C-[illegible] D[illegible]
F[illegible] C[illegible]

H[illegible] [1,3,4]
[illegible]
A[illegible]
C[illegible]
[illegible]
[illegible] [2]
A[illegible]

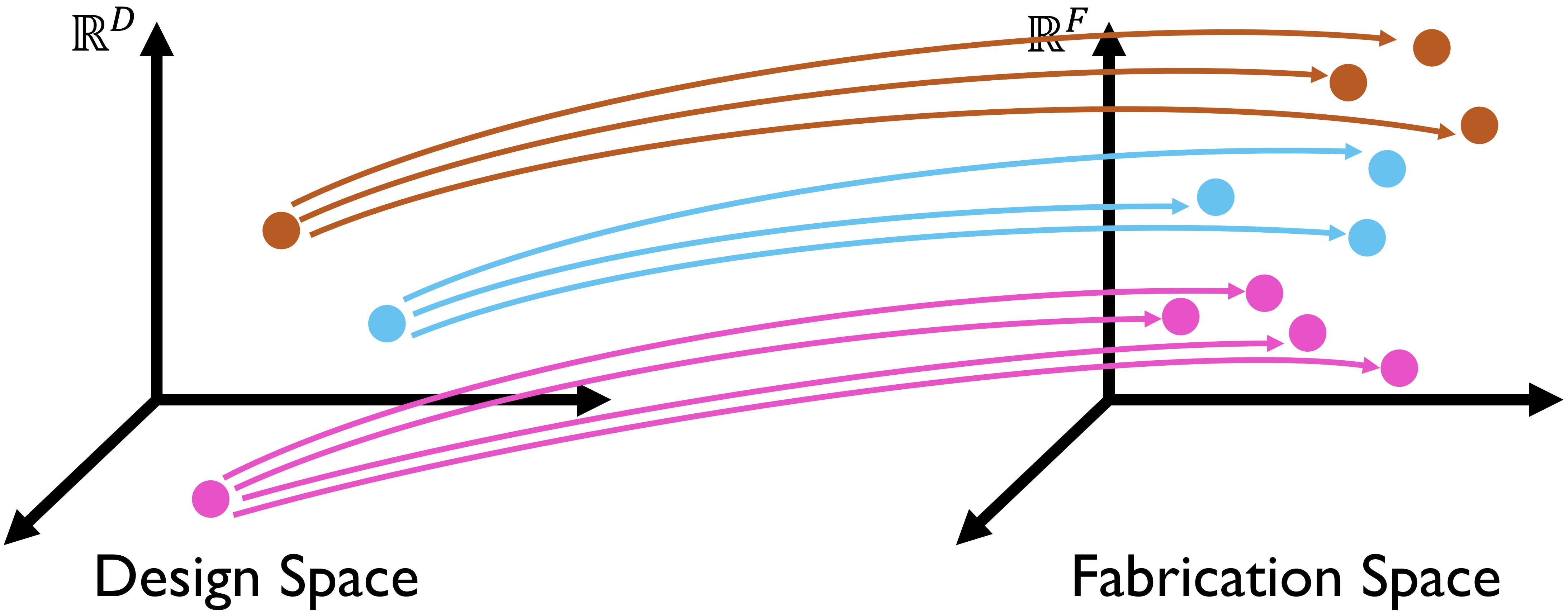
[1] [illegible]
[2] [illegible]
[3] [illegible]
[4] I[illegible] A[illegible]

PAUL G. ALLEN SCHOOL
OF COMPUTER SCIENCE & ENGINEERING

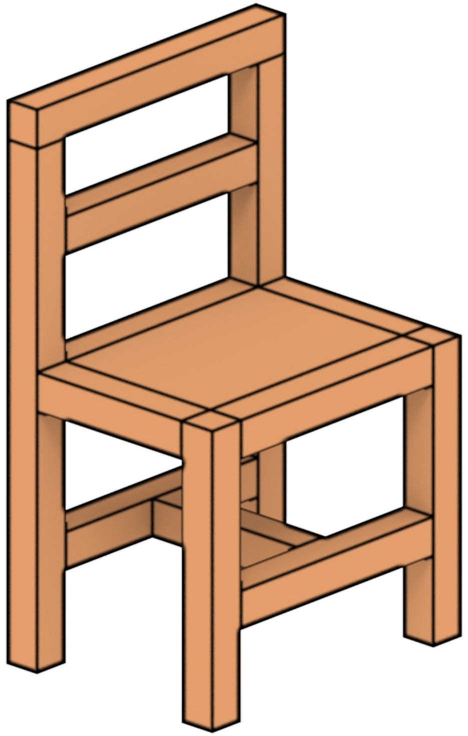
Fabrication-Oriented Design

There is a unique map from a design to a fabrication plan

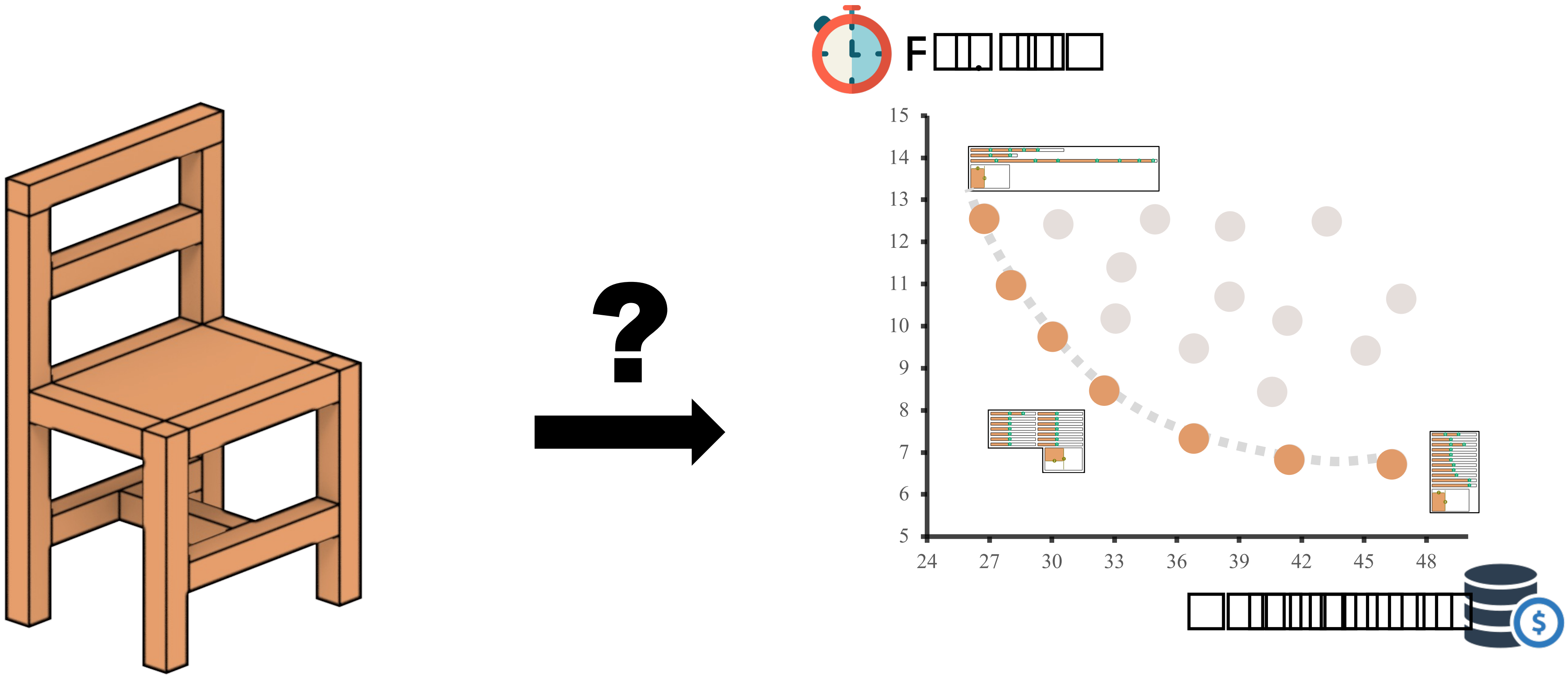
Fabrication-Oriented Design



From A Design to Multiple Fabrication Plans

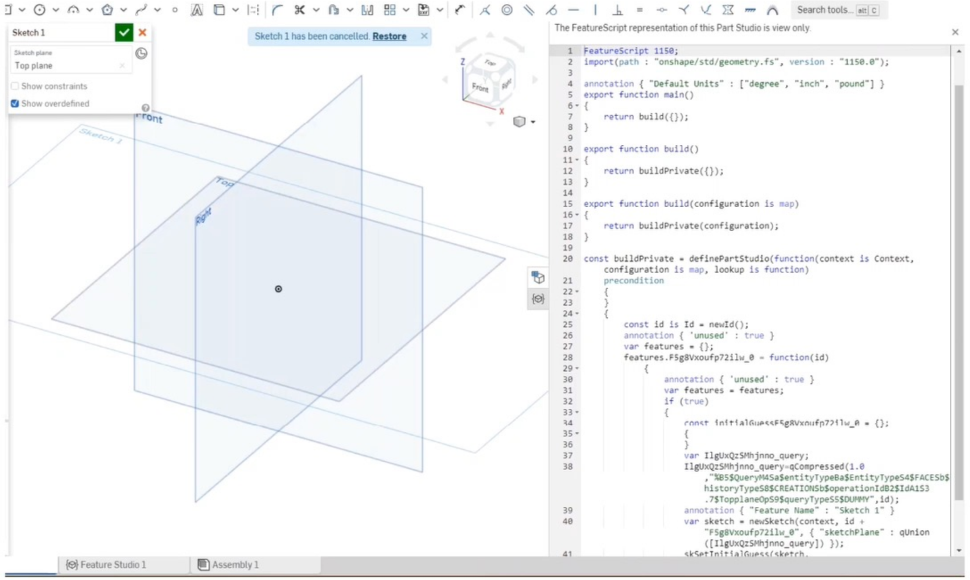


From A Design to Multiple Fabrication Plans



Design and Fabrication Plans as Programs

D[illegible]

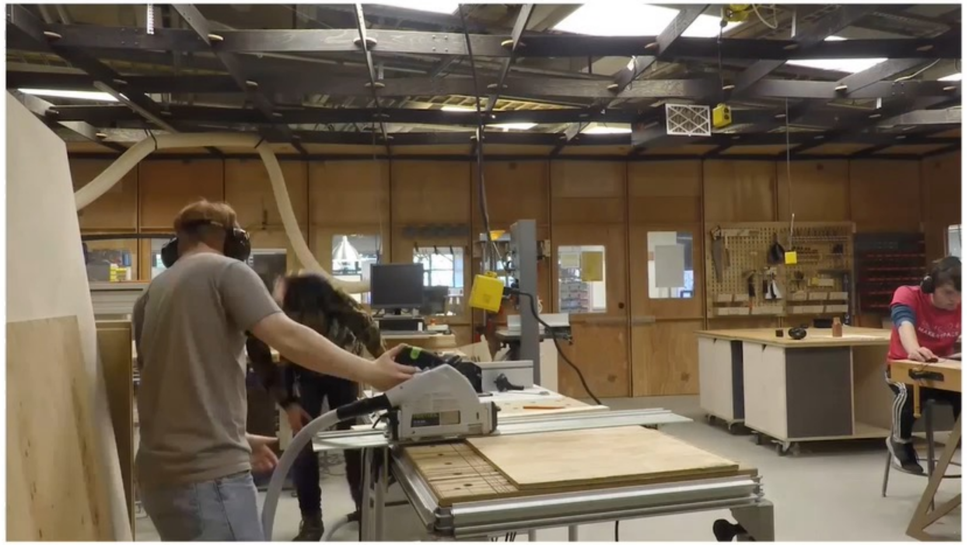


[Onshape]

A [illegible]

(C[illegible])

F[illegible]



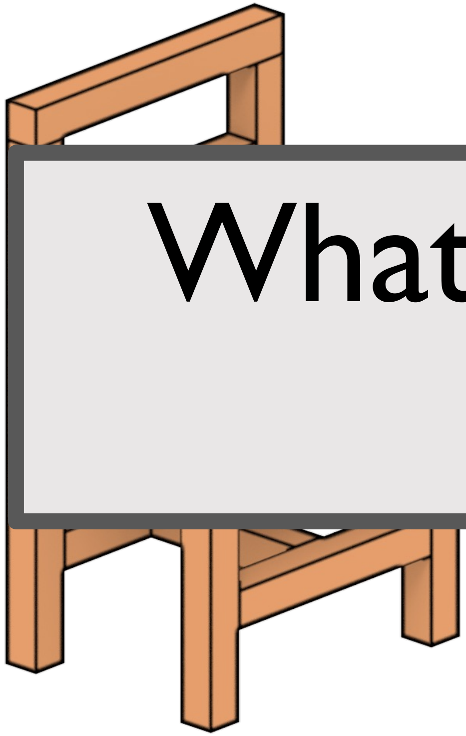
[illegible]

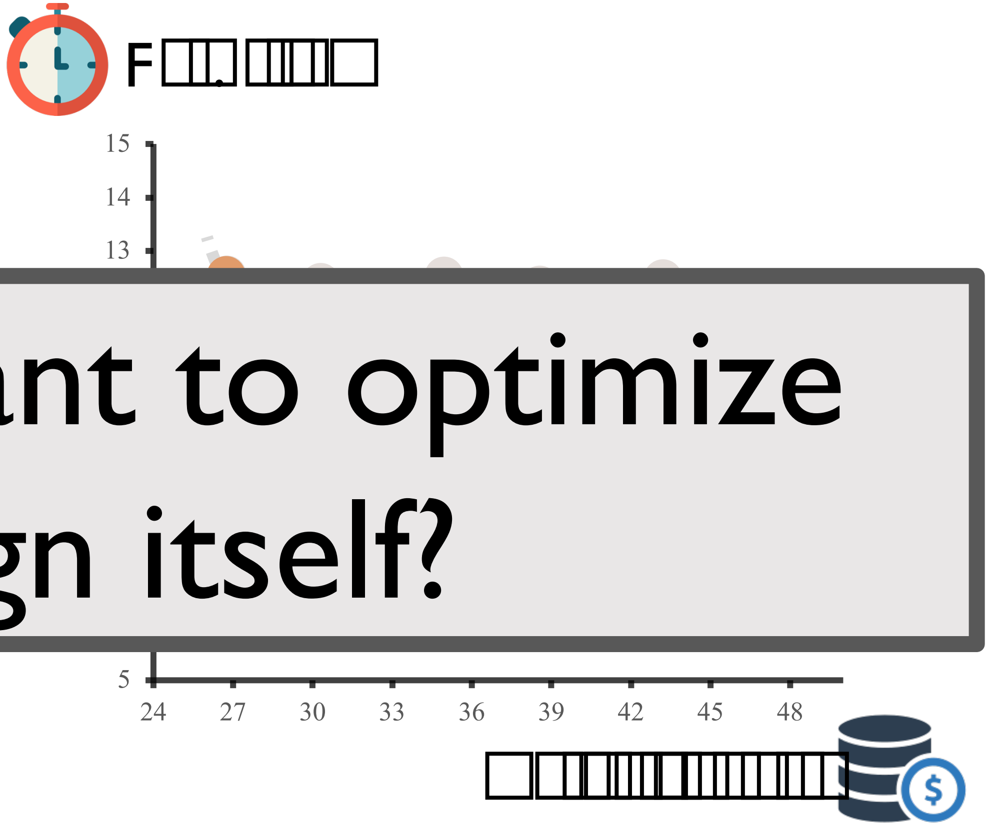
A [illegible]

(C[illegible])

Wu, Chenming, Haisen Zhao, Chandrakana Nandi, Jeffrey I. Lipton, Zachary Tatlock, and Adriana Schulz. "Carpentry compiler." ACM Transactions on Graphics (TOG) 38, no. 6 (2019): 1-14.

