

# Planning With First-Order Representations

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FOPC Inference and Planning

Douglas H. Fisher, Ph.D.

# First-Order Planning, Part I

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Representation of operators: A PREcondition list and an EFFects list

**pickup(?x):**        PRE: ONTABLE(?x), CLEAR(?x), HANDEEMPTY  
                      EFF: ~ONTABLE(?x), ~CLEAR(?x), ~HANDEEMPTY,  
                              HOLDING(?x)

**putdown(?x):**        PRE: HOLDING(?x)  
                      EFF: ~HOLDING(?x),  
                              ONTABLE(?x), CLEAR(?x), HANDEEMPTY

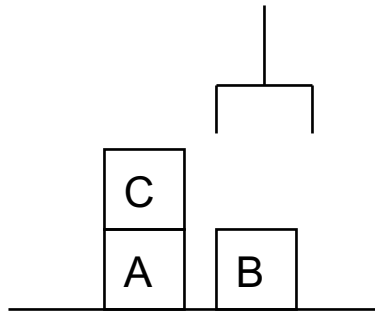
**stack(?x, ?y):**        PRE: HOLDING(?x), CLEAR(?y)  
                      EFF: ~HOLDING(?x), ~CLEAR(?y),  
                              HANDEEMPTY, ON(?x, ?y), CLEAR(?x)

**unstack(?x, ?y):**    PRE: HANDEEMPTY, CLEAR(?x), ON(?x,?y)  
                      EFF: ~HANDEEMPTY, ~CLEAR(?x), ~ON(?x,?y),  
                              HOLDING(?x), CLEAR(?y)

# First-Order Planning, Part II

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Tweak: the following slides represent *one* path in a search for a plan



ON(C,A)  
ONTAB(A)  
ONTAB(B)  
CLEAR(B)  
CLEAR(C)  
HANDEEMPTY

**Initial state**



ON(A,B)  
ON(B,C)

**Goal spec**

# First-Order Planning, Part III

Why was the Stack operator chosen? Because it contained an effect,  $ON(?x, ?y)$ , that unified with a subgoal,  $ON(A, B)$

ON(C,A)  
ONTAB(A)  
ONTAB(B)  
CLEAR(B)  
CLEAR(C)  
HANDEEMPTY

STACK(A,B)	
CLEAR(B) HOLDING(A)	HANDEEMPTY ON(A,B) ~CLEAR(B) ~HOLDING(A) CLEAR(A)

Causal link (protected)  
No operator can be placed between STACK(A,B) and goal that undoes (clobbers) the protected condition,  $ON(A,B)$ .

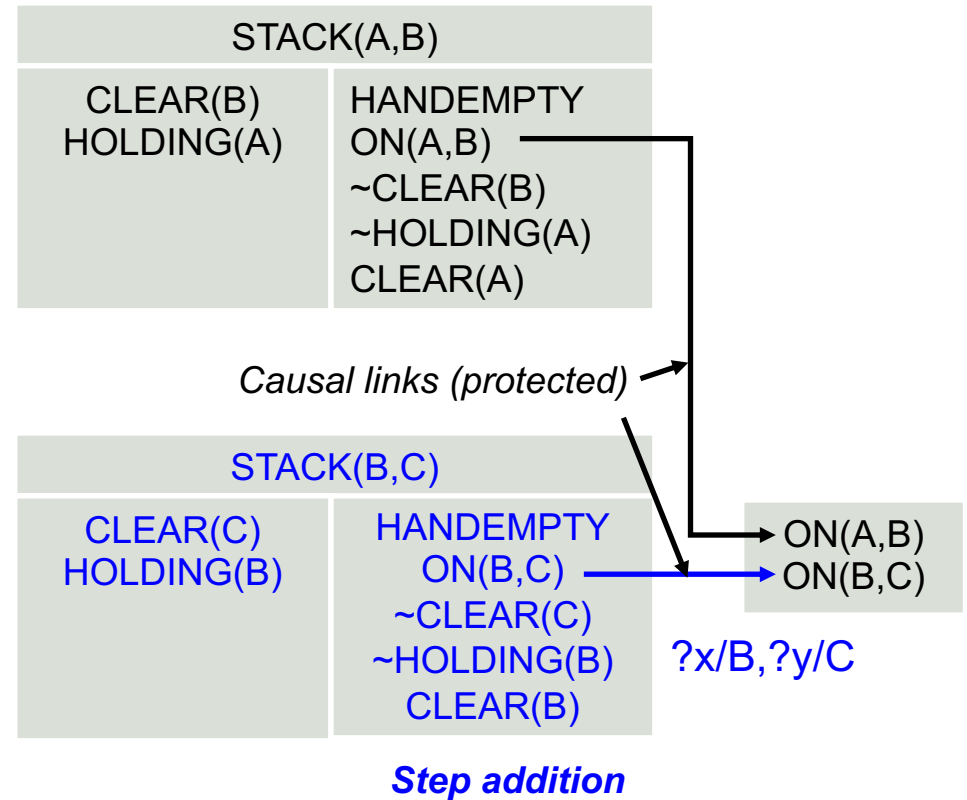
Step addition

?x/A, ?y/B

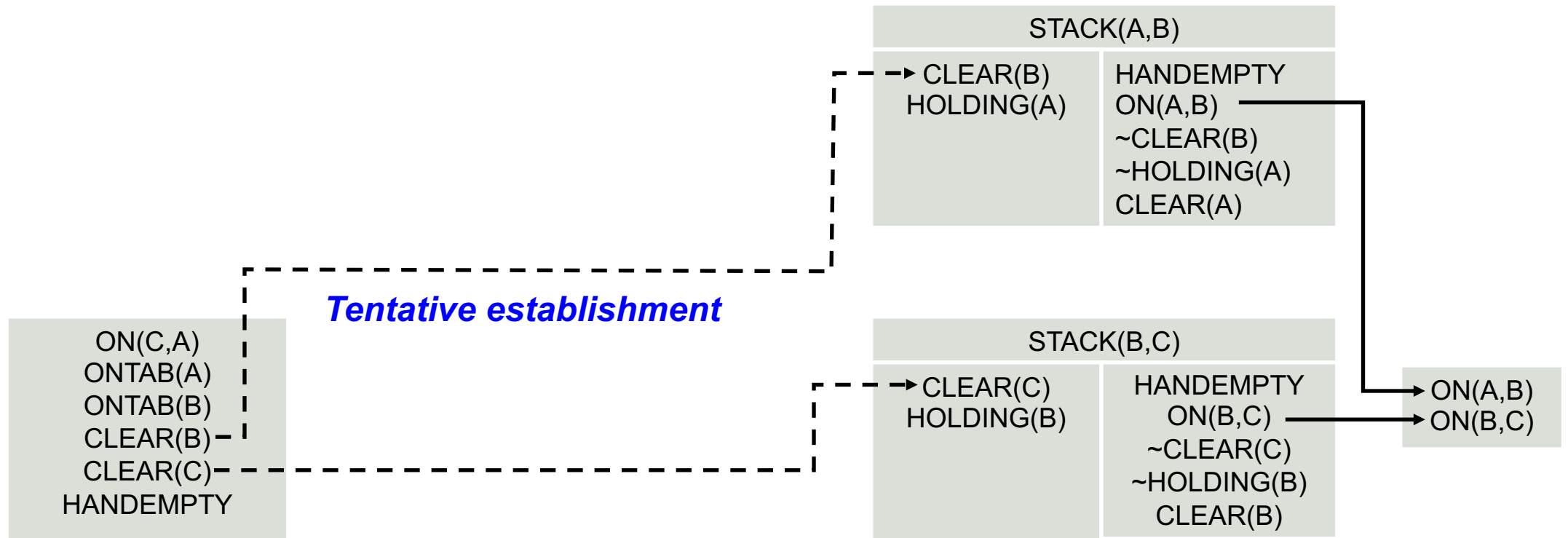
ON(A,B)  
ON(B,C)

