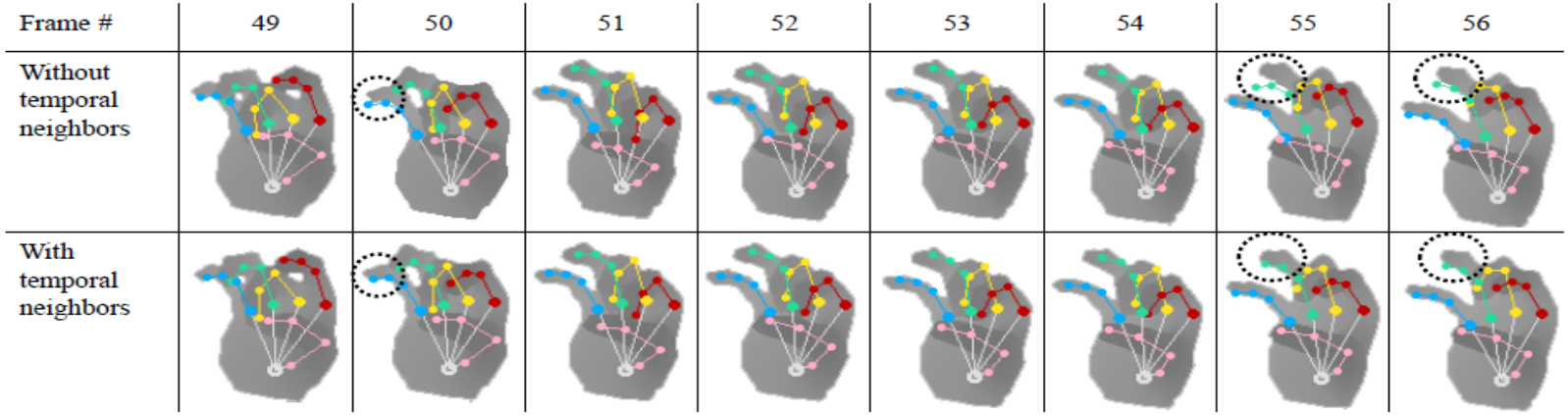


Summary



SCD Framework with NUI will open up avenues for creative design and making

Thanks

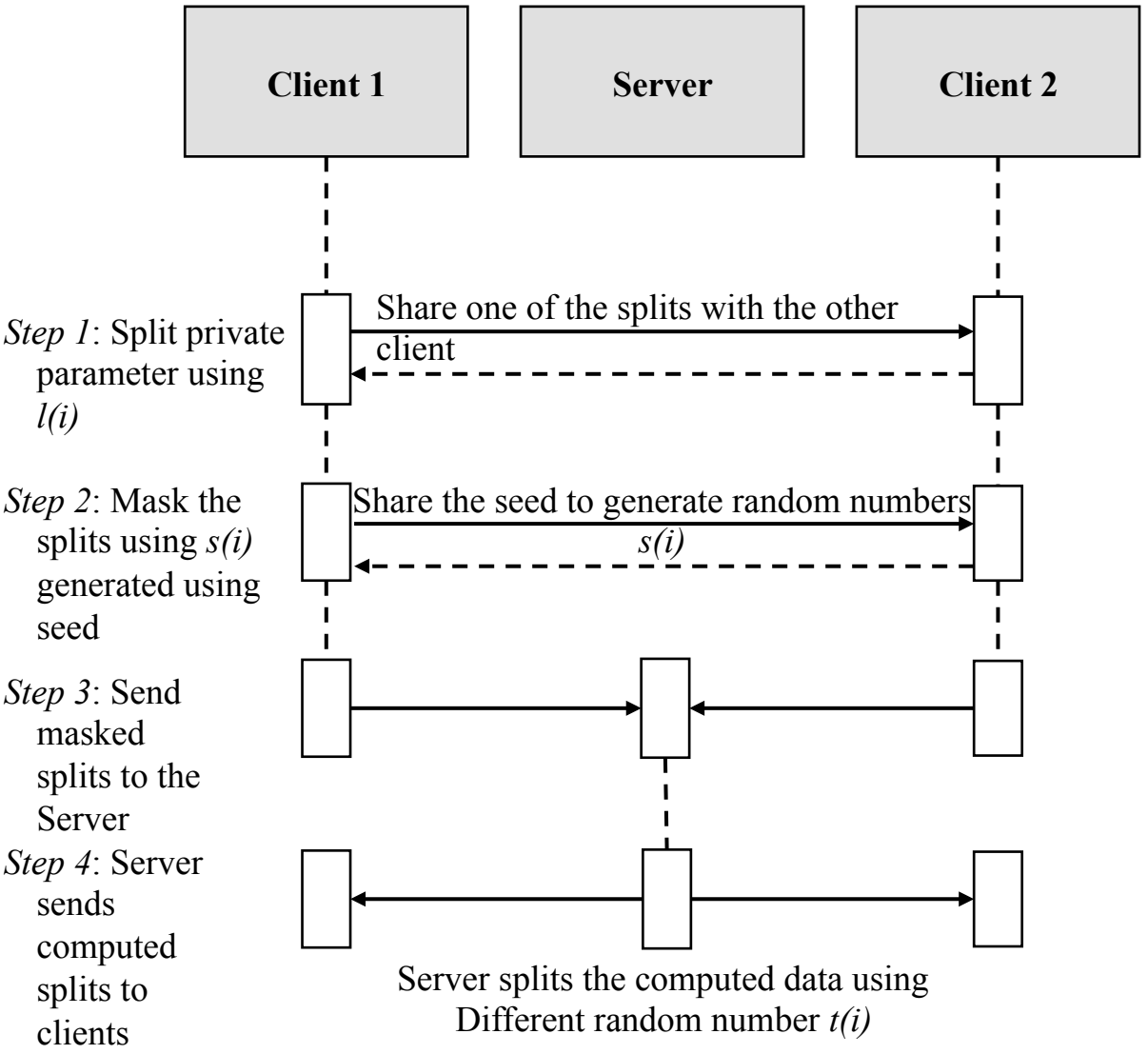


Chiho Choi, Ayan Sinha, Joon Hee Choi, Sujin Jang, and Karthik Ramani,
A Collaborative Filtering Approach to Real-time Hand Pose Estimation
In Proc. IEEE International Conference on Computer Vision (ICCV) 2015, Santiago, Chile, to appear.

Backup

Our Approach: Secure Co-Design (SCD) Framework

- Principles:
  - Adding/Multiplying a parameter's value with a random number hides the value of the parameter
  - Adding/Multiplying is orders of magnitude faster than competing cryptographic techniques
- A secure multi-party computation[1] protocol is built based on such splits and with the help of a server
- No Approximations
- Computational time is far less than encryption methods
- Achieve optimal without revealing confidential information



[1]S. Wang, S. Bhandari, M. Atallah, J. H. Panchal, K. Ramani, Secure collaborations in engineering system design, ASME, Buffalo, NY, USA, 2014.

Merits

Natural User Interface

- Touch, hold, and manipulate the proxy gives a realistic impression of controlling planar shapes.
- Tactile feedback provides rich information about how the planar shapes are being controlled.

Secure Co-Design

- Protection against misuse (purpose control)
- Achieves optimal solutions while preserving confidentiality
- No Approximations in determining optimal solutions
- Computationally “lightweight” compared to competing approaches such as fully homomorphic encryption

- Applications beyond co-design:

Online Auctions

SCD Framework can be deployed in privacy preserving computations as well

Application : Co-design Scenario

	Co-design Scenario	Pros	Cons
	**Leader Follower**	Faster development Cycles	Follower(s) may have to reveal his/her confidential information
	**Pareto Co-operation**	Pareto Optimal Solutions (best solutions) are achievable	Confidentiality preservation is based on trust
	**Nash Non-Cooperation**	No leakage of Confidential information	Pareto optimal solutions are difficult to achieve

Basic Arithmetic Secure Computations

- Addition and Subtraction (ASP)
- Multiplication (MP) and Division (DP)
- Exponentiation (EP)
- Greater than Zero (GT0)
- Equivalence with Zero (EW0)

Higher Level Protocols

- Vector Inner Product (VIP)
- Matrix Multiplication (MM)
- Matrix Inverse
- Numerical Methods (Newton's method)