From A Design to Multiple Fabrication Plans

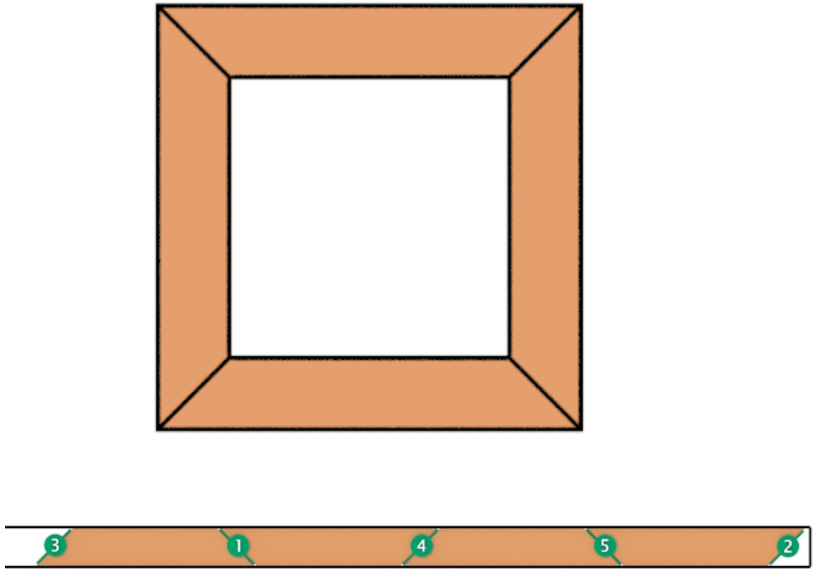




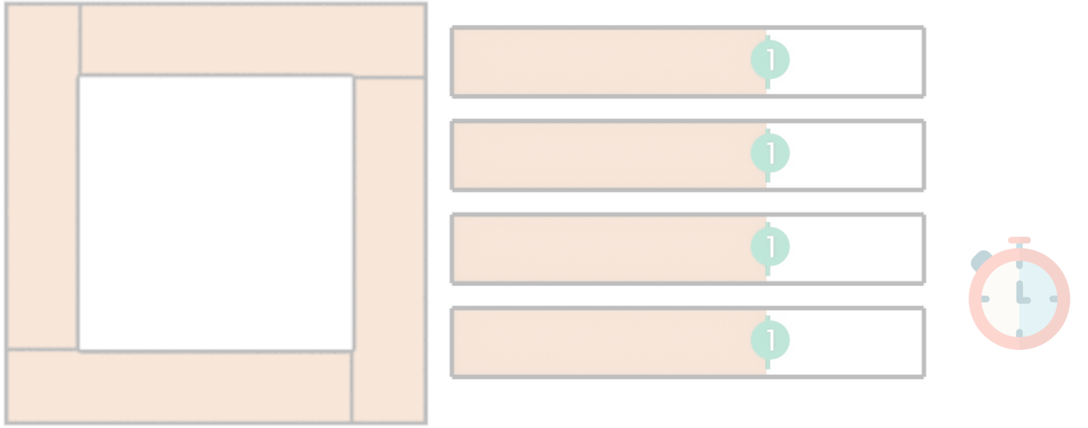
What if you want to optimize the design itself?

Considering Design Variations

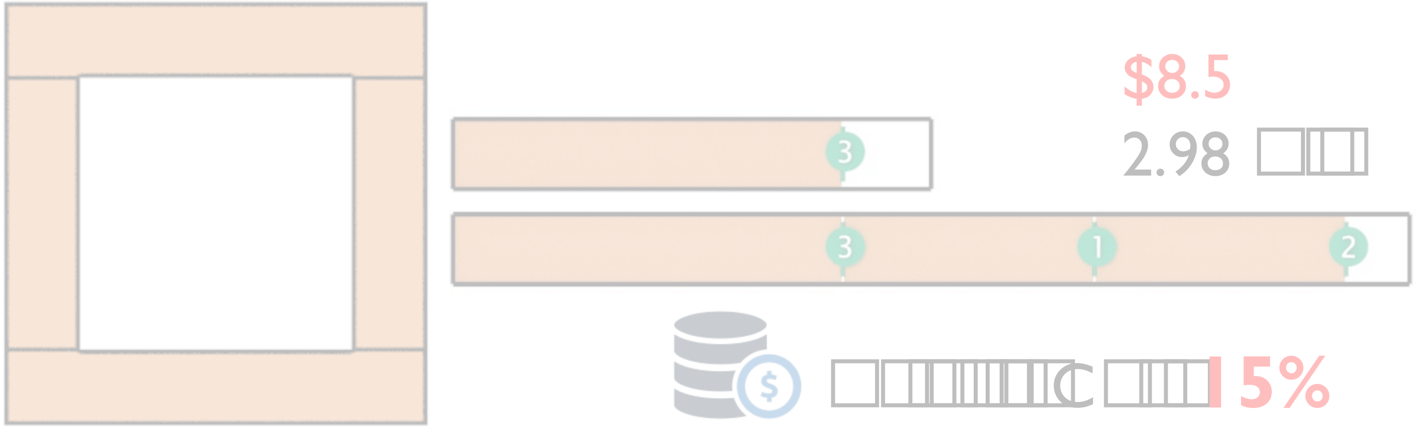
I



$10.0
6.67



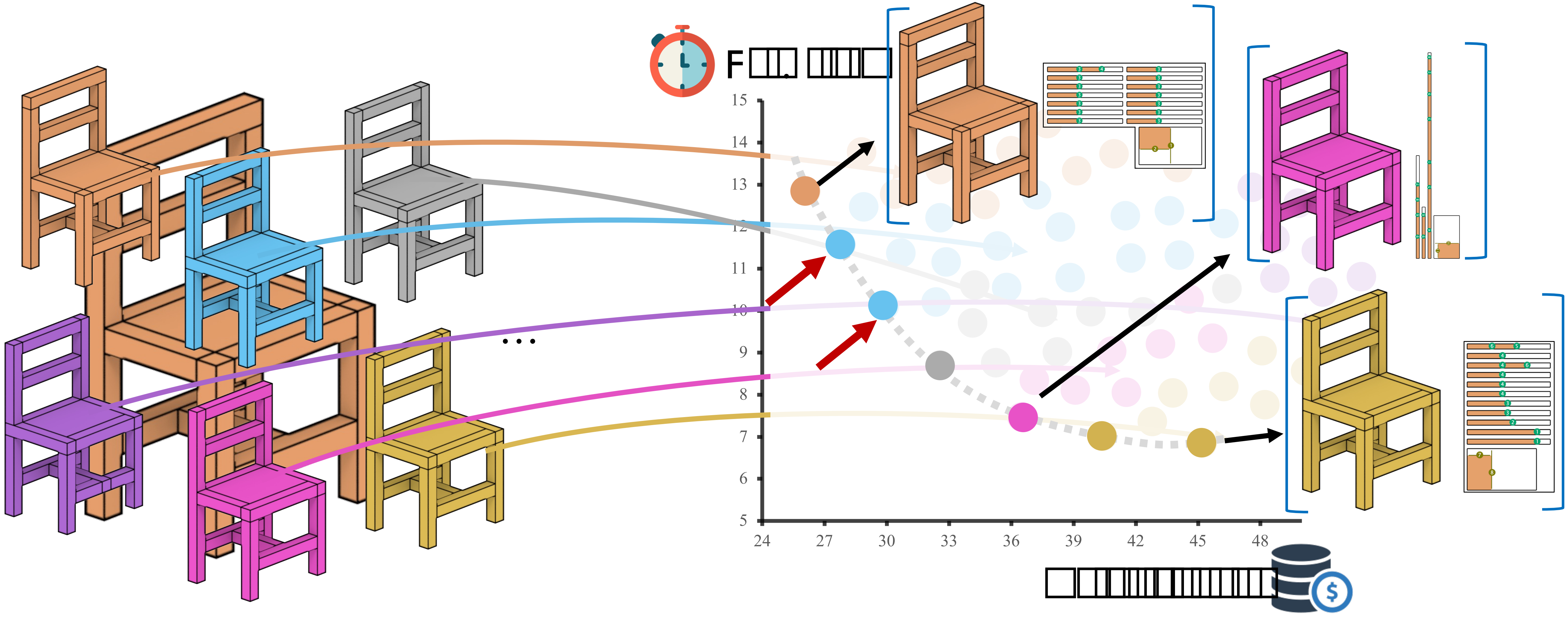
$12.0
1.37
F 80%



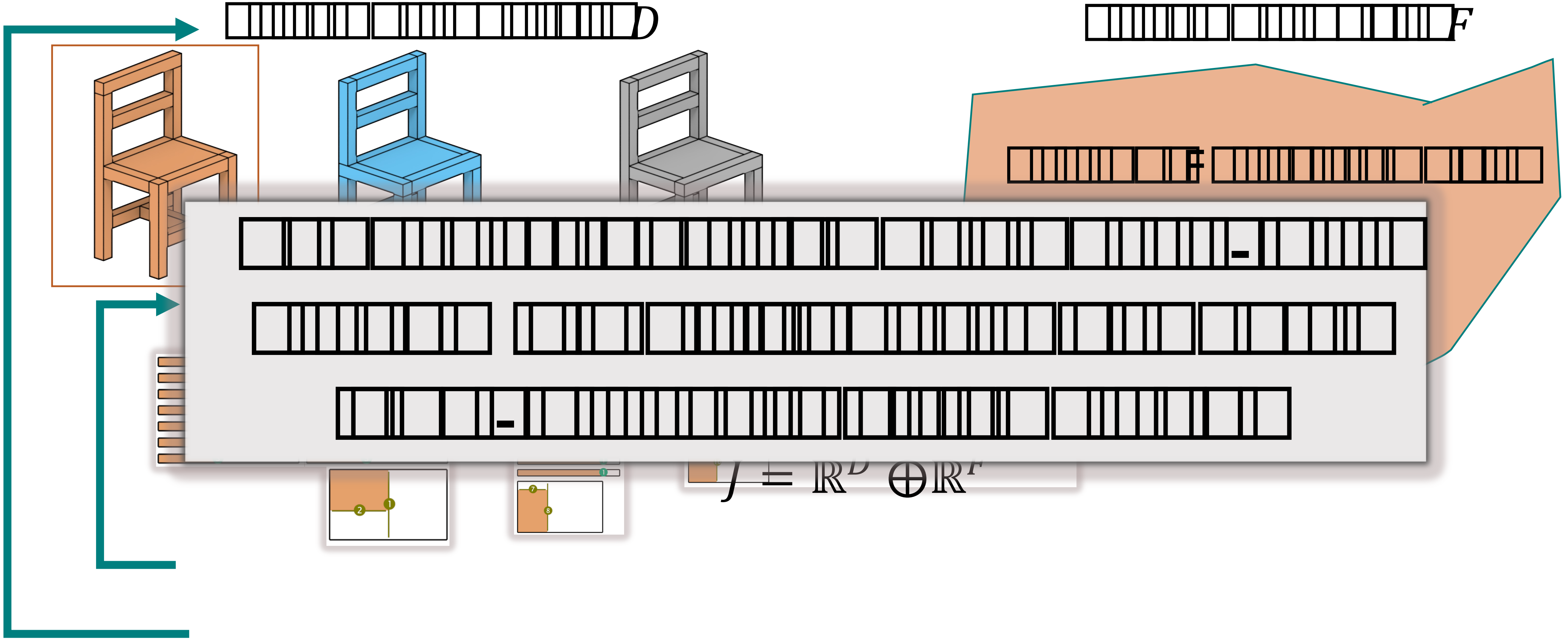
$8.5
2.98
C 15%

D

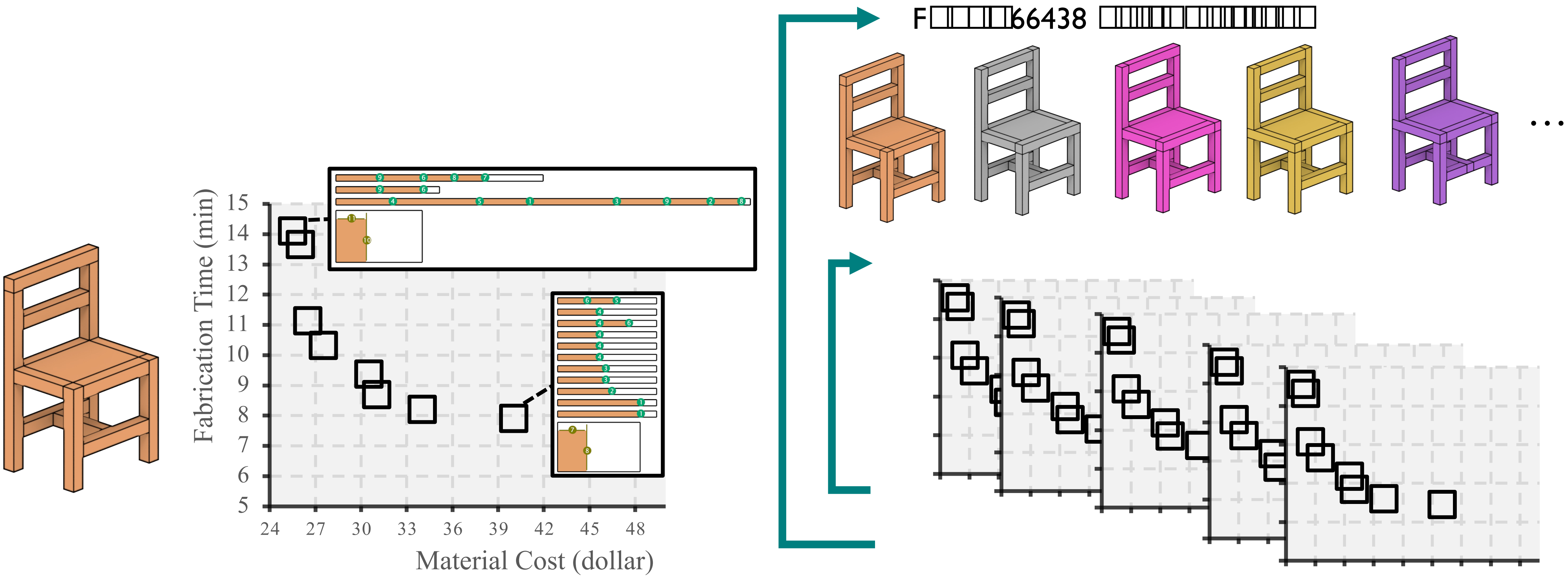
Co-optimization of Design and Fabrication Plans



Search Challenges: Multi-Level



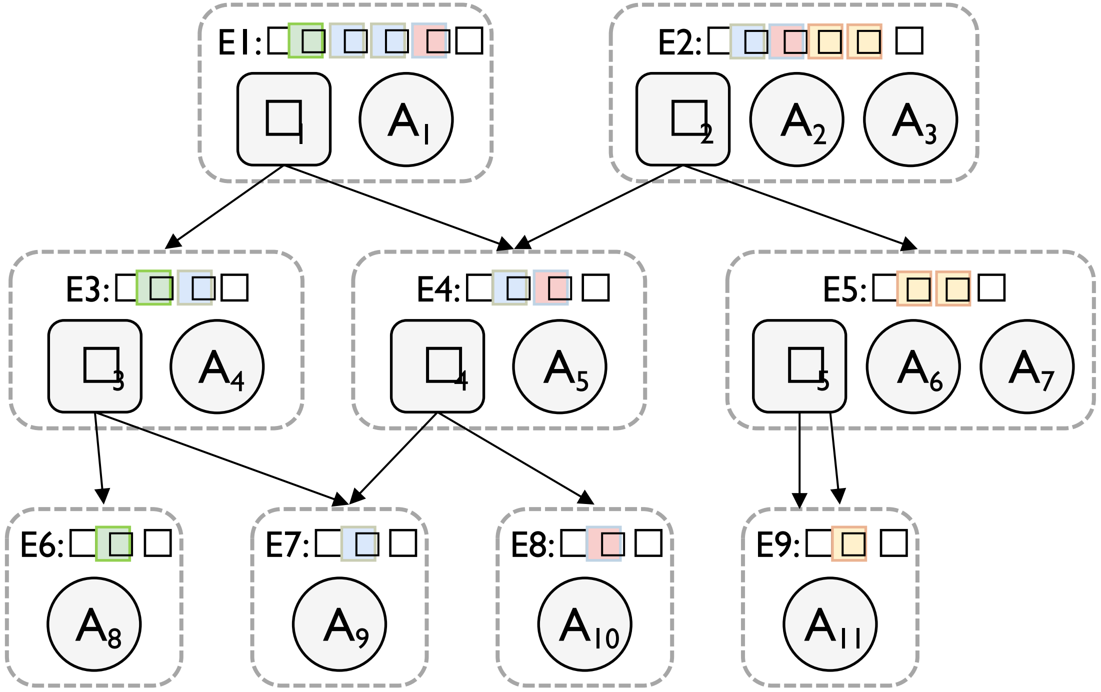
Search Challenges: Multi-Level

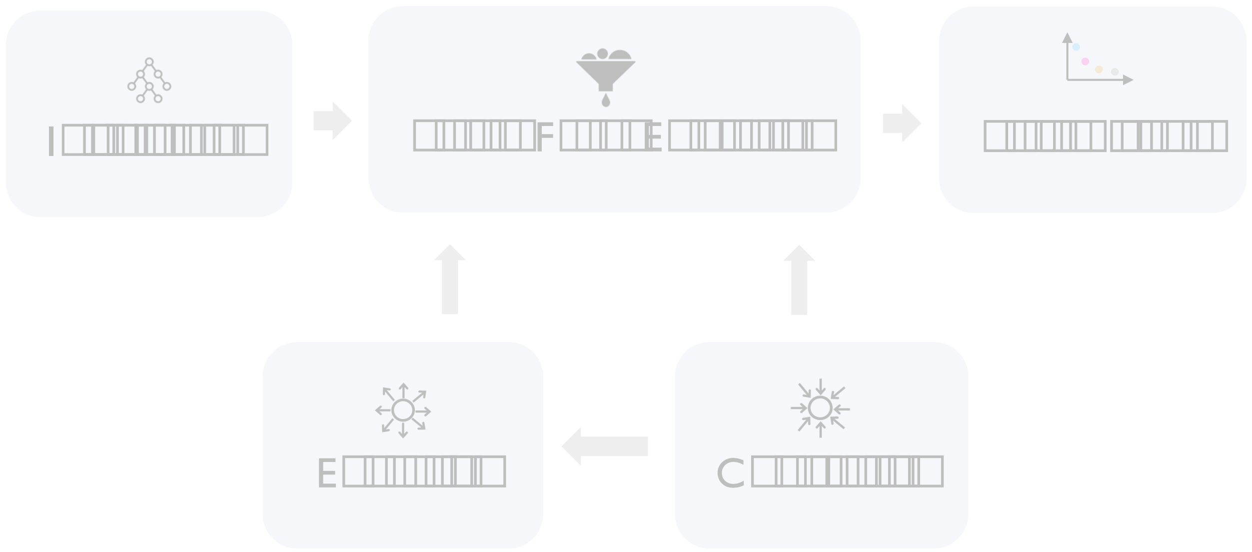


8-10 [illegible]