# First-Order Planning, Part IV

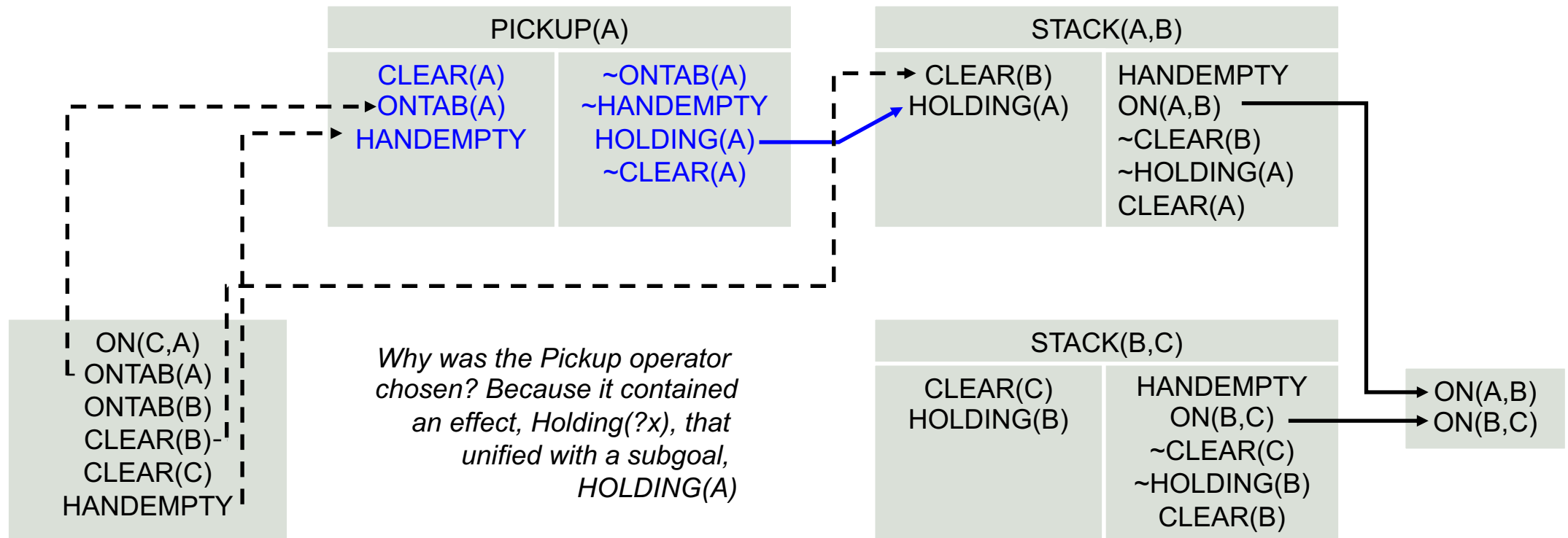
ON(C,A)  
ONTAB(A)  
ONTAB(B)  
CLEAR(B)  
CLEAR(C)  
HANDEEMPTY