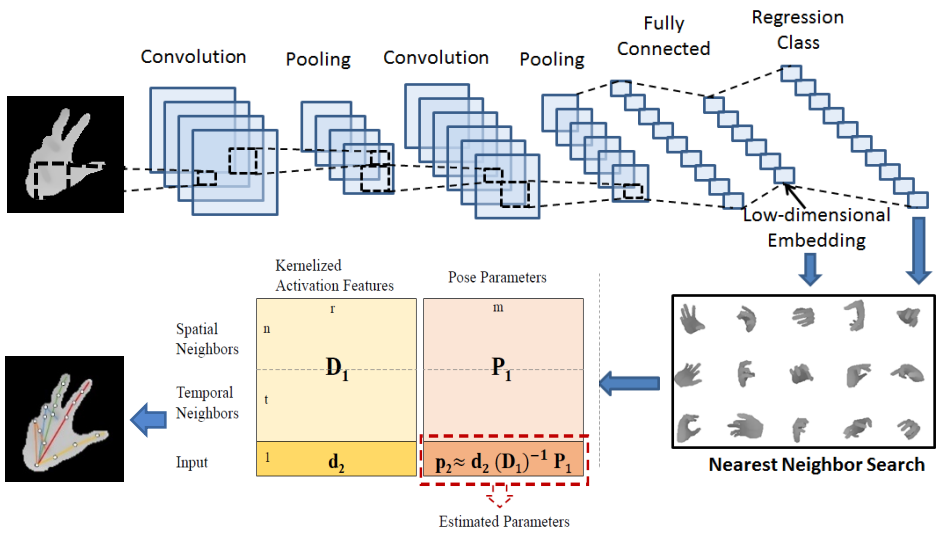
Application to Co-Design Scenarios

- Leader Follower
- Pareto Co-operation
- Nash Non-Cooperation

SCD Framework is tested and validated for achieving optimal solutions while preserving confidentiality in these co-design scenarios