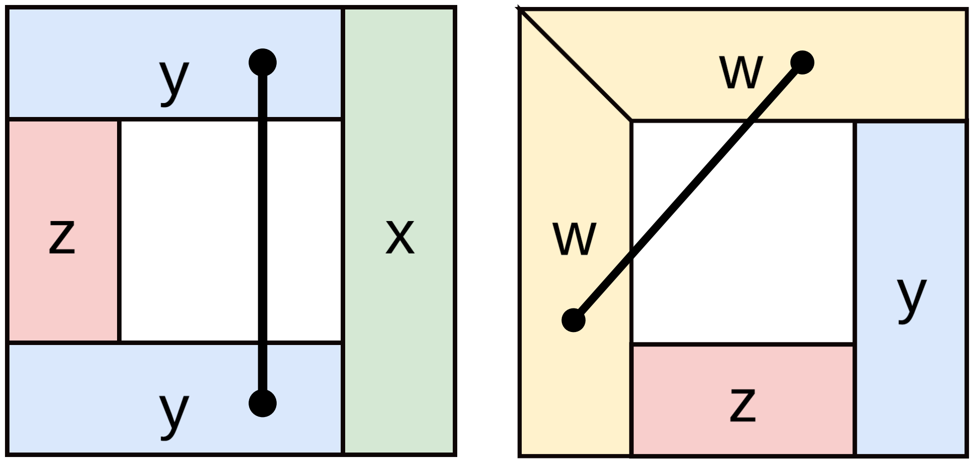
[illegible] 10000 [illegible]

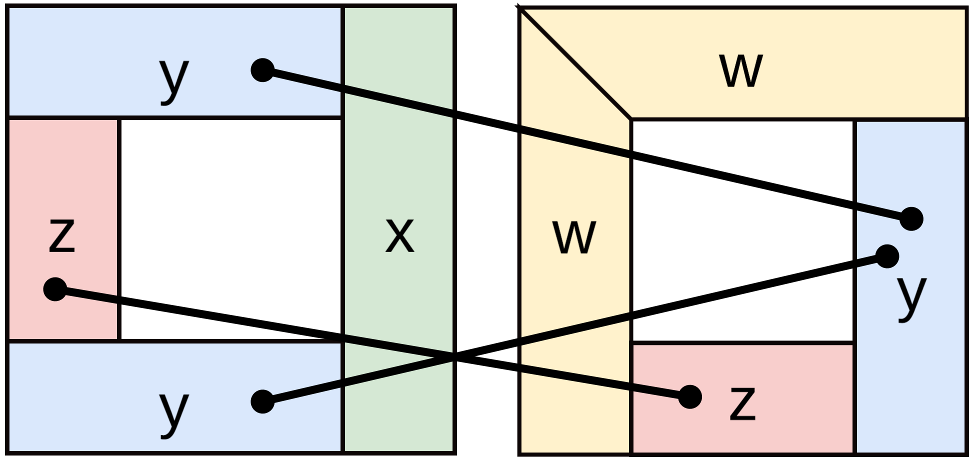
Approach





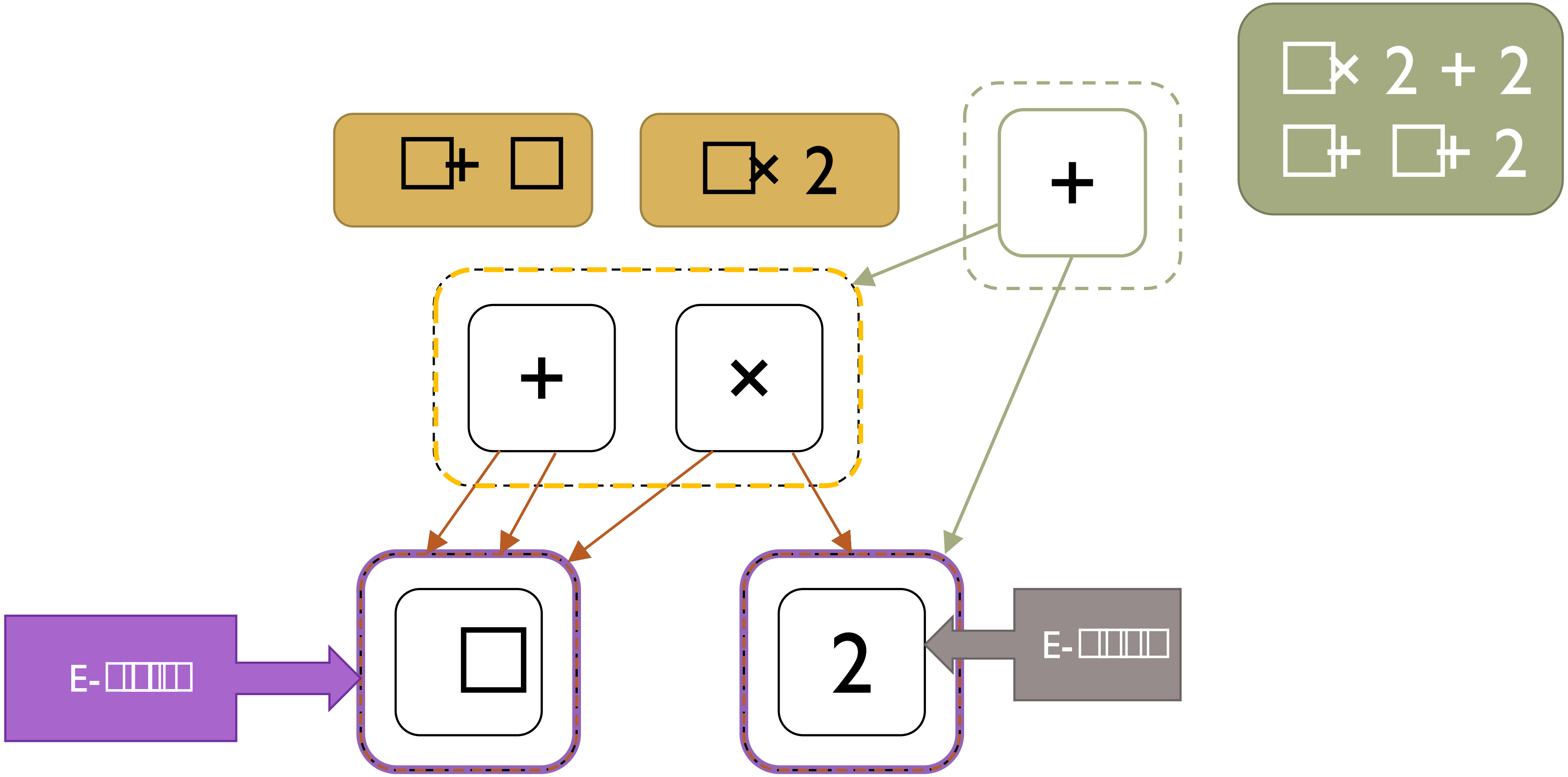
Key Insight: Equivalent Substructures!





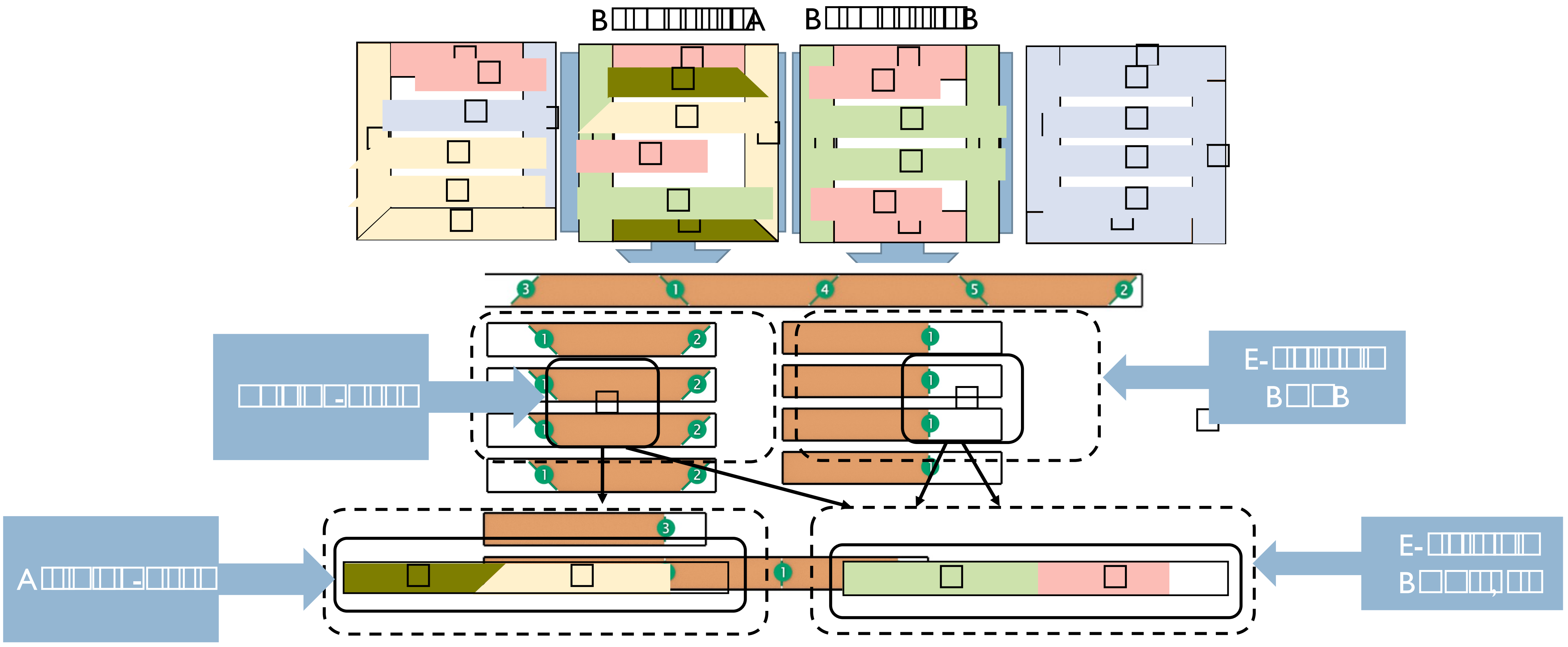
A

Equivalence graphs (E-graphs)

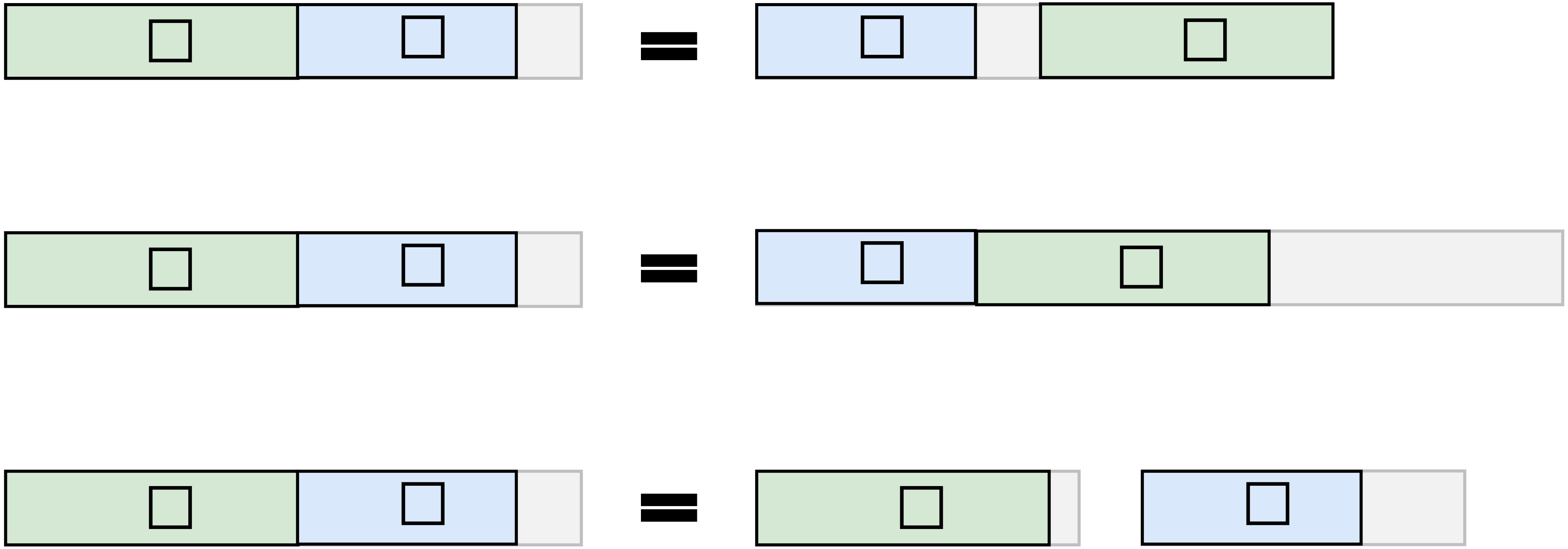


Charles Gregory Nelson. 1980. Techniques for Program Verification. Ph.D. Dissertation. Stanford University, Stanford, CA, AAI8011683.