# First-Order Planning, Part V

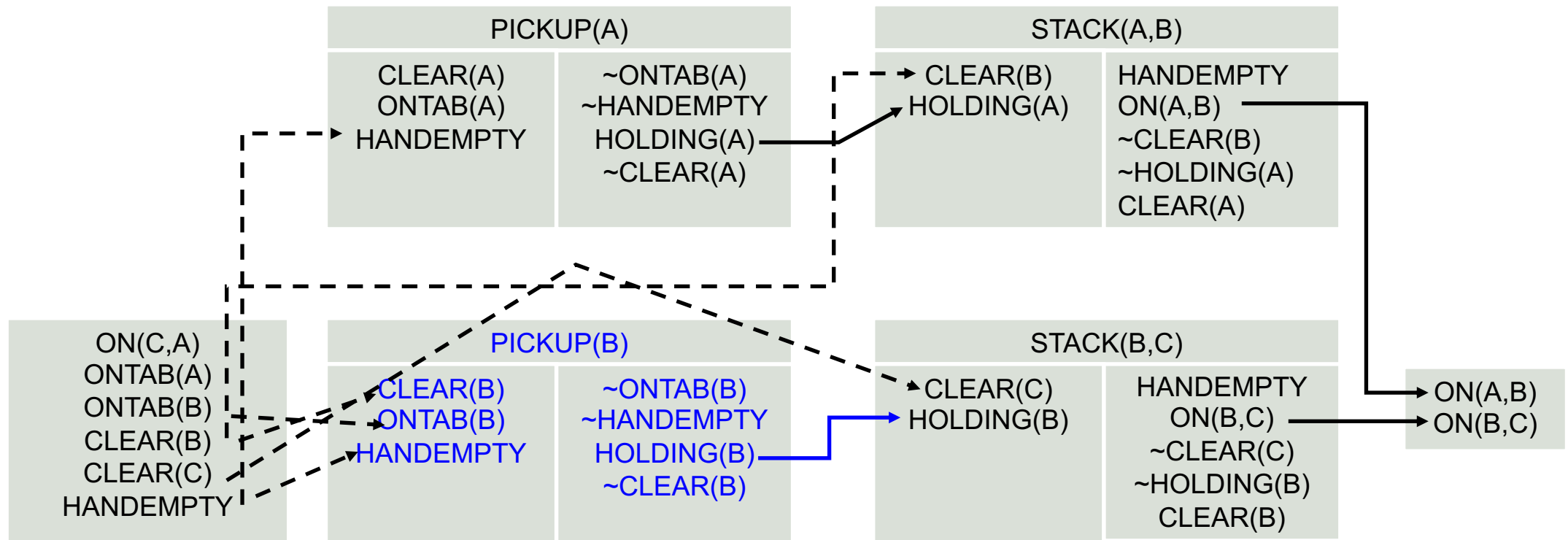


# First-Order Planning, Part VI



*Step addition and tentative establishment*

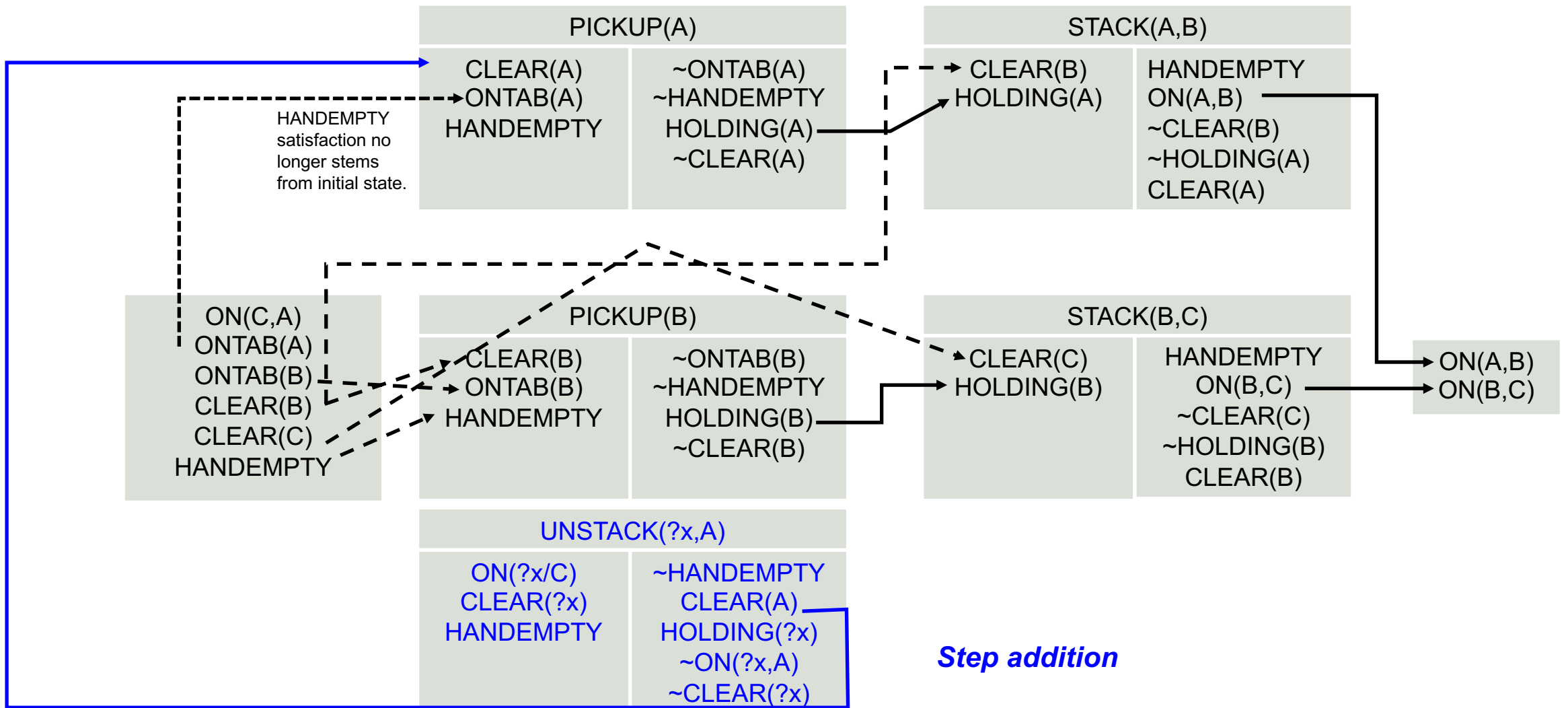