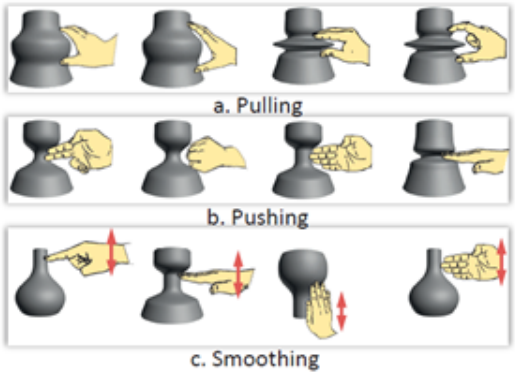
Hand as an Interactive Modality

Hand Tracking System

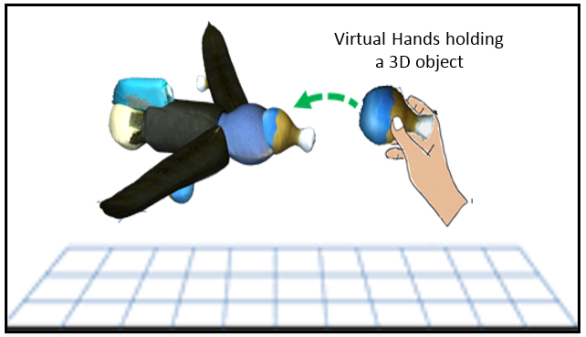


- Robust hand pose estimation
- Occlusion management
- Real-time performance

Applications



Virtual Pottery Sculpting

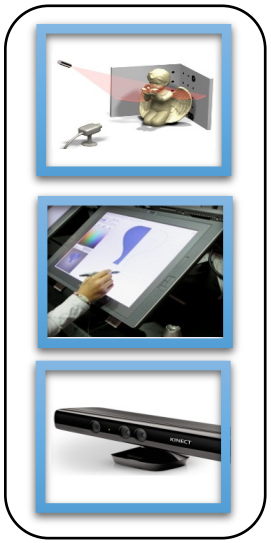


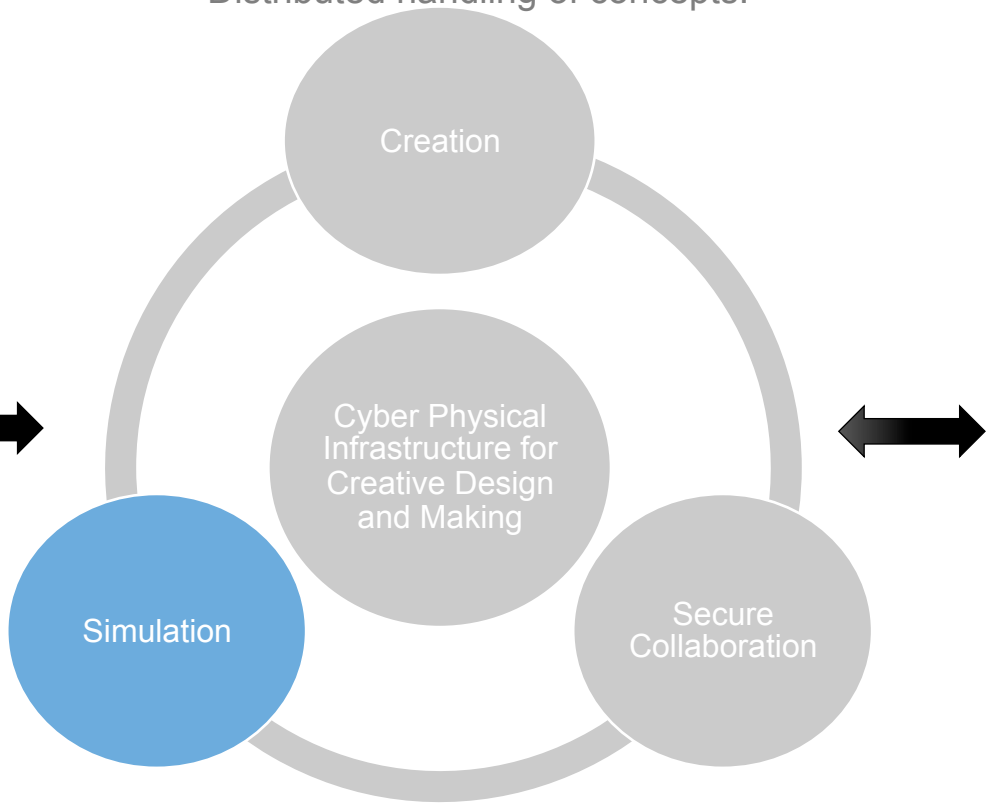
3D Assembly

Future Work

Pen, touch, and gesture based NUI;
Incorporation of physical constraints;
Embedding physical objects;
Distributed handling of concepts.

Natural interfaces



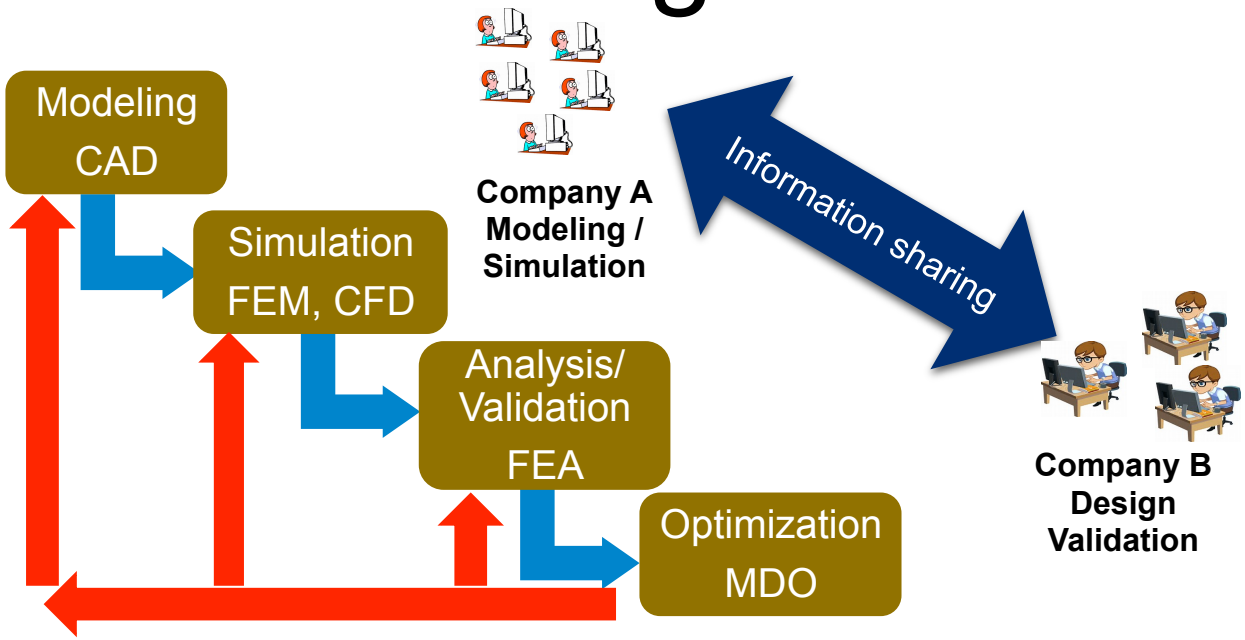


Physical realization

Design knowledge representations;
Real-time validation and guidance;
Model-based design coordination.

Minimum disclosure interactions;
Quality of inputs assurance;
Provenance and integrity;
Usage control

Research Challenge



- Lack of secure information sharing inhibits designers to share confidential information. For example,

Actual Information:
E=780 Mpa

Information shared
E~(780-900 Mpa)

How to preserve confidentiality of designer's information during handshakes?