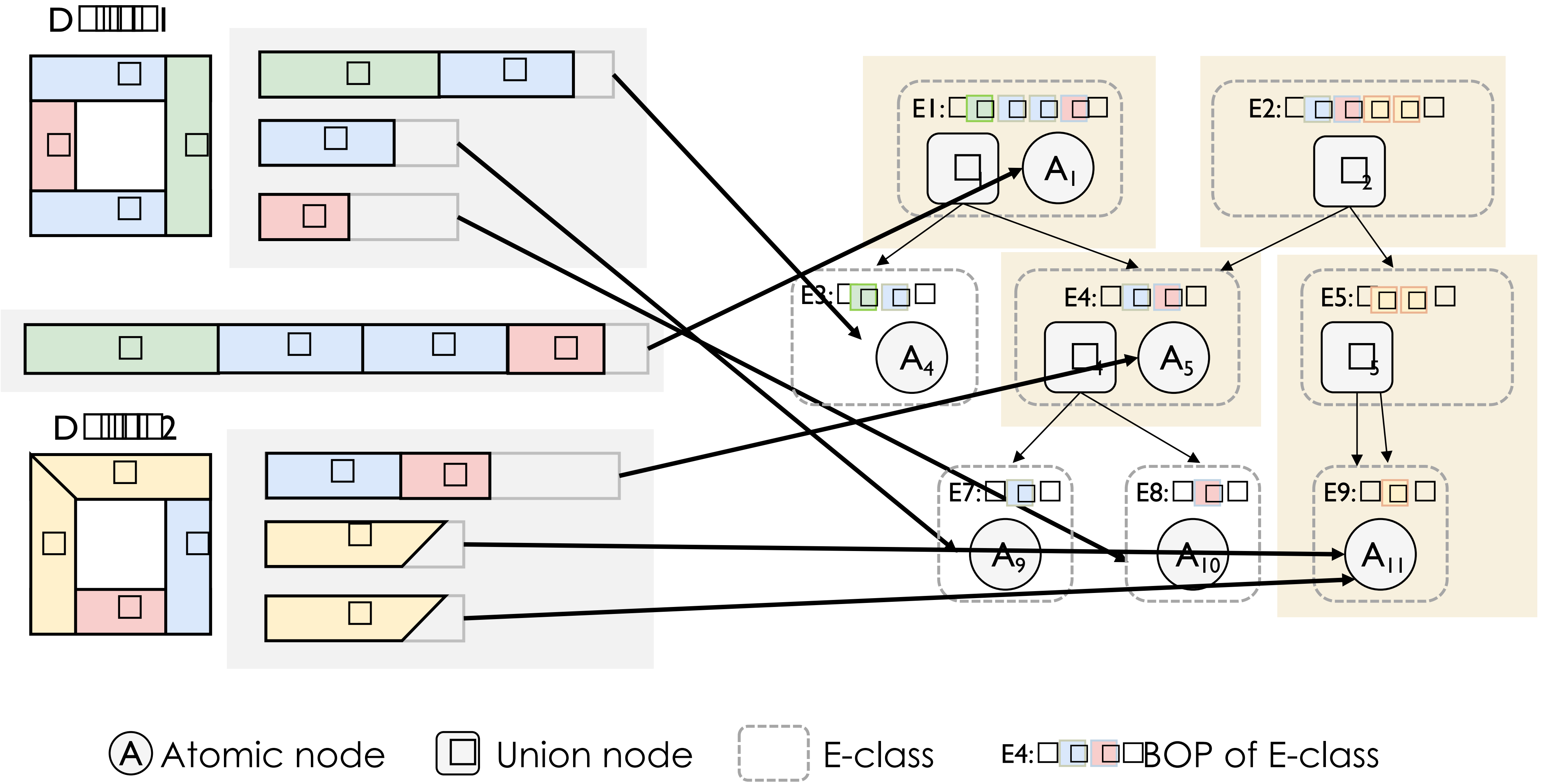
E-graphs for design and fabrication



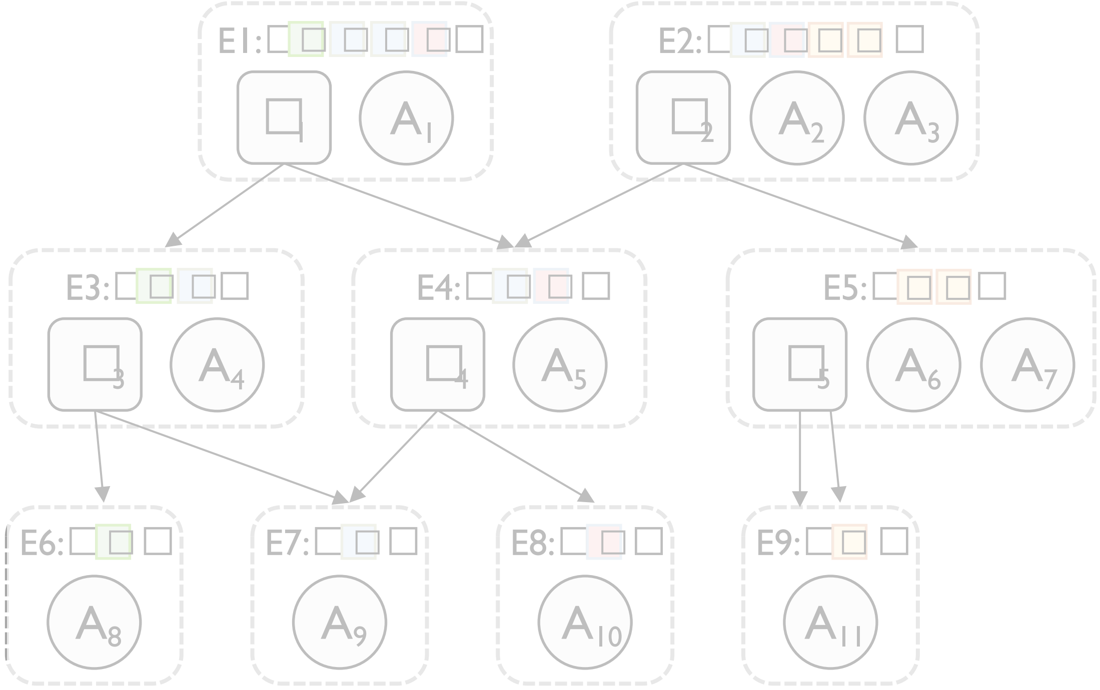
Defining equivalence

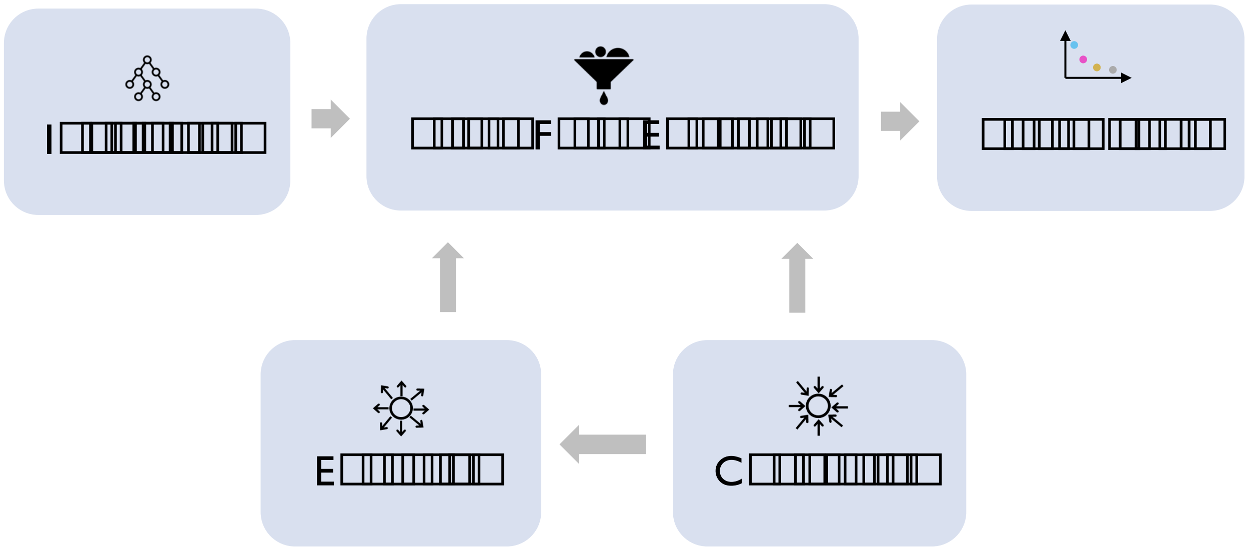


Bag-of-Parts (BOP) E-graph

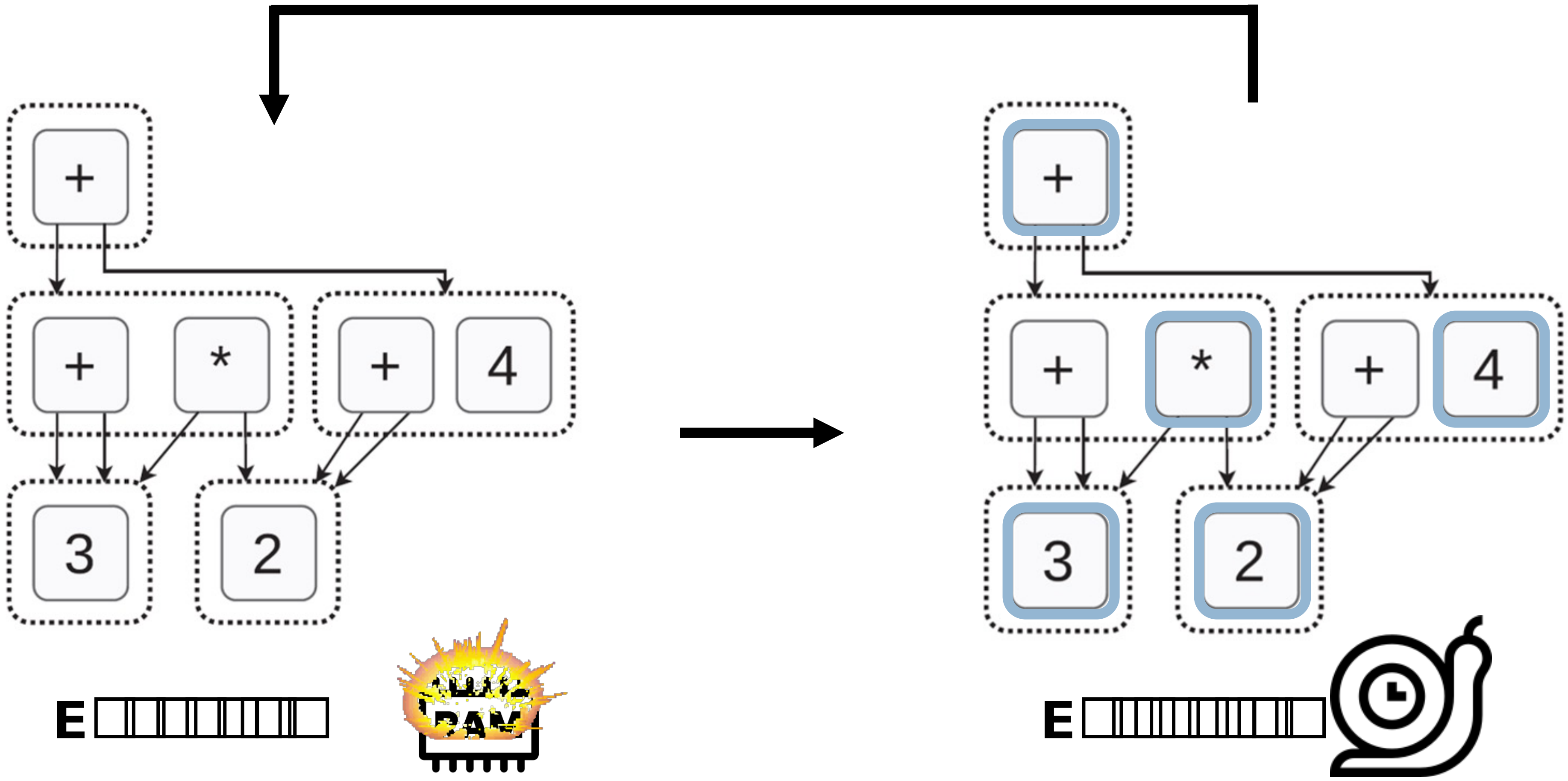


Approach

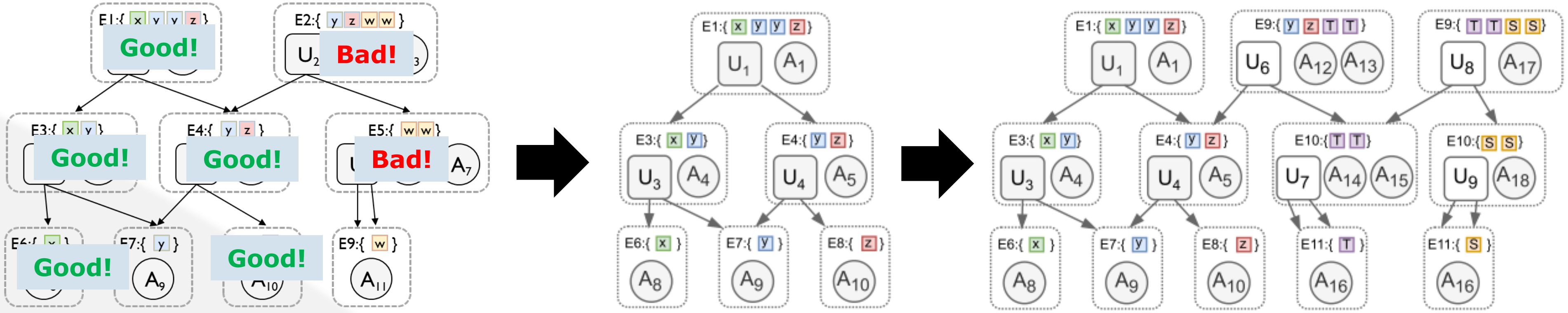




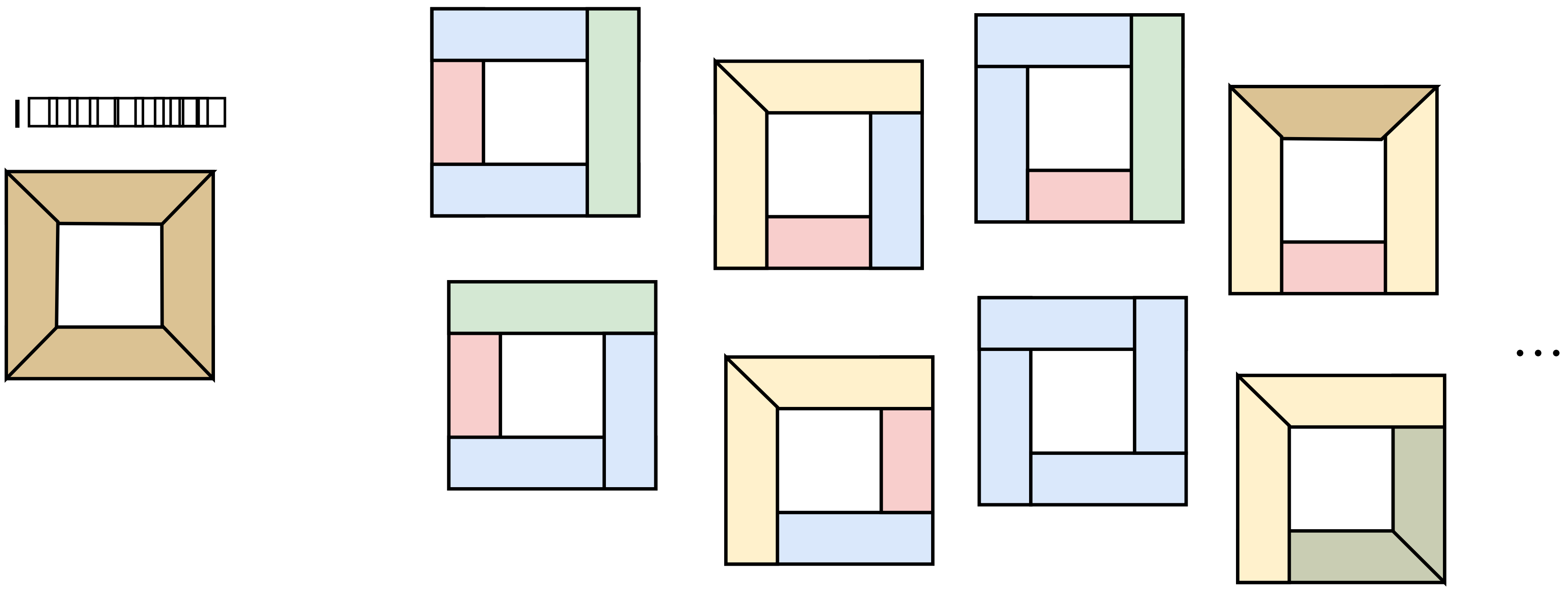
Typical E-Graph Search



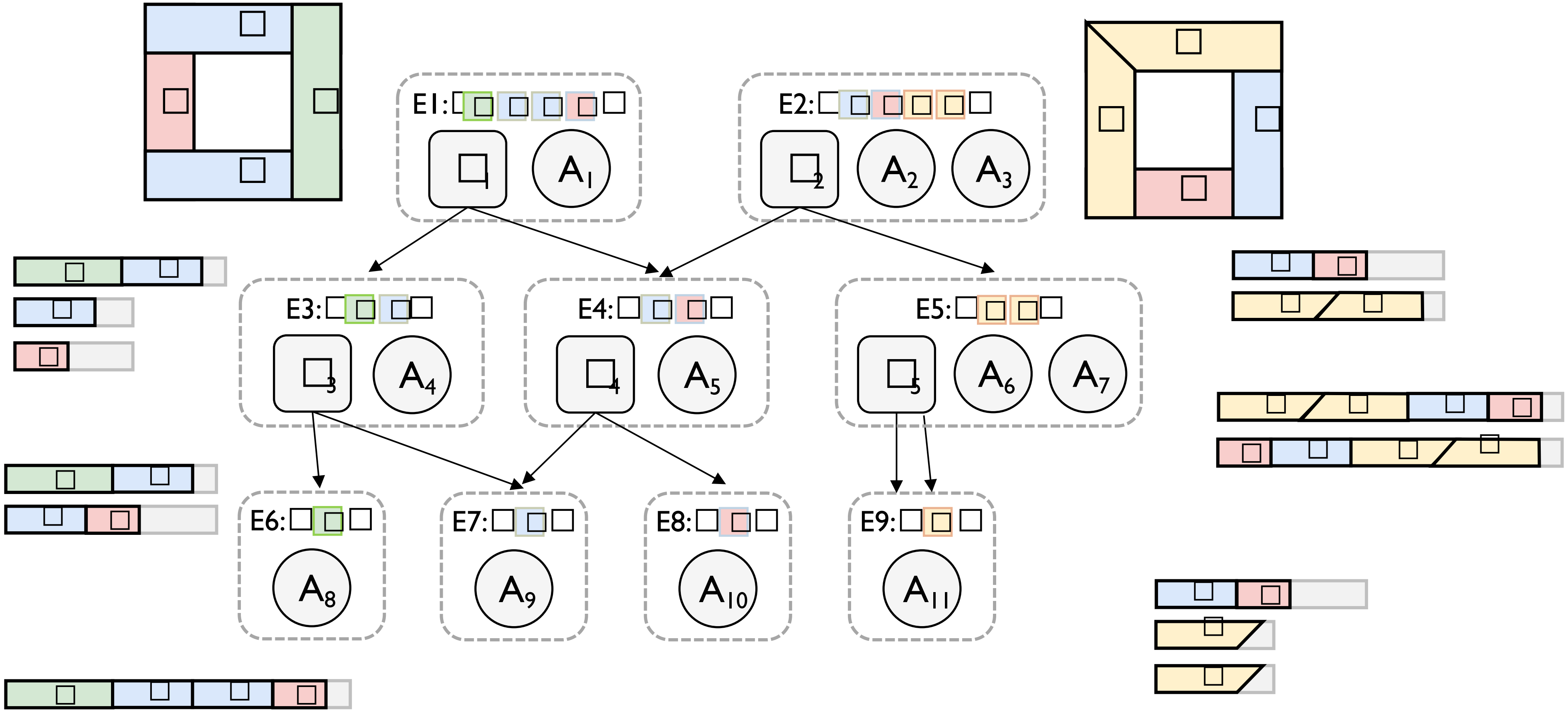
Iterative Contraction and Expansion on E-graphs