# First-Order Planning, Part VII

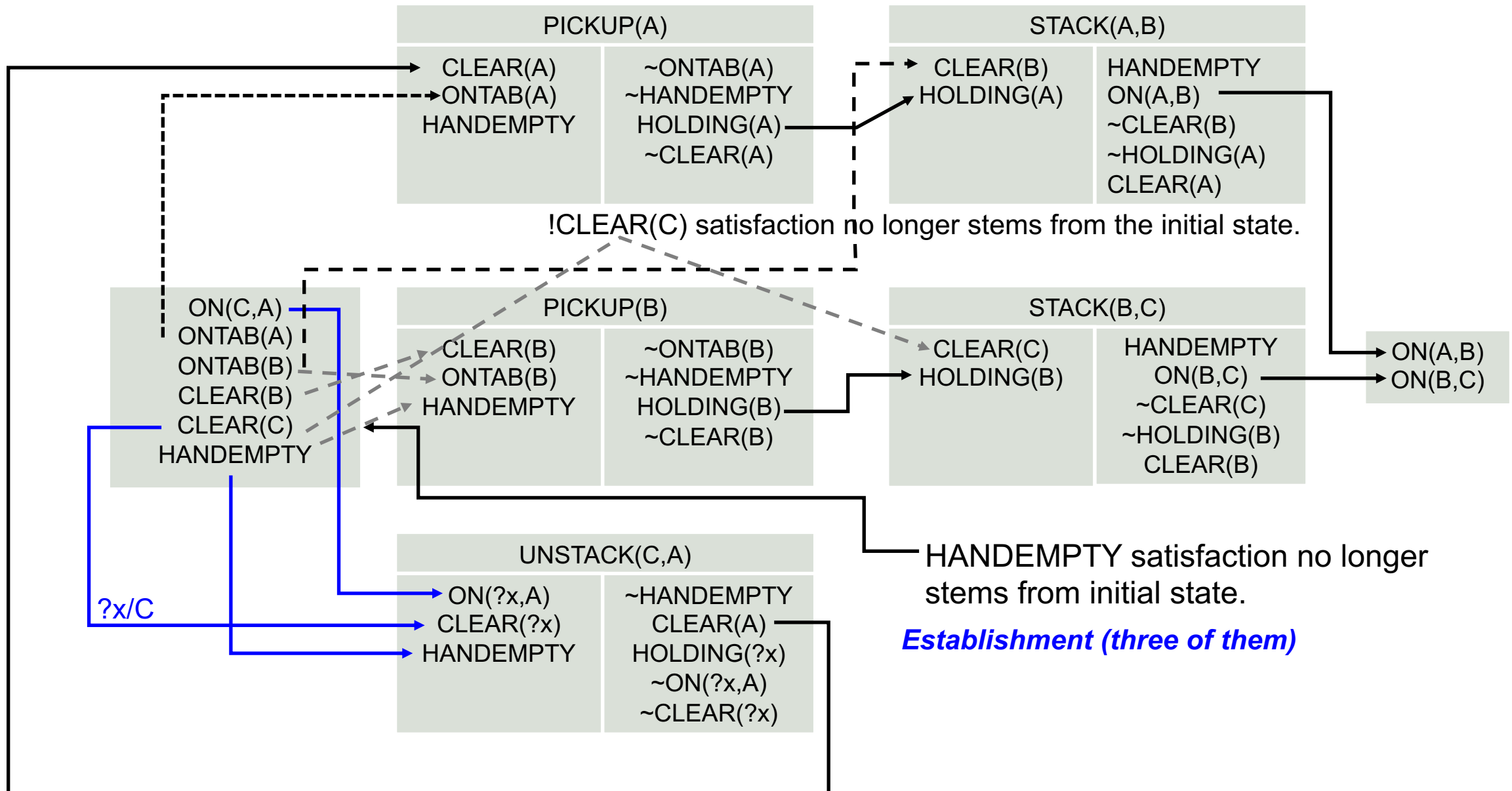


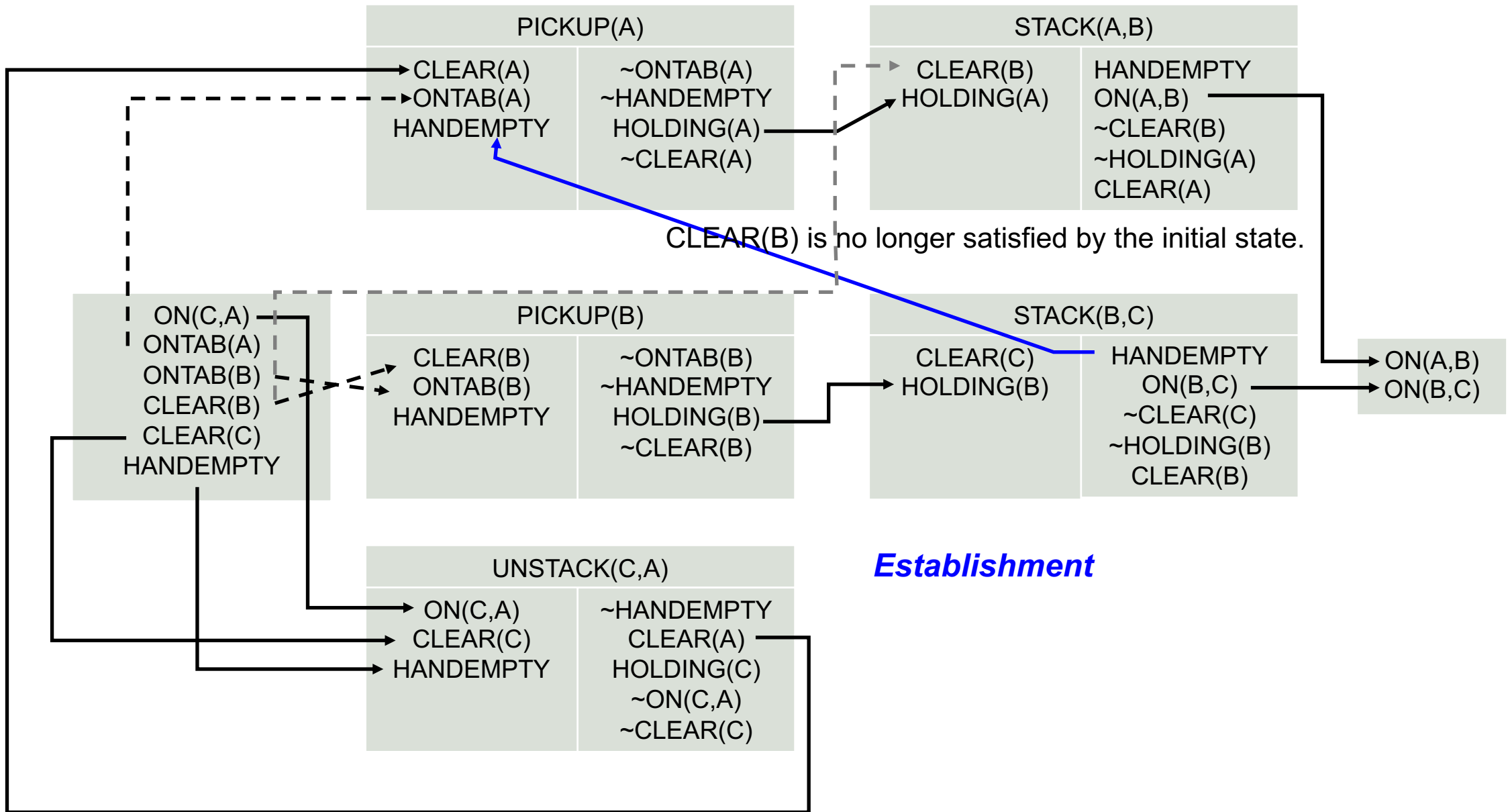
*Step addition and tentative establishment*

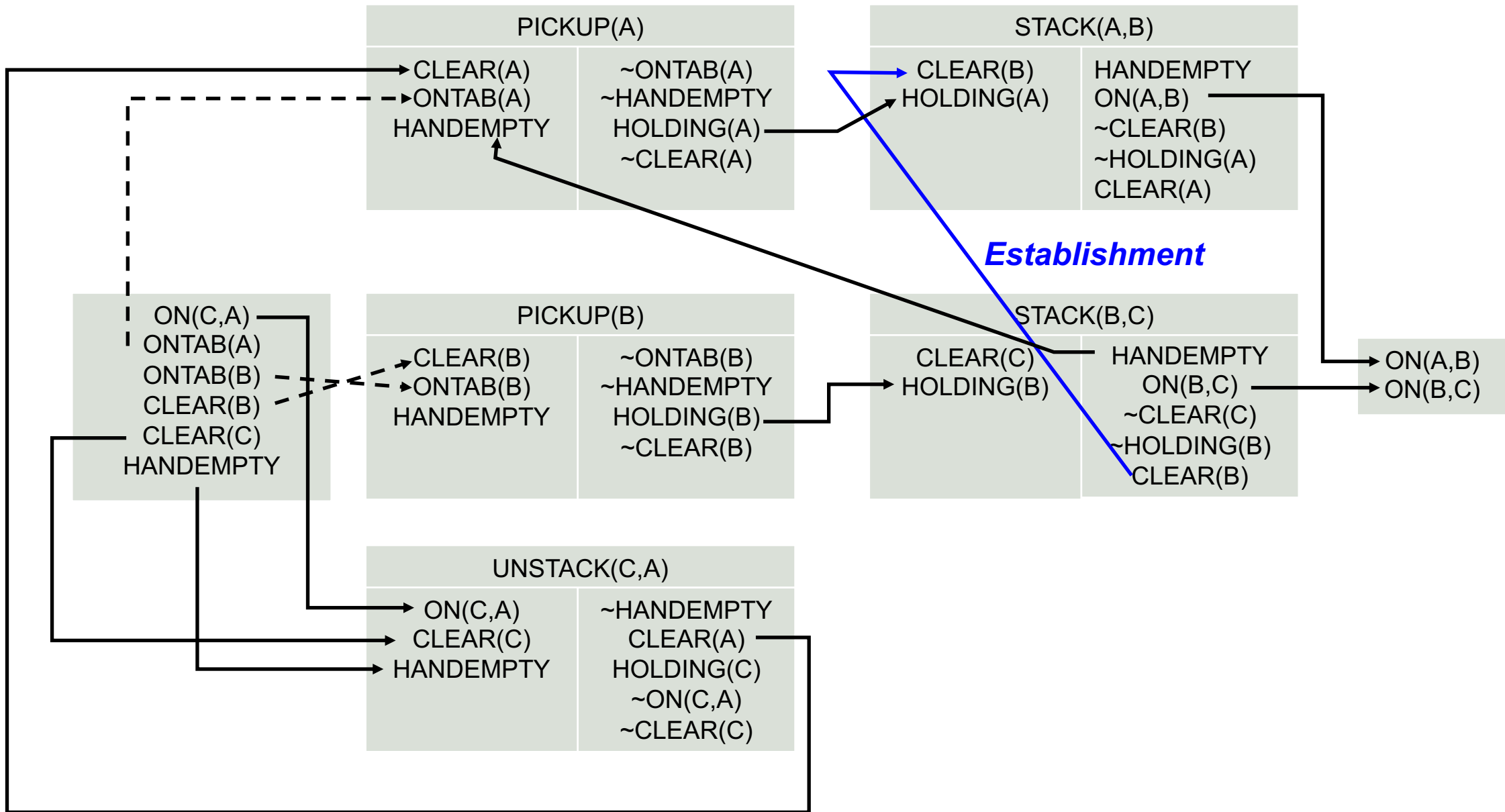


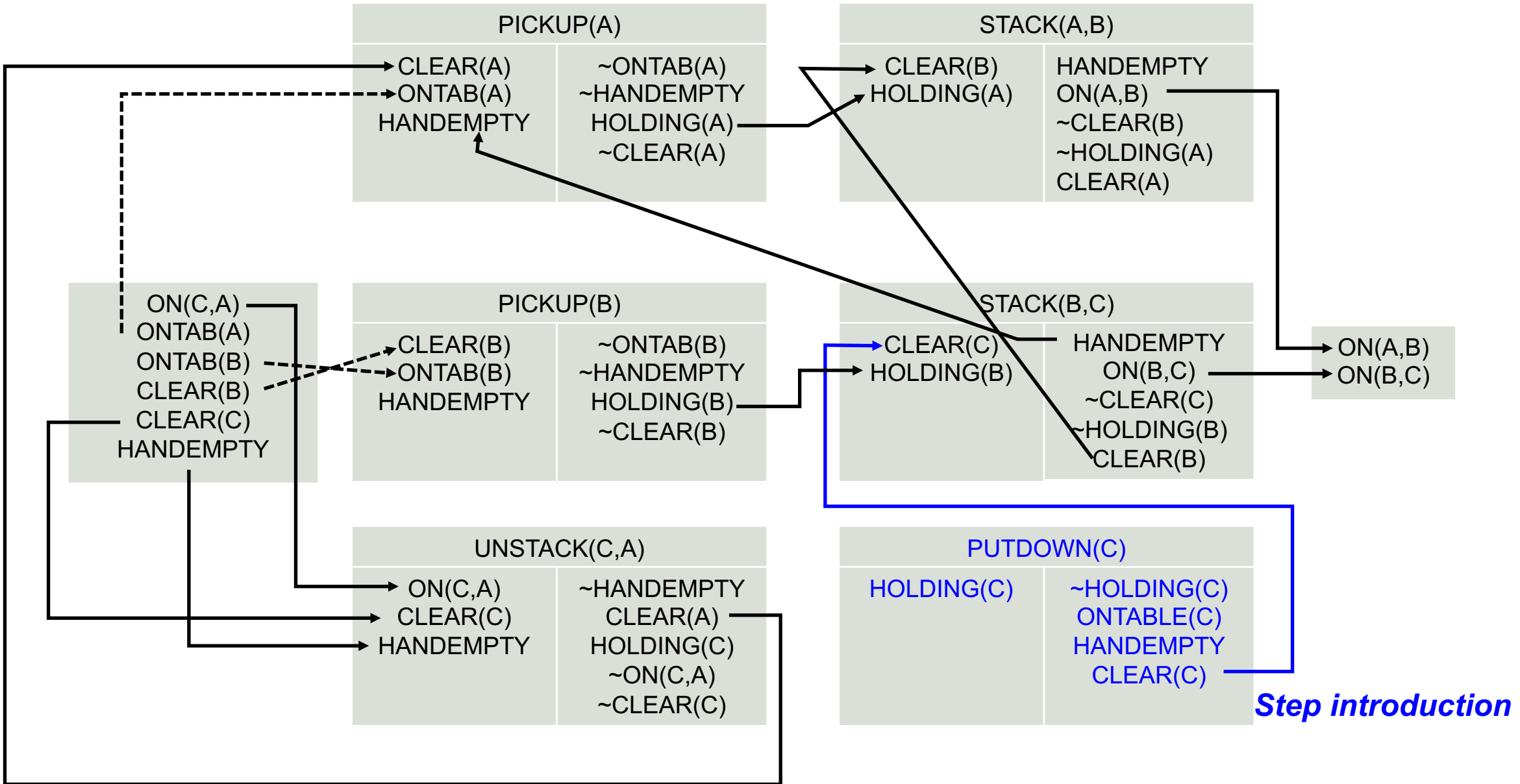
# First-Order Planning, Part VIII

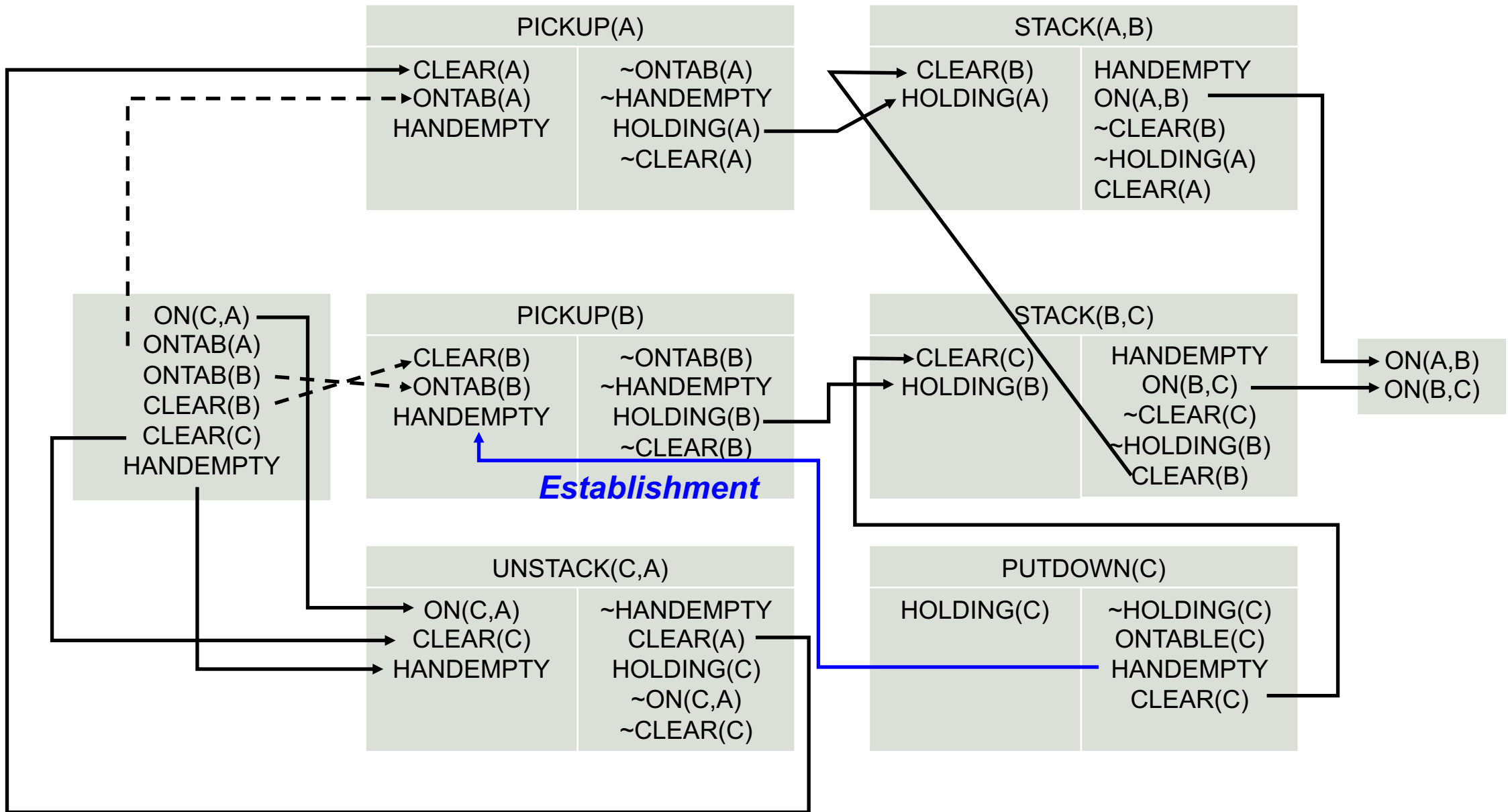


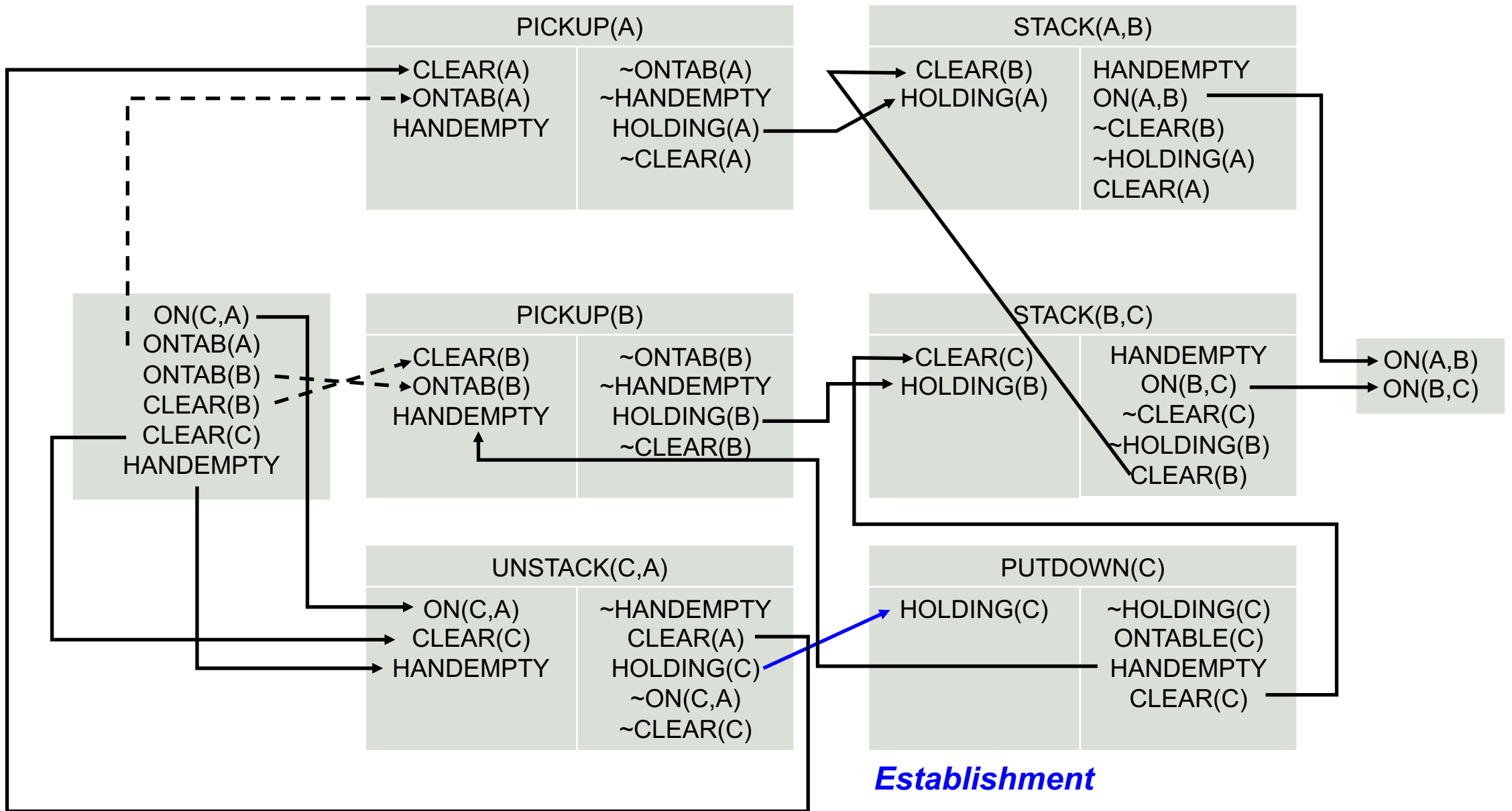




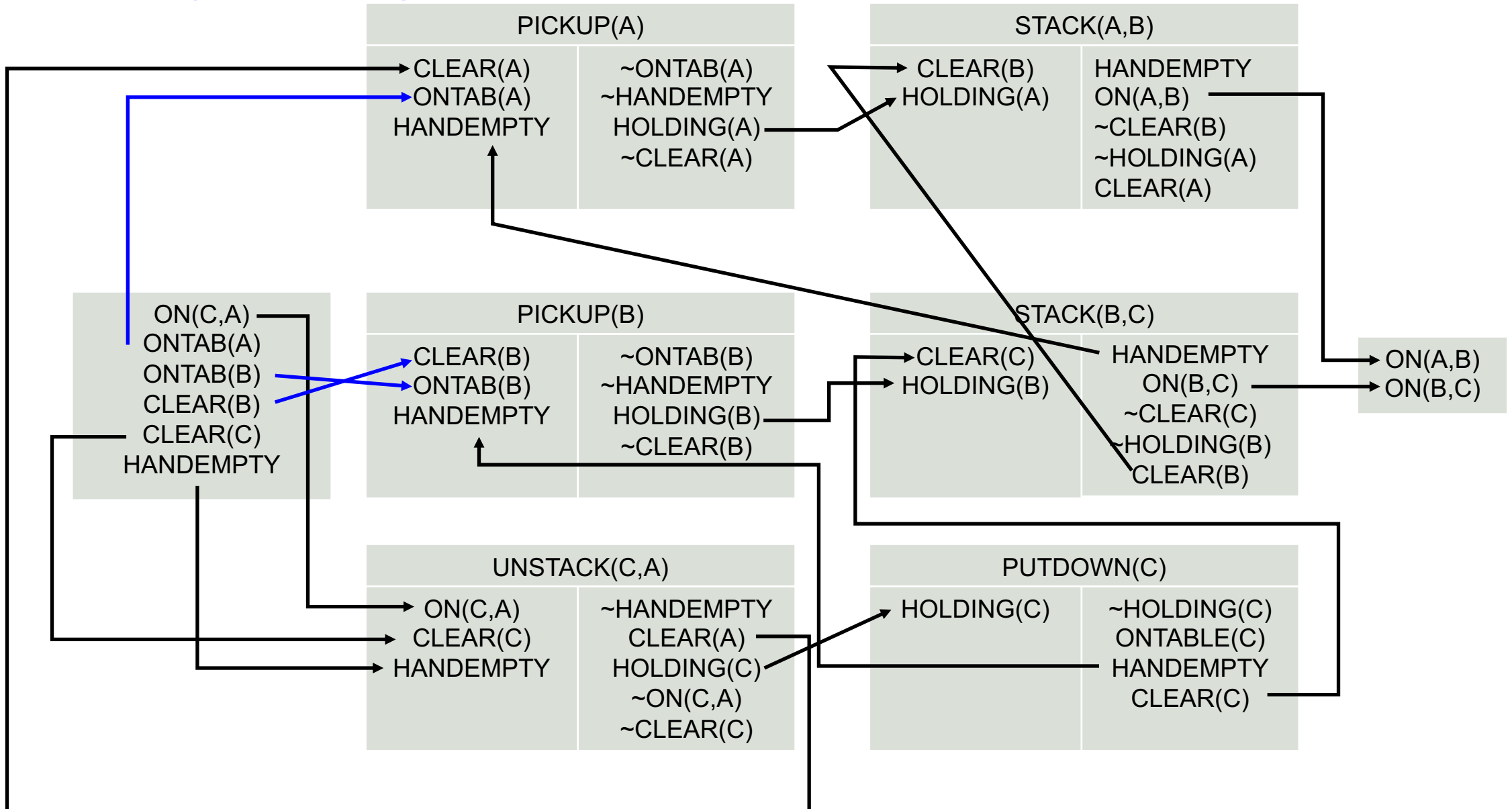






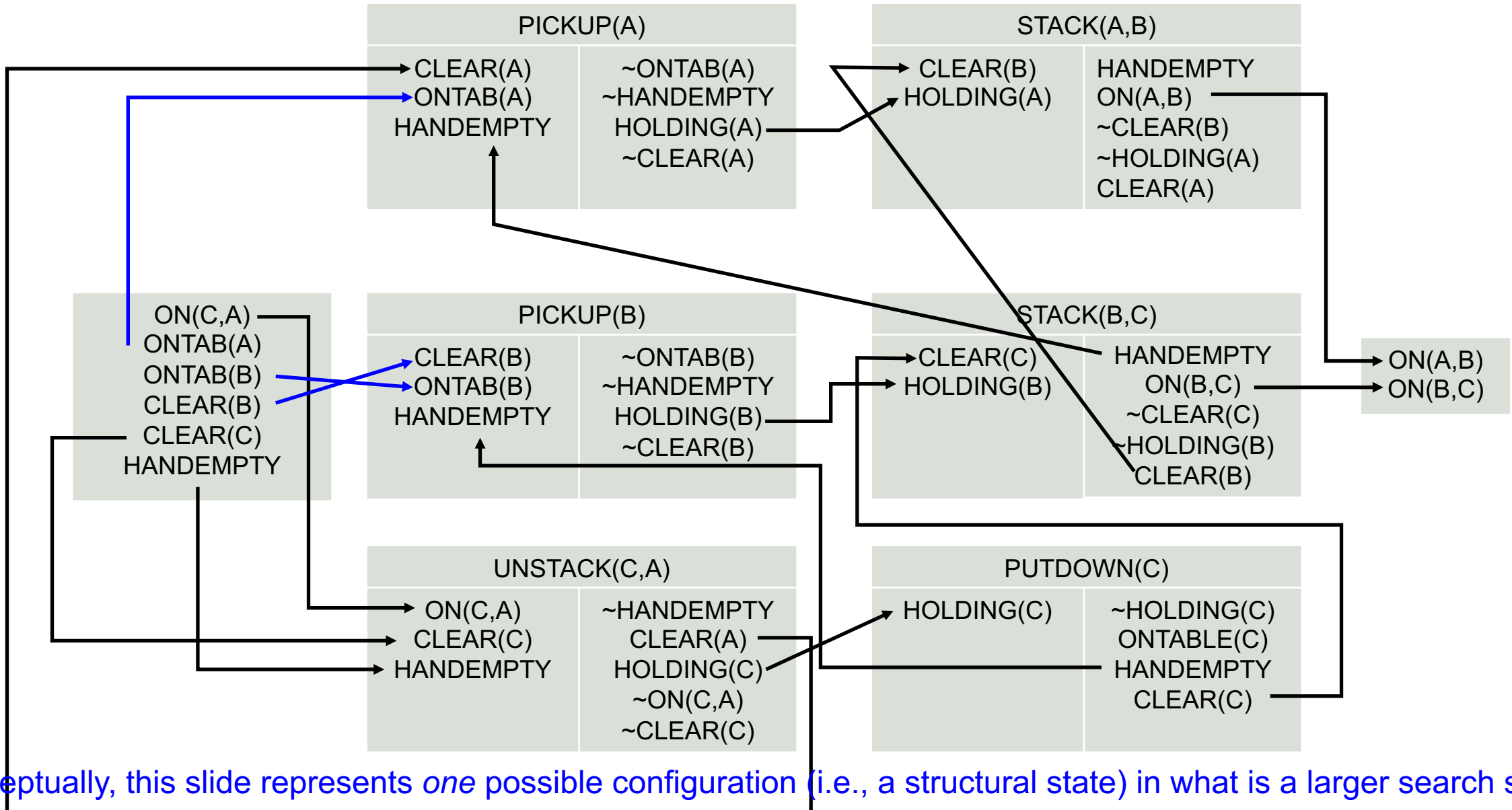


## Establishment (three of them)



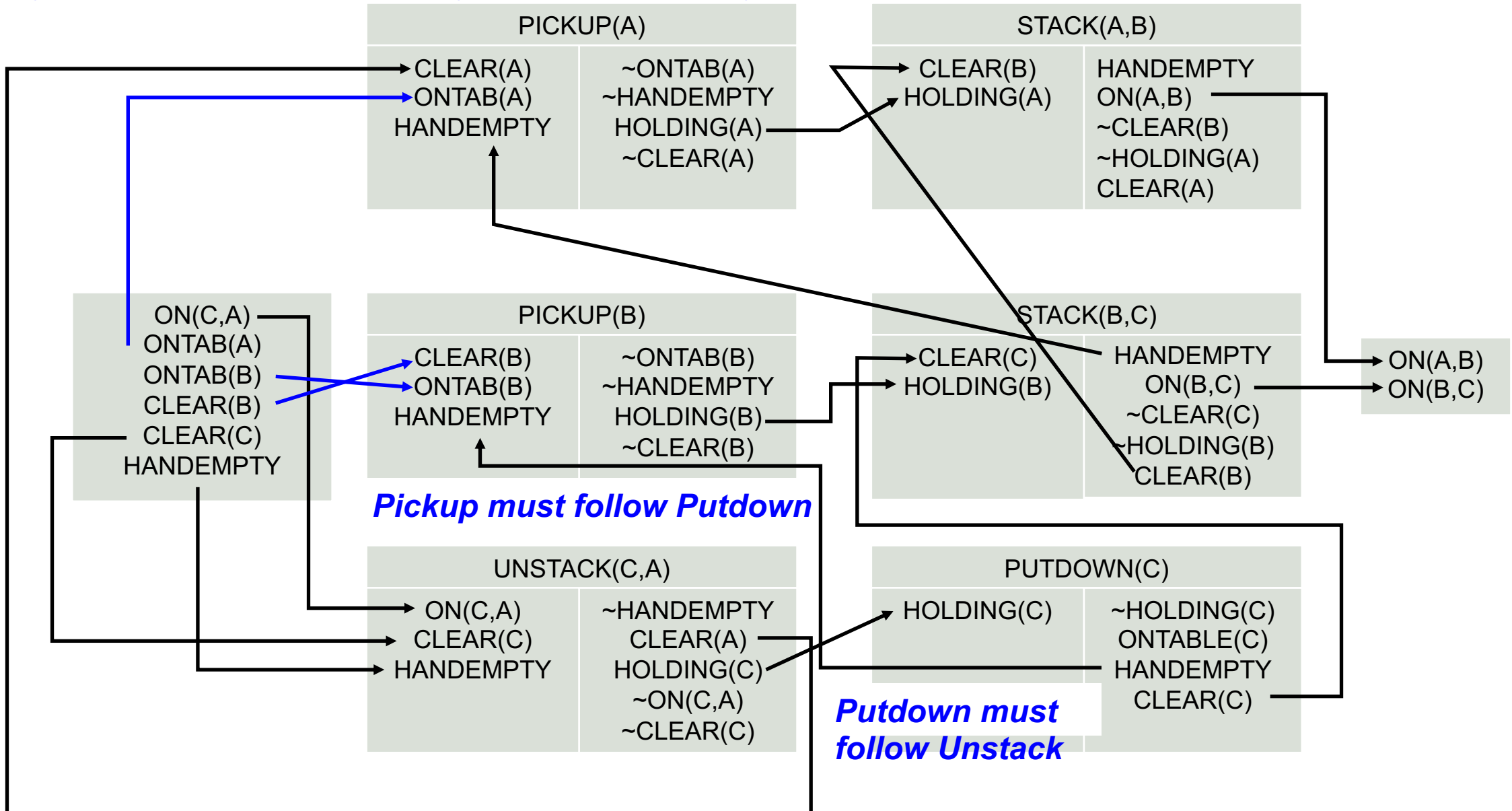