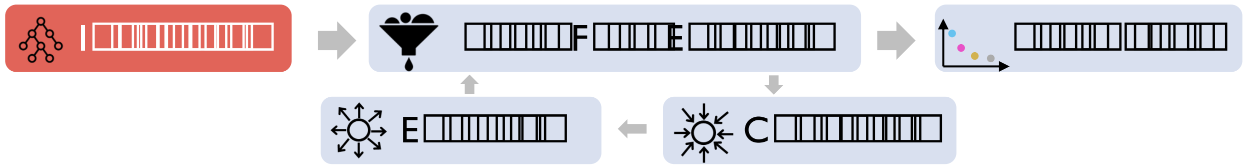


ICEE Overview

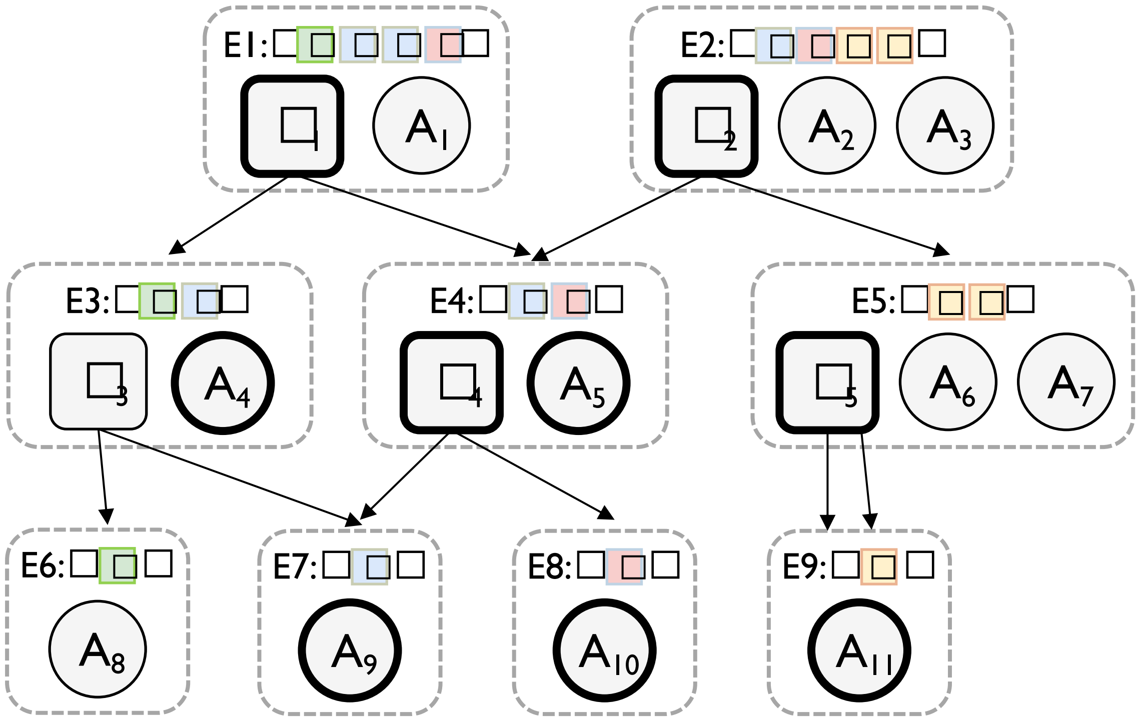


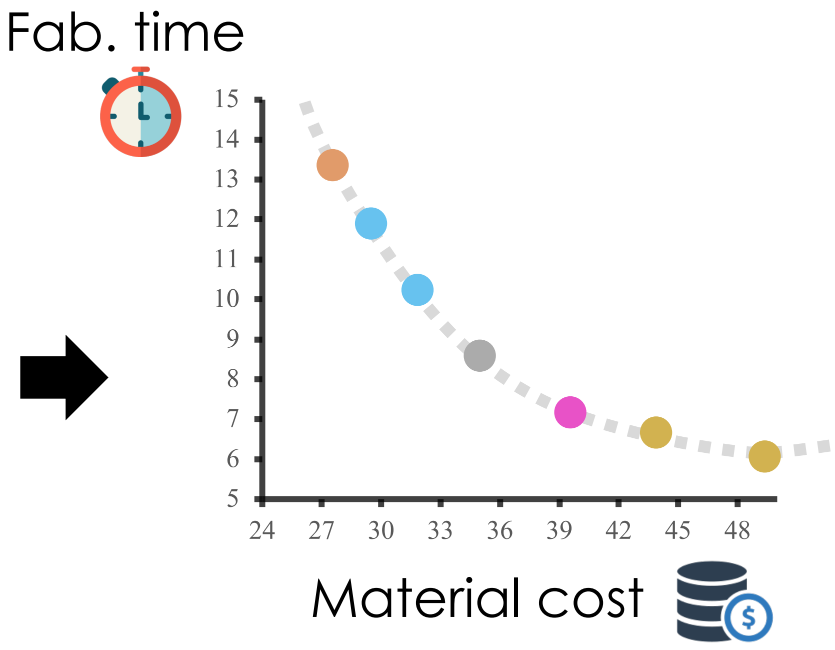
Initialization

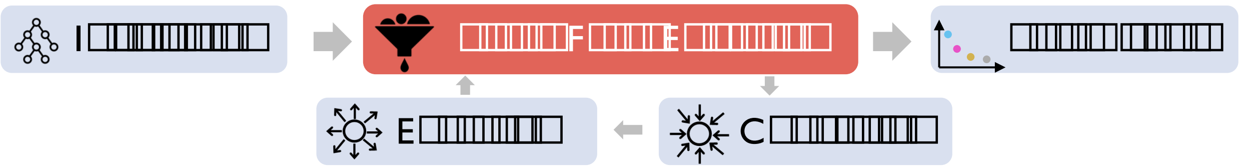




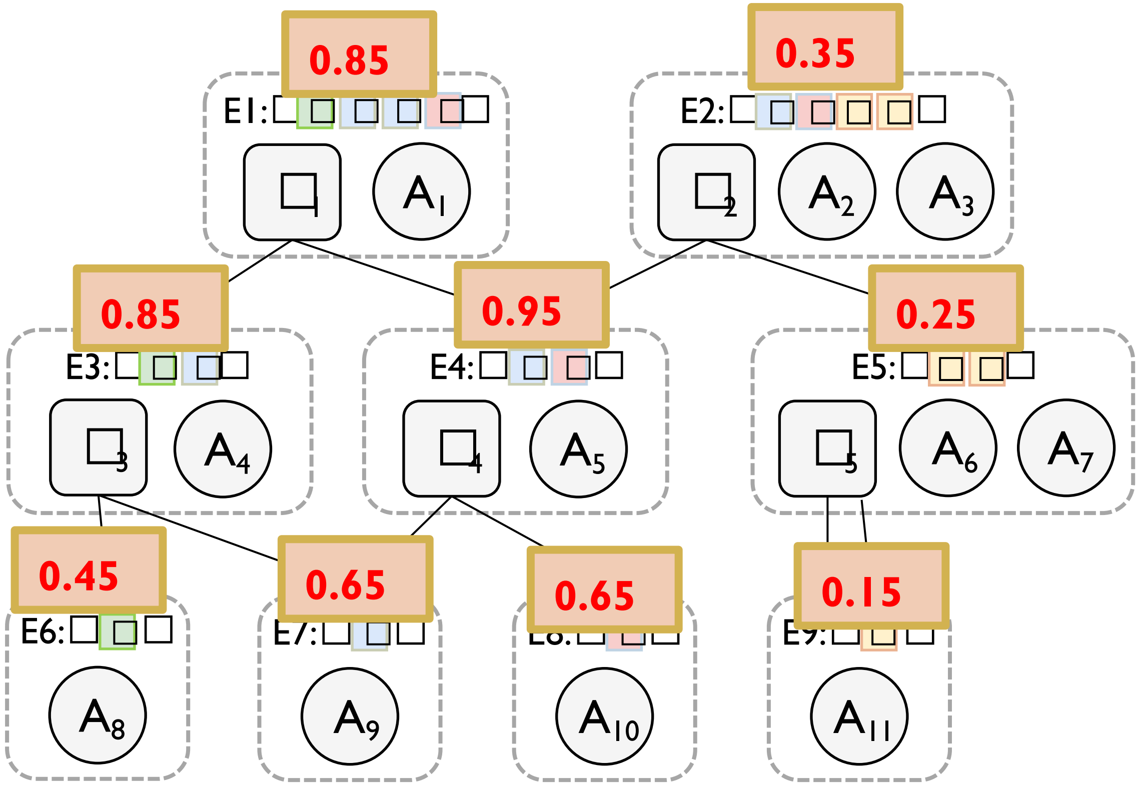
Extraction

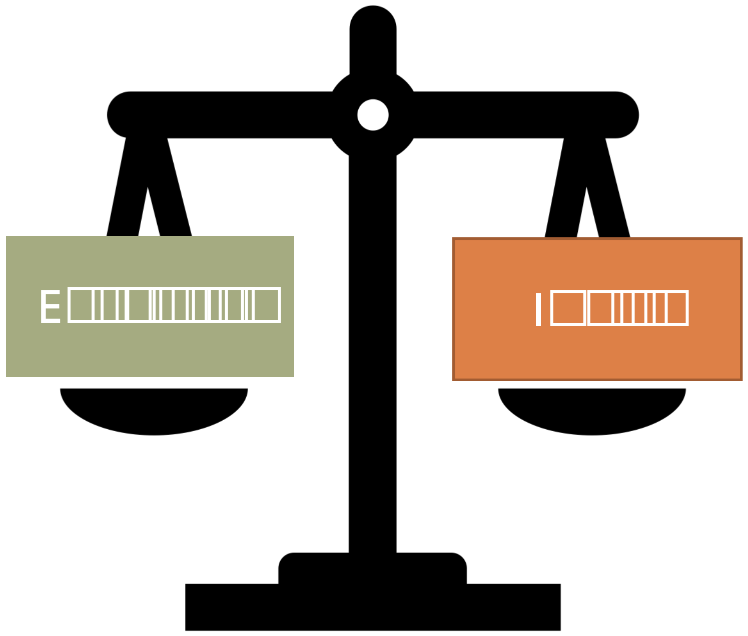

E1:
A1
E2:
A2
A3
E3:
A4
E4:
A5
E5:
A6
A7
E6:
A8
E7:
A9
E8:
A10
E9:
A11

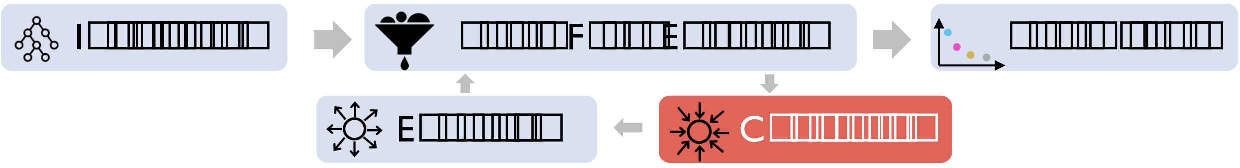

Fab. time
15
14
13
12
11
10
9
8
7
6
5
24
27
30
33
36
39
42
45
48
Material cost



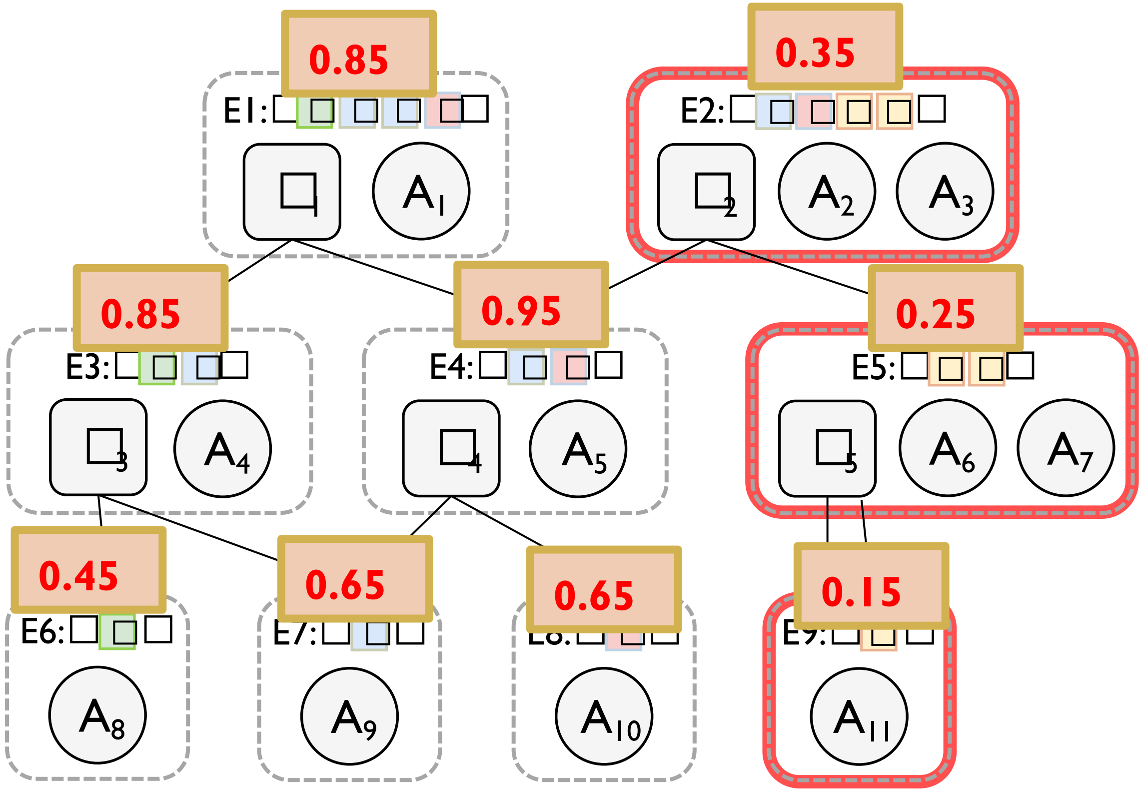
Preparing to Contract and Expand

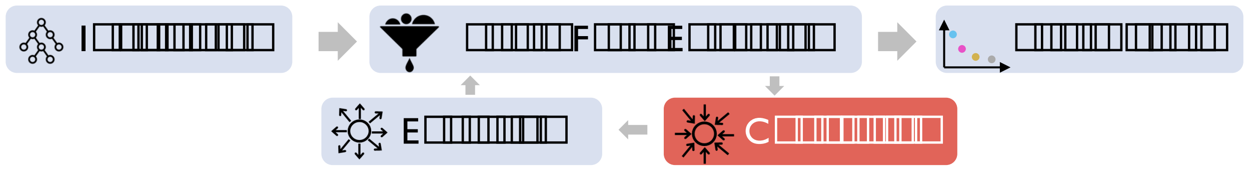