Study the dependencies carefully – in this case they dictate one possible plan



Conceptually, this slide represents *one* possible configuration (i.e., a structural state) in what is a larger search space

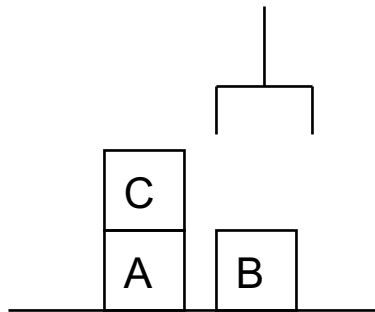
*Study the dependencies carefully – in this case they dictate one possible plan*



# First-Order Planning

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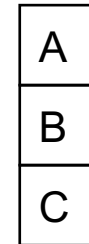
Tweak: the following slides represent *one* path in a search for a plan



ON(C,A)  
ONTAB(A)  
ONTAB(B)  
CLEAR(B)  
CLEAR(C)  
HANDEEMPTY

**Initial state**

Unstack(C,A) → Putdown(C) → Pickup(B) → Stack(B,C) → Pickup(A) → Stack(A,B)

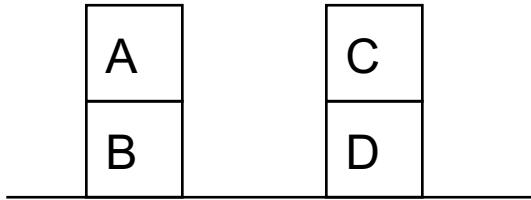
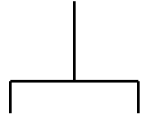


ON(A,B)  
ON(B,C)

**Goal spec**

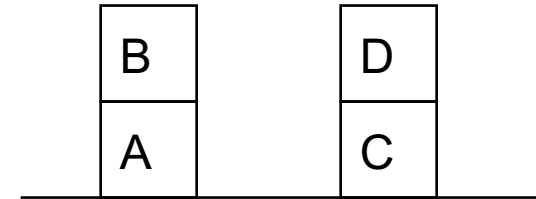
# First-Order Planning, Part I

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Initial state

ON(A,B)  
ONTAB(B)  
CLEAR(A)  
ON(C,D)  
ONTAB(D)  
CLEAR(C)  
HANDEEMPTY



Goal spec

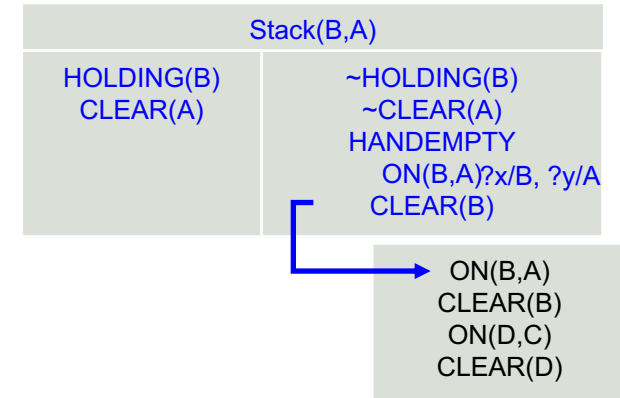
ON(B,A)  
CLEAR(B)  
ON(D,C)  
CLEAR(D)

# First-Order Planning, Part II

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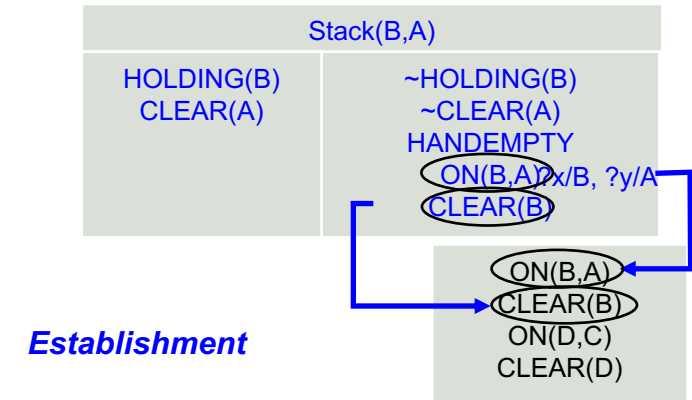
ON(A,B)  
ONTAB(B)  
CLEAR(A)  
ON(C,D)  
ONTAB(D)  
CLEAR(C)  
HANDEEMPTY

*Step addition*



# First-Order Planning, Part III

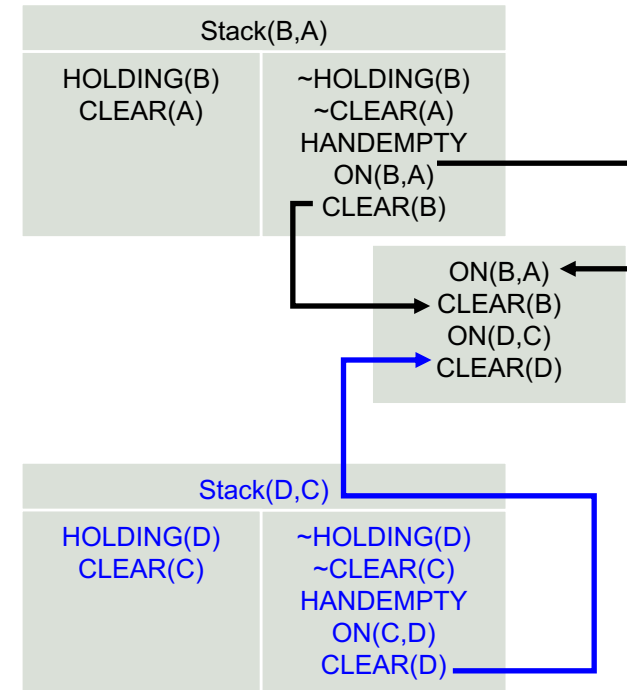
ON(A,B)  
ONTAB(B)  
CLEAR(A)  
ON(C,D)  
ONTAB(D)  
CLEAR(C)  
HANDEEMPTY



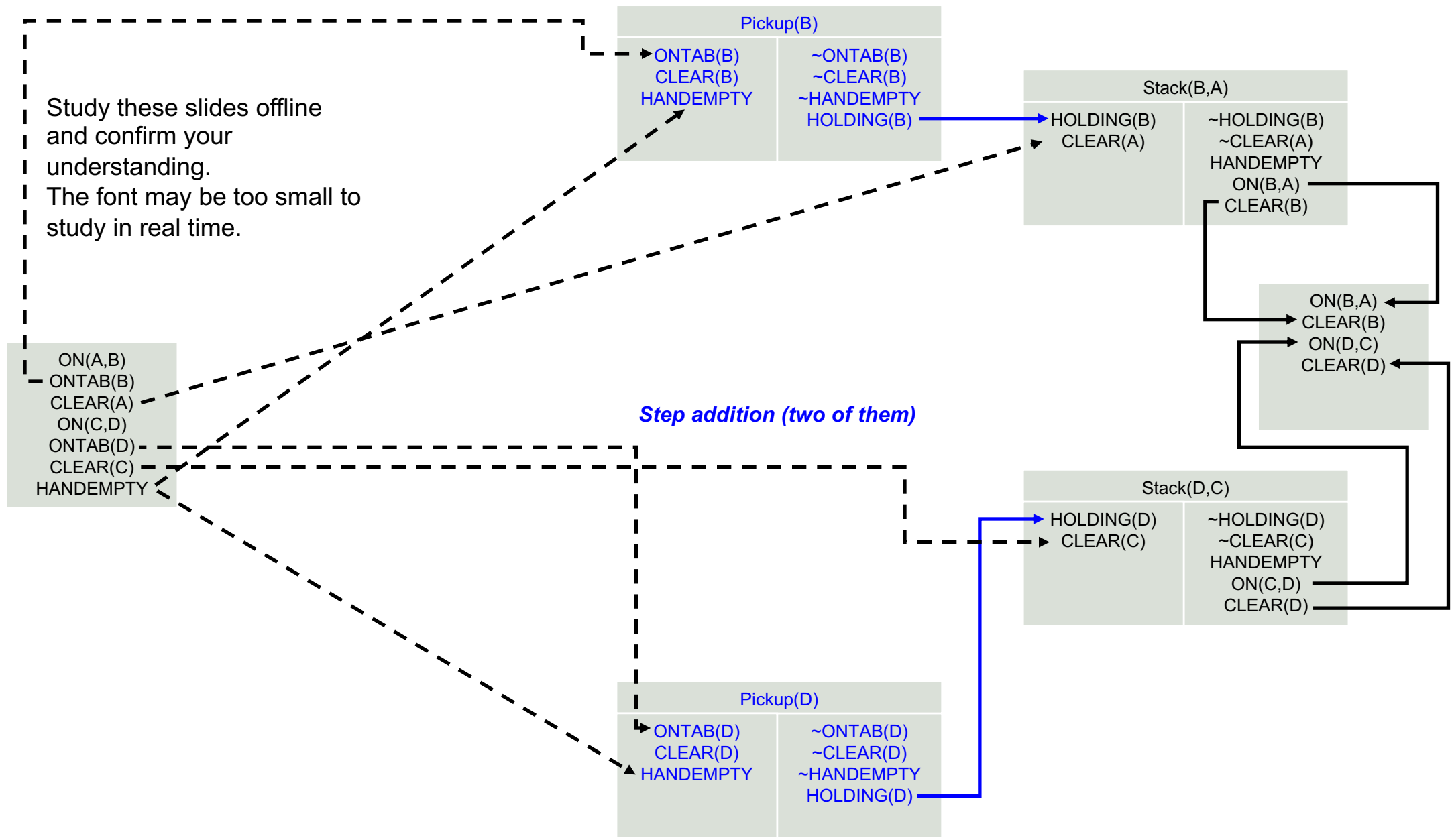
# First-Order Planning, Part IV

ON(A,B)  
ONTAB(B)  
CLEAR(A)  
ON(C,D)  
ONTAB(D)  
CLEAR(C)  
HANDEEMPTY