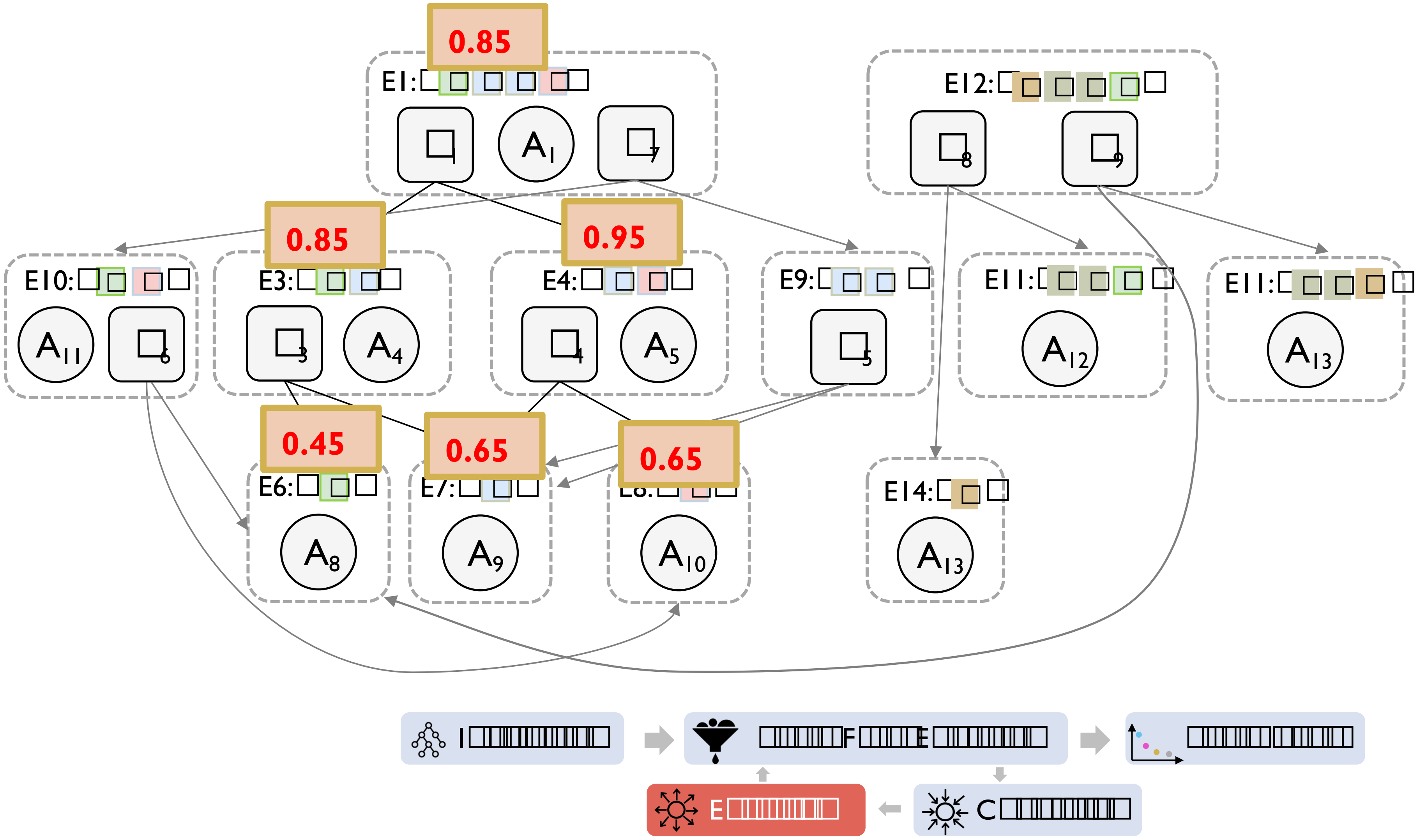


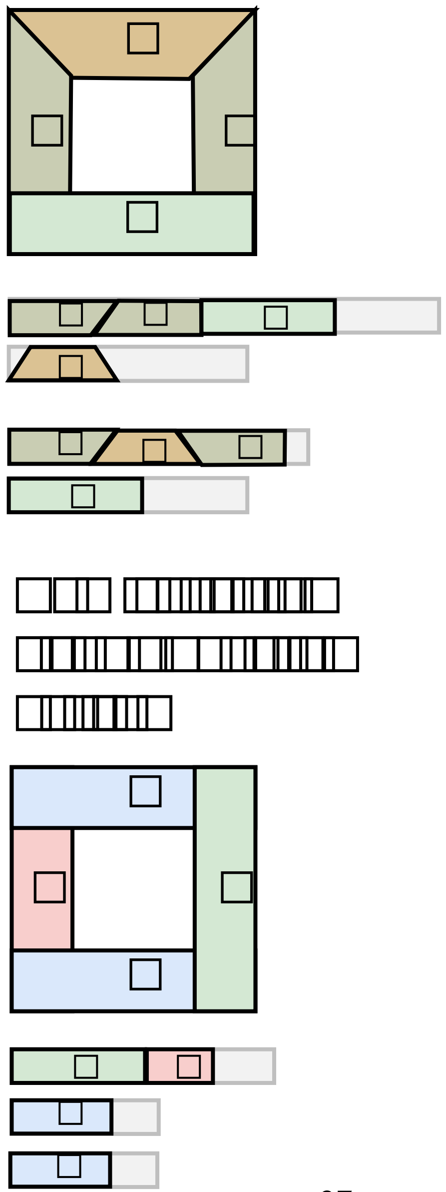
Contraction



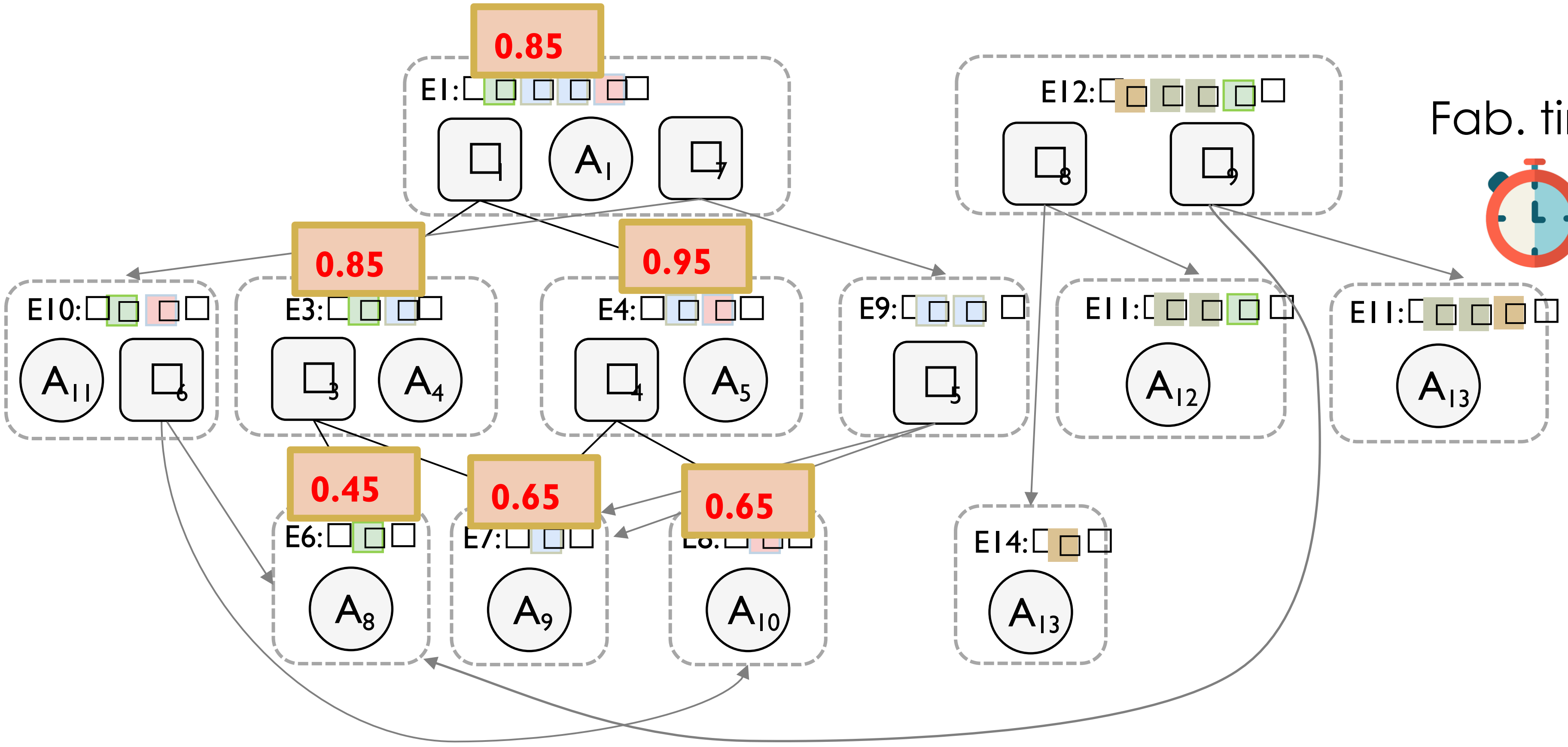


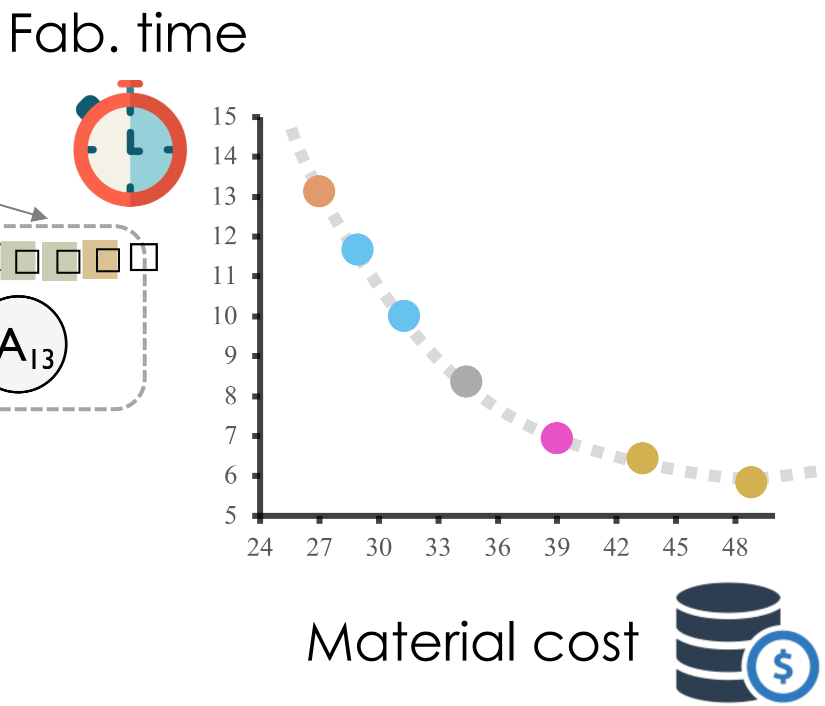
Expansion

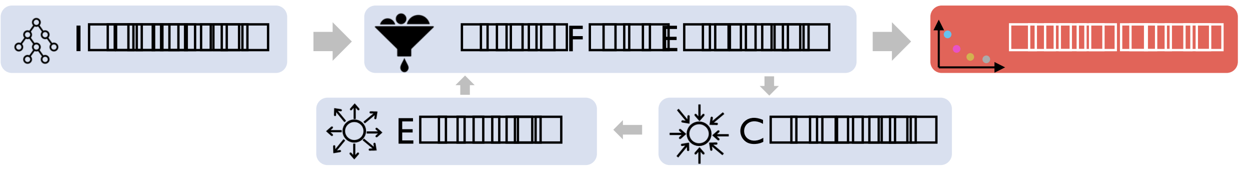

0.85
E1:
A1
E12:
0.85
0.95
E10:
A11
E3:
A4
E4:
A5
E9:
E11:
A12
E11:
A13
0.45
0.65
0.65
E6:
E7:
A8
A9
A10
E14:
A13



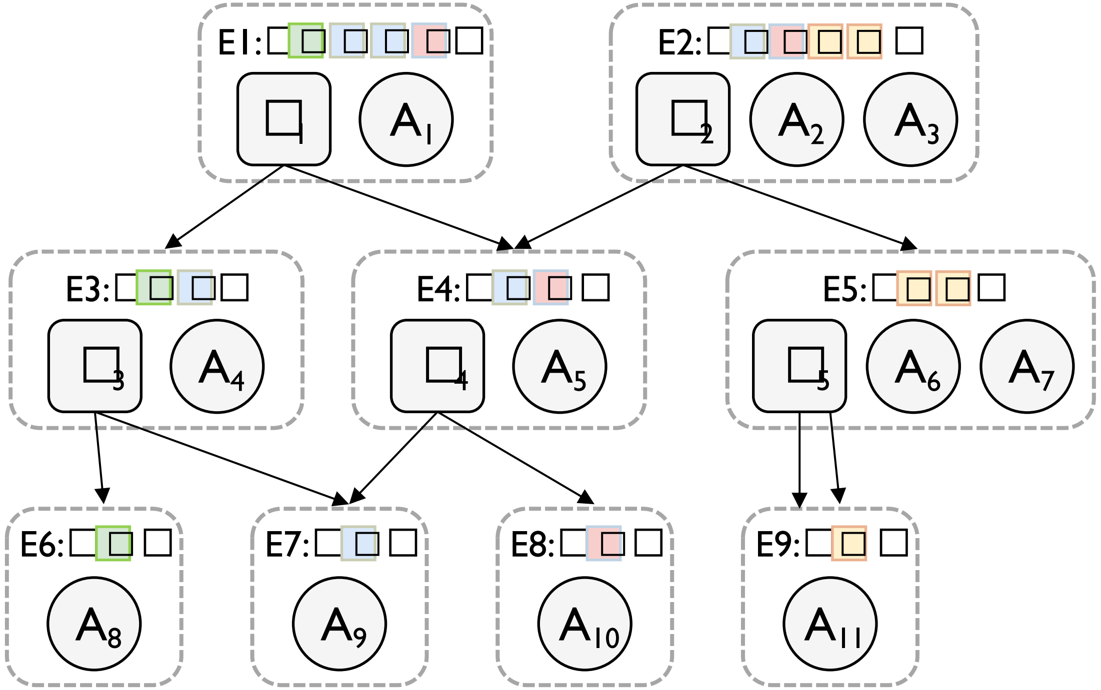
Terminal Conditions



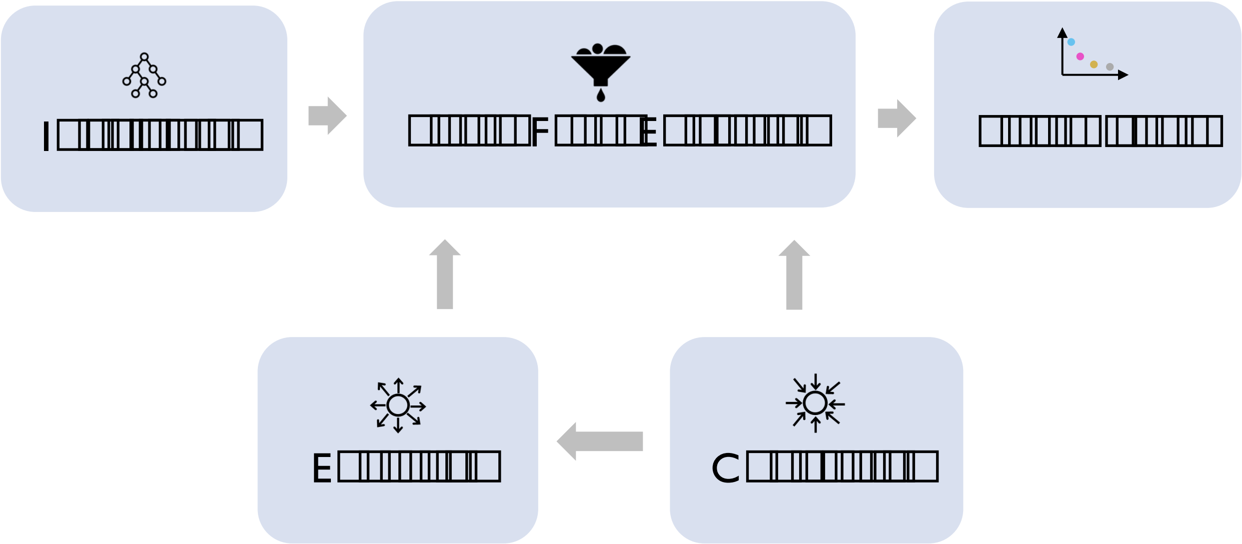




Approach

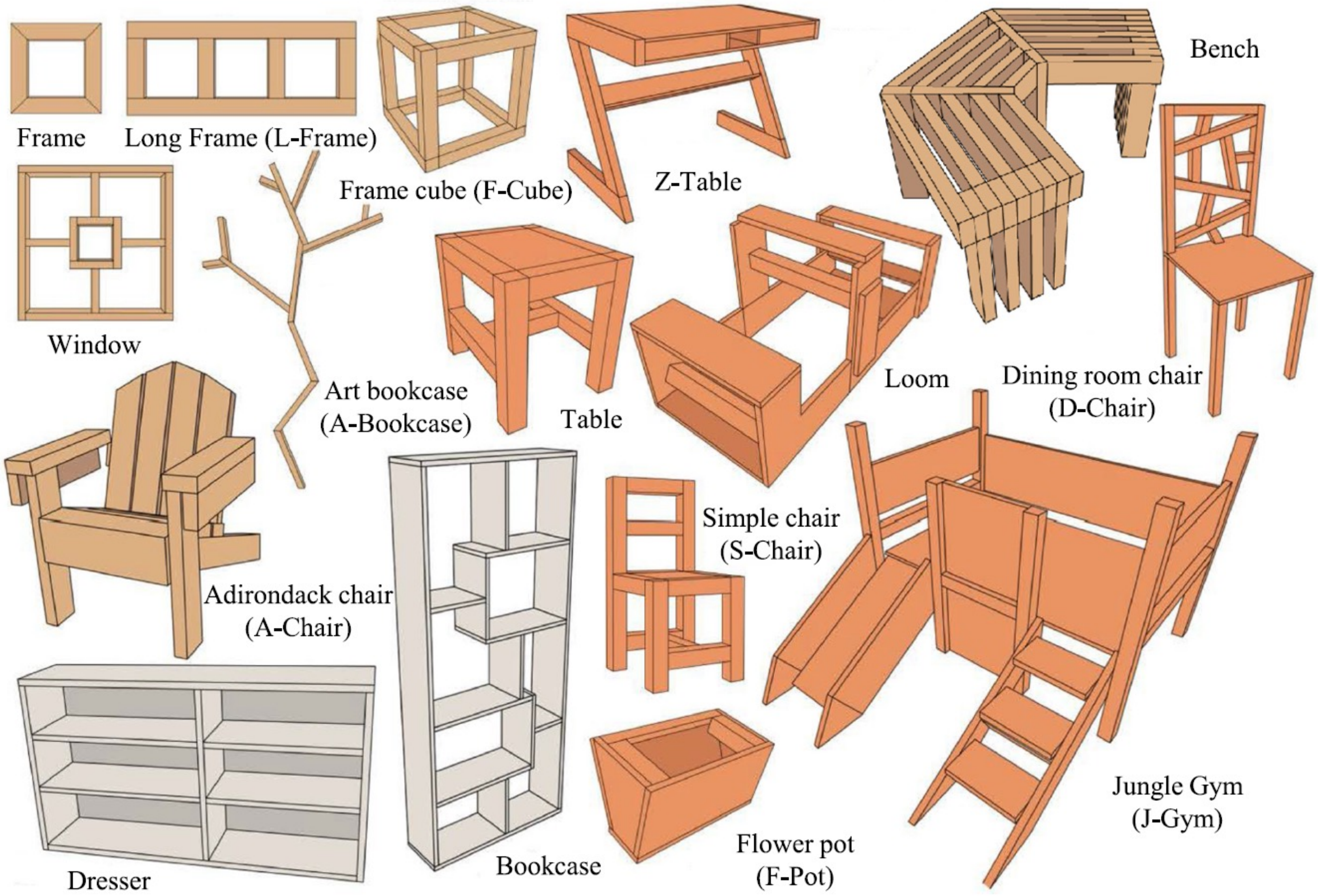


B[illegible]-[illegible]-[illegible] (B[illegible]) E-[illegible]

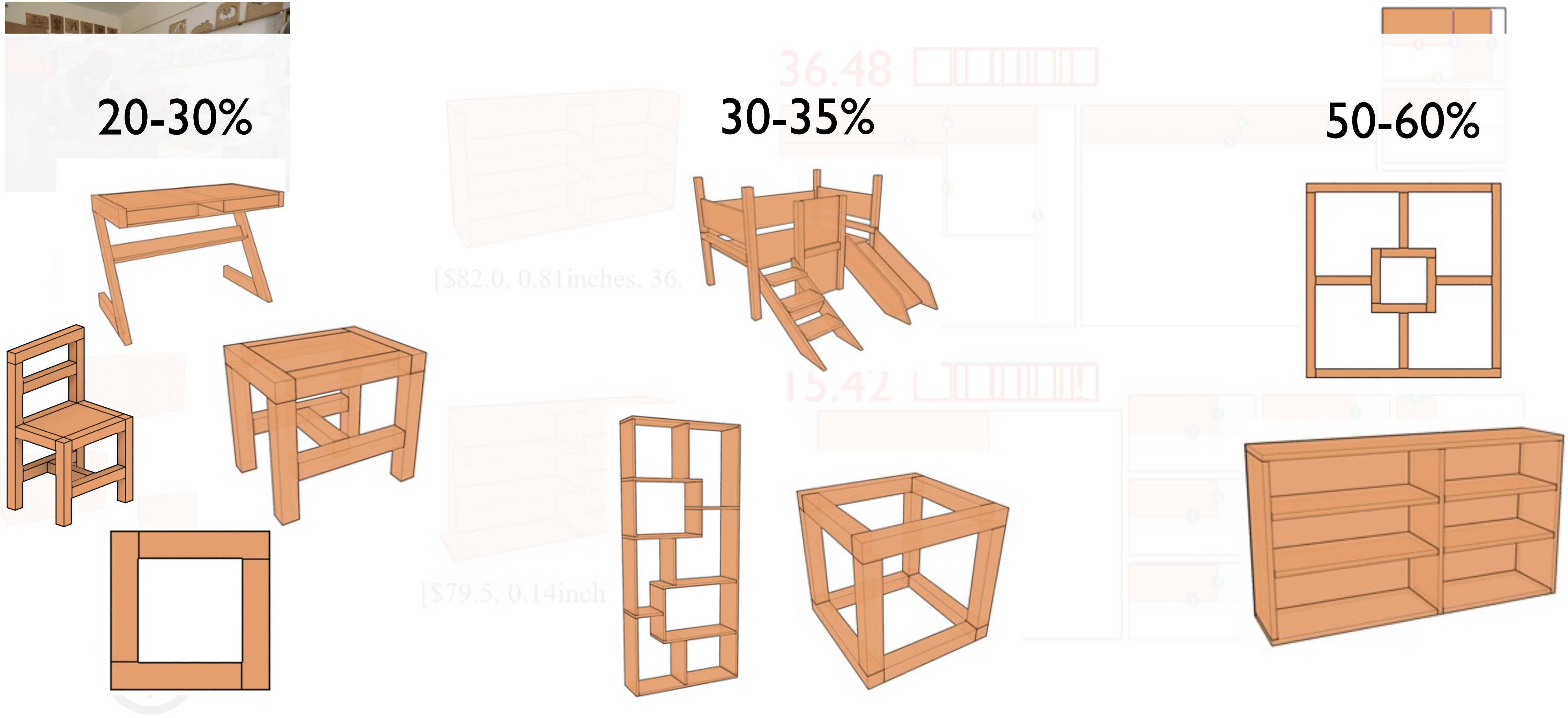


I[illegible] C[illegible]
E[illegible] E-[illegible]

Models


Frame
Long Frame (L-Frame)
Frame cube (F-Cube)
Z-Table
Bench
Window
Art bookcase
(A-Bookcase)
Table
Loom
Dining room chair
(D-Chair)
Adirondack chair
(A-Chair)
Simple chair
(S-Chair)
Jungle Gym
(J-Gym)
Dresser
Bookcase
Flower pot
(F-Pot)

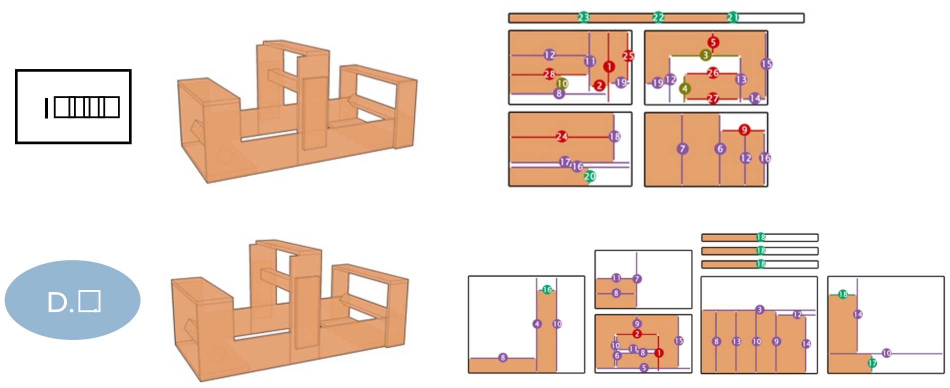
Benefits of Design Exploration



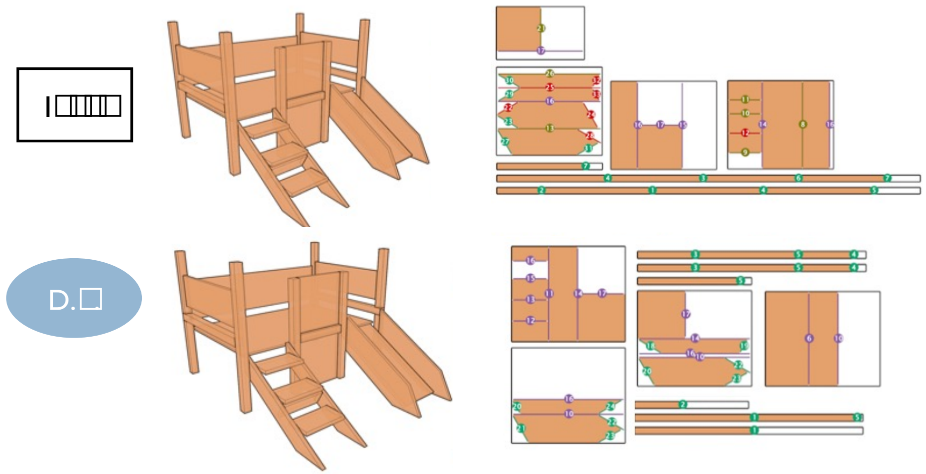
Benefits of Design Exploration

Benefits of Design Exploration

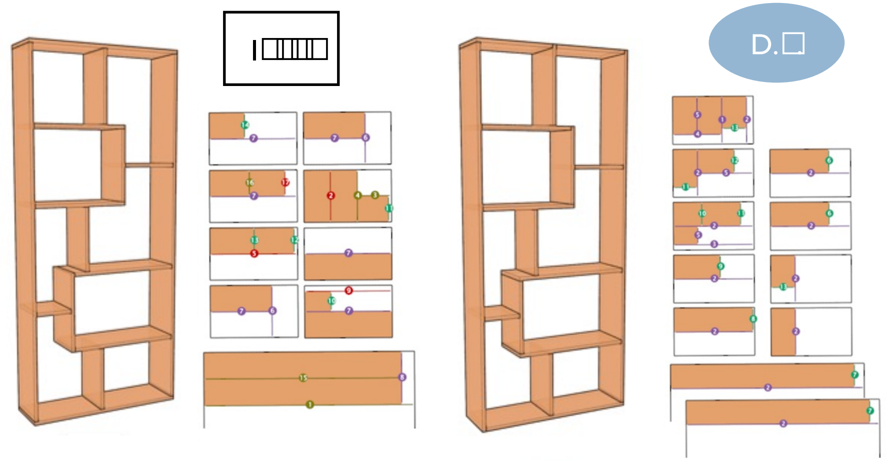
62% [illegible]



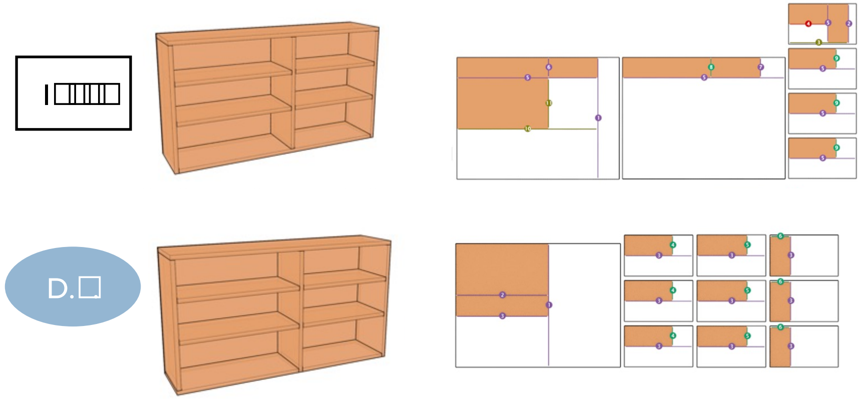
74% [illegible]



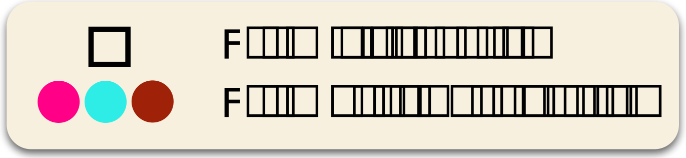
79% [illegible]

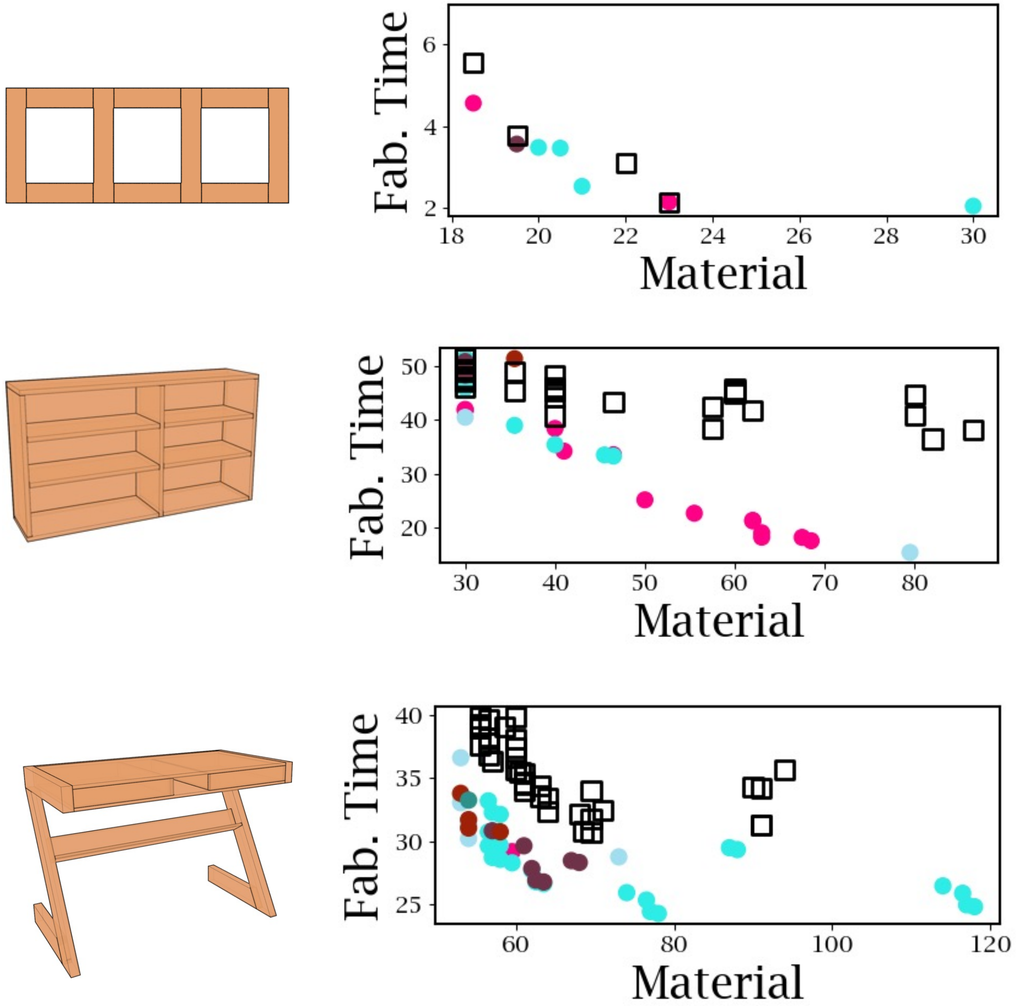


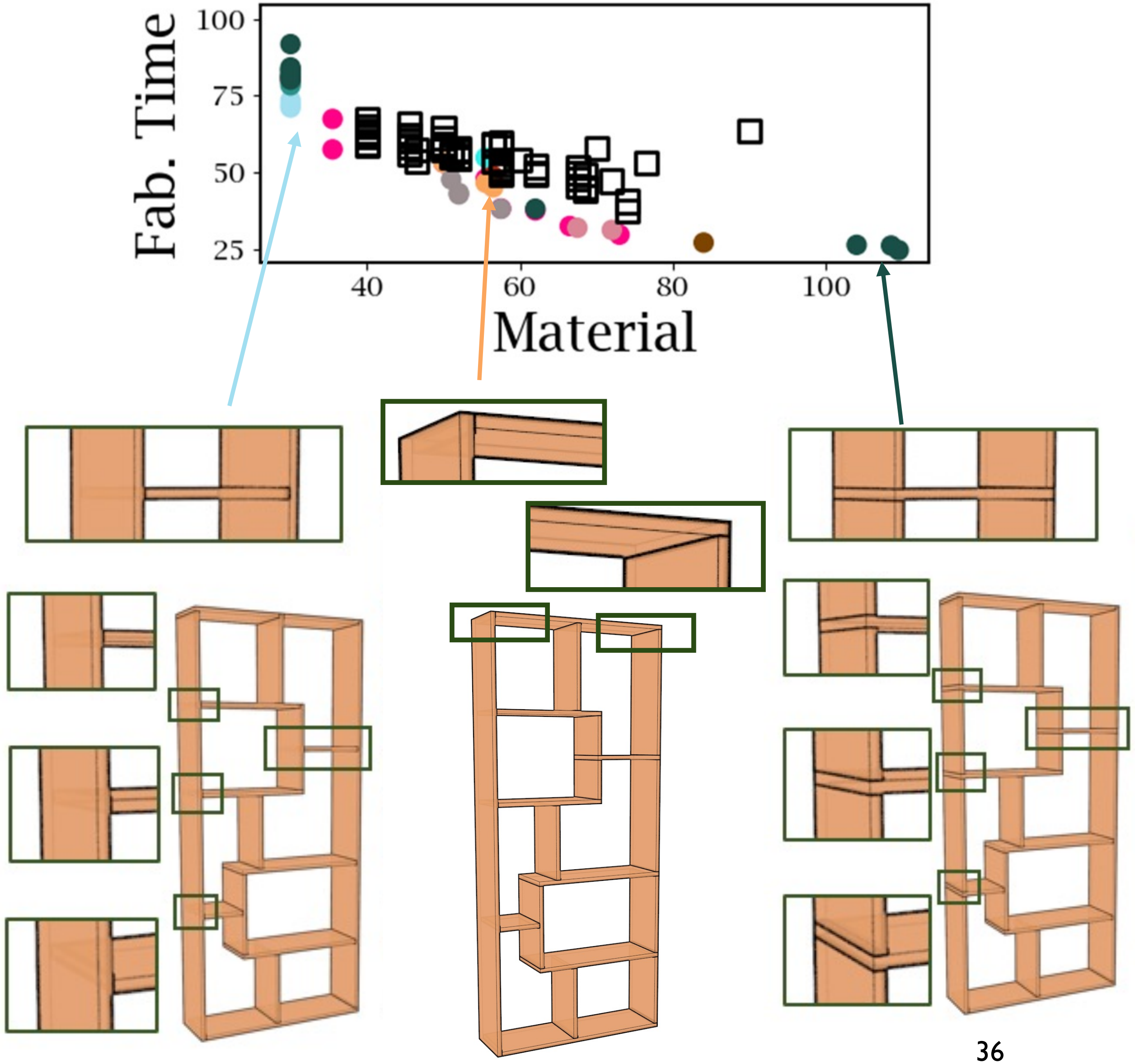
82% [illegible]



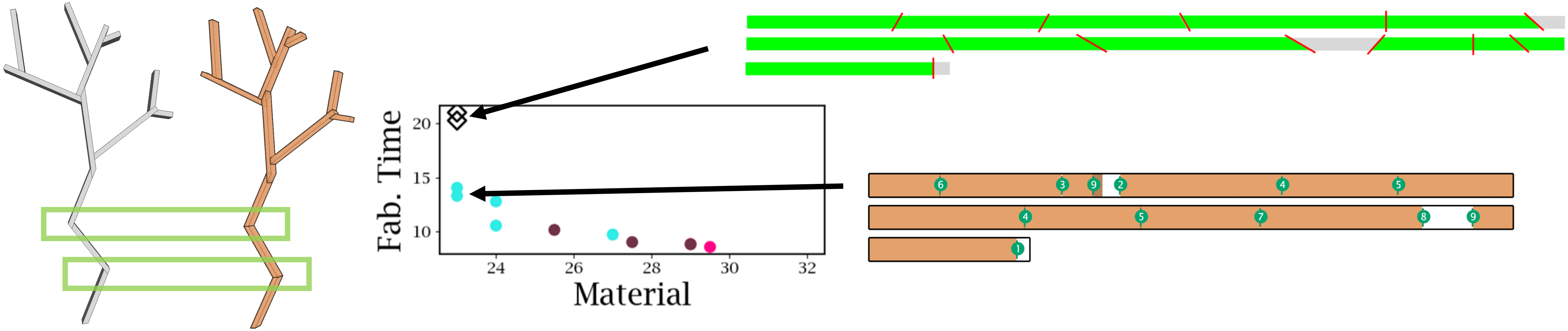
Benefits of Design Exploration



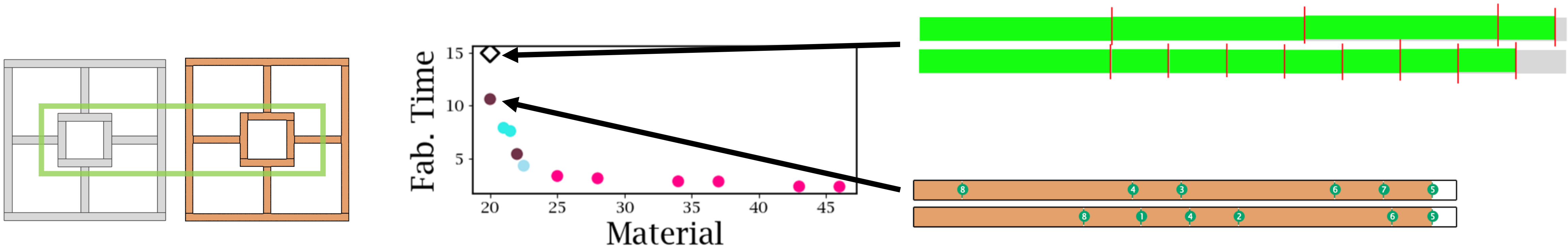




Comparison with Experts



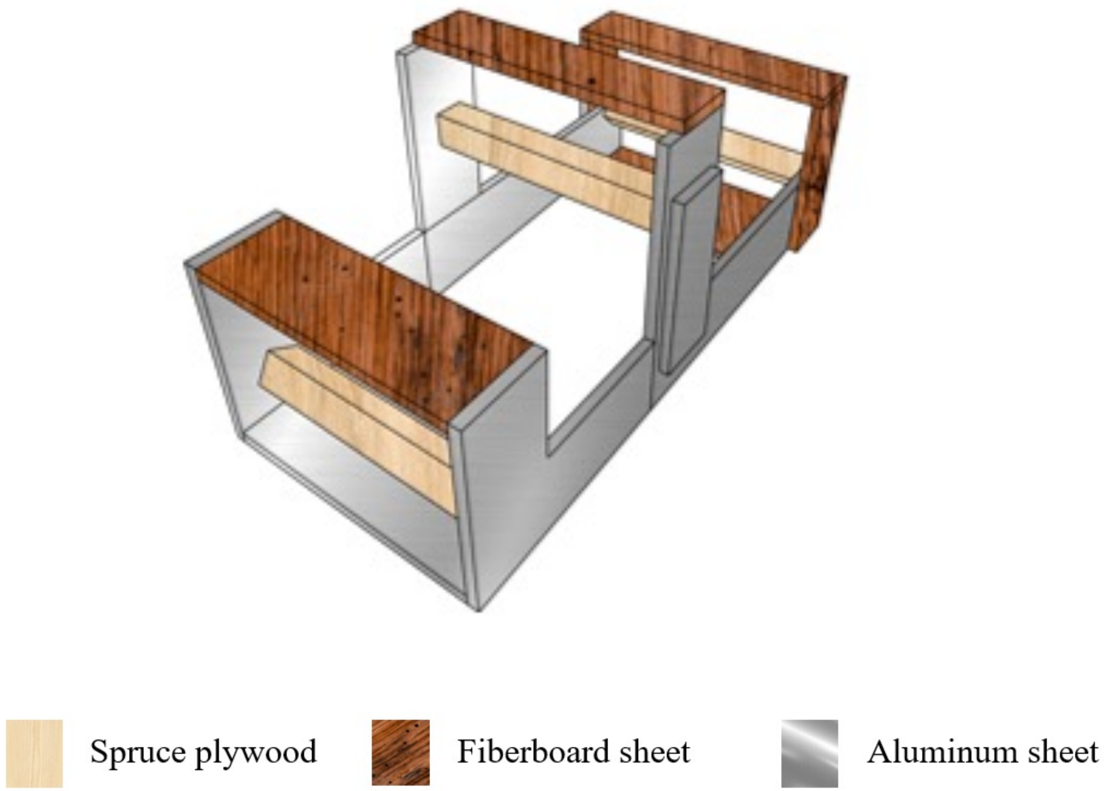
[illegible] [illegible]



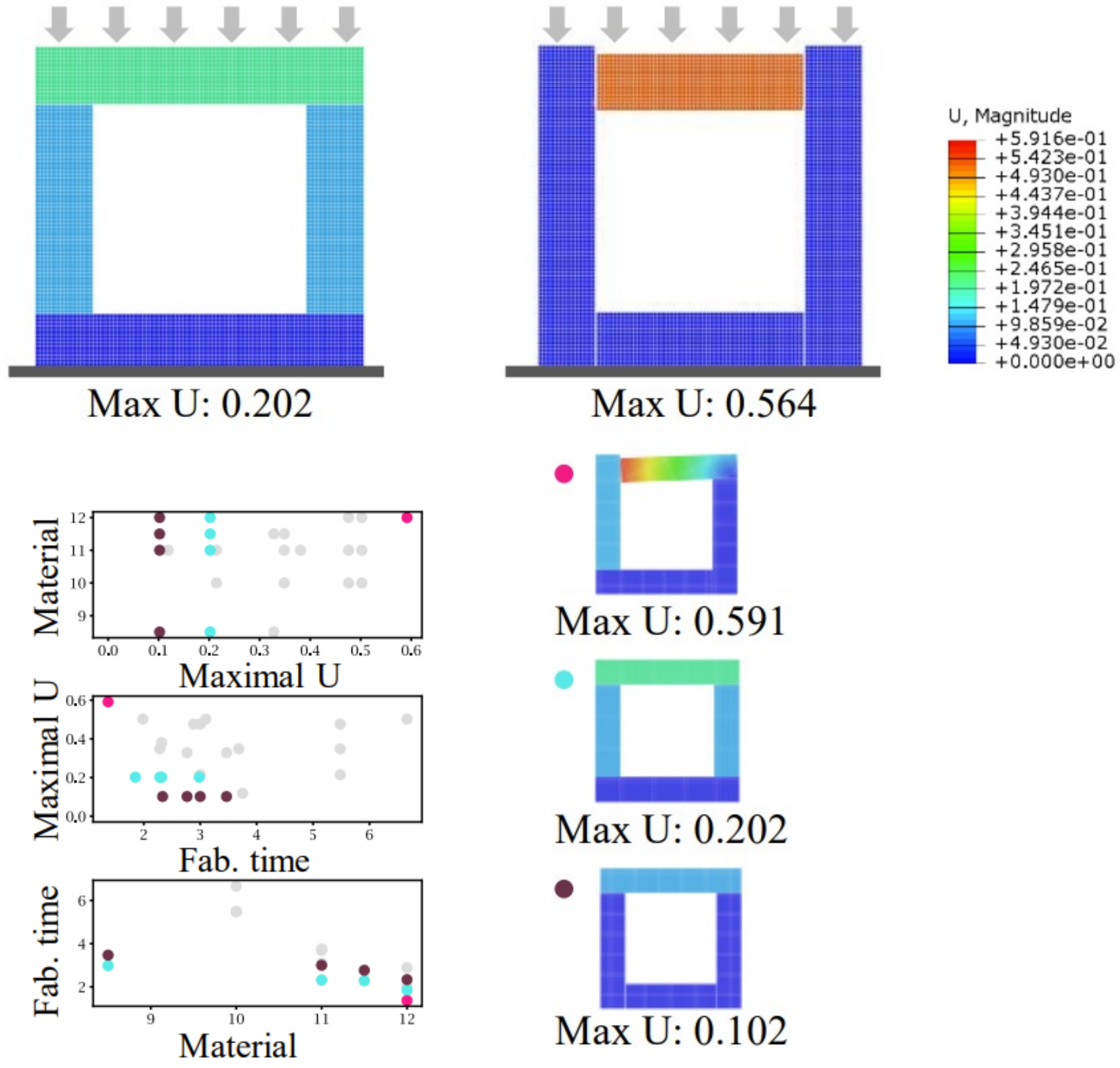
Comparison with Baseline Method

Model	$\lvert\mathcal{D}\rvert$	#EDV	Time (min)	
			Ours	Baseline
Frame	13	8	2.8	6.5
Jungle Gym	54	18	109.0	761.2
Long frame	65	19	8.2	59.7
Table	1140	59	40.8	612.8
Window	10463	116	131.7	2050.0

E[redacted]



Spruce plywood
Fiberboard sheet
Aluminum sheet



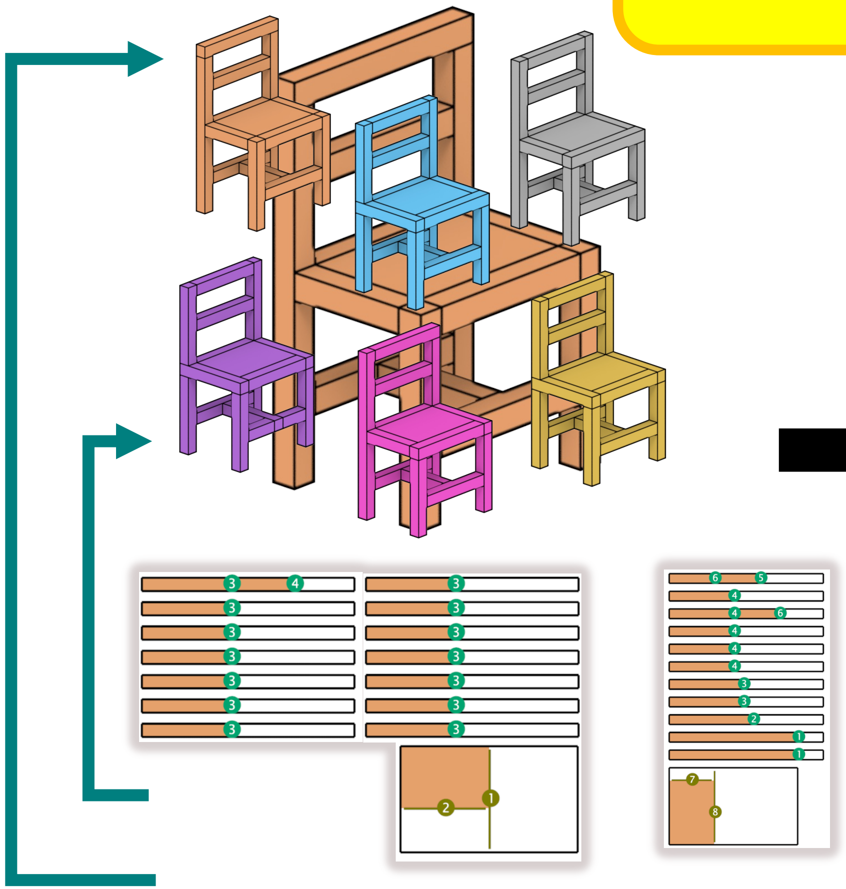
Max U: 0.202
Max U: 0.564
U, Magnitude
+5.916e-01
+5.423e-01
+4.930e-01
+4.437e-01
+3.944e-01
+3.451e-01
+2.958e-01
+2.465e-01
+1.972e-01
+1.479e-01
+9.859e-02
+4.930e-02
+0.000e+00
Material
Maximal U
Maximal U
Fab. time
Fab. time
Material
Max U: 0.591
Max U: 0.202
Max U: 0.102

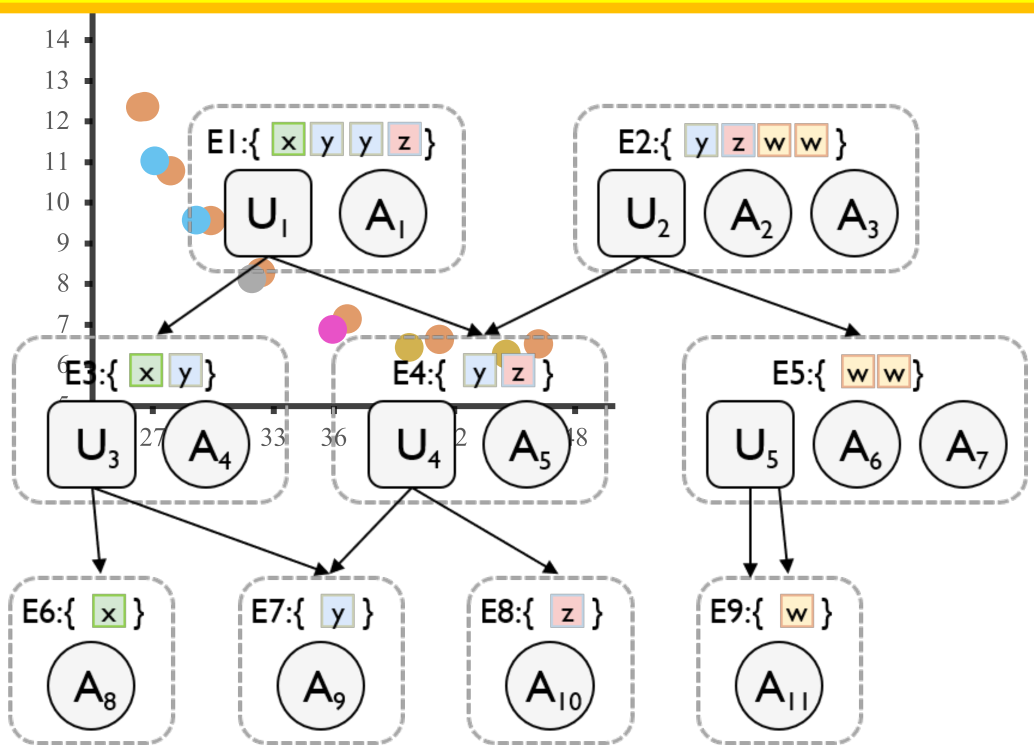
Future Work

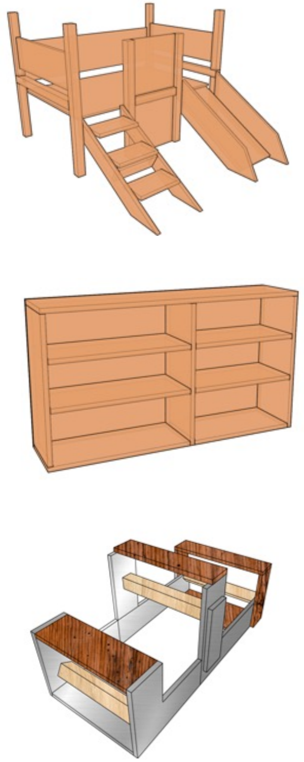
- Continuous design variations
- Application of the ICEE strategy
- Objective extension: appearance, ease of assembly…
- Learning-based method to speedup the Pareto front extraction phase
  - Predict the objective metrics of an arrangement

C[redacted]

D[redacted]!







F[redacted]

B[redacted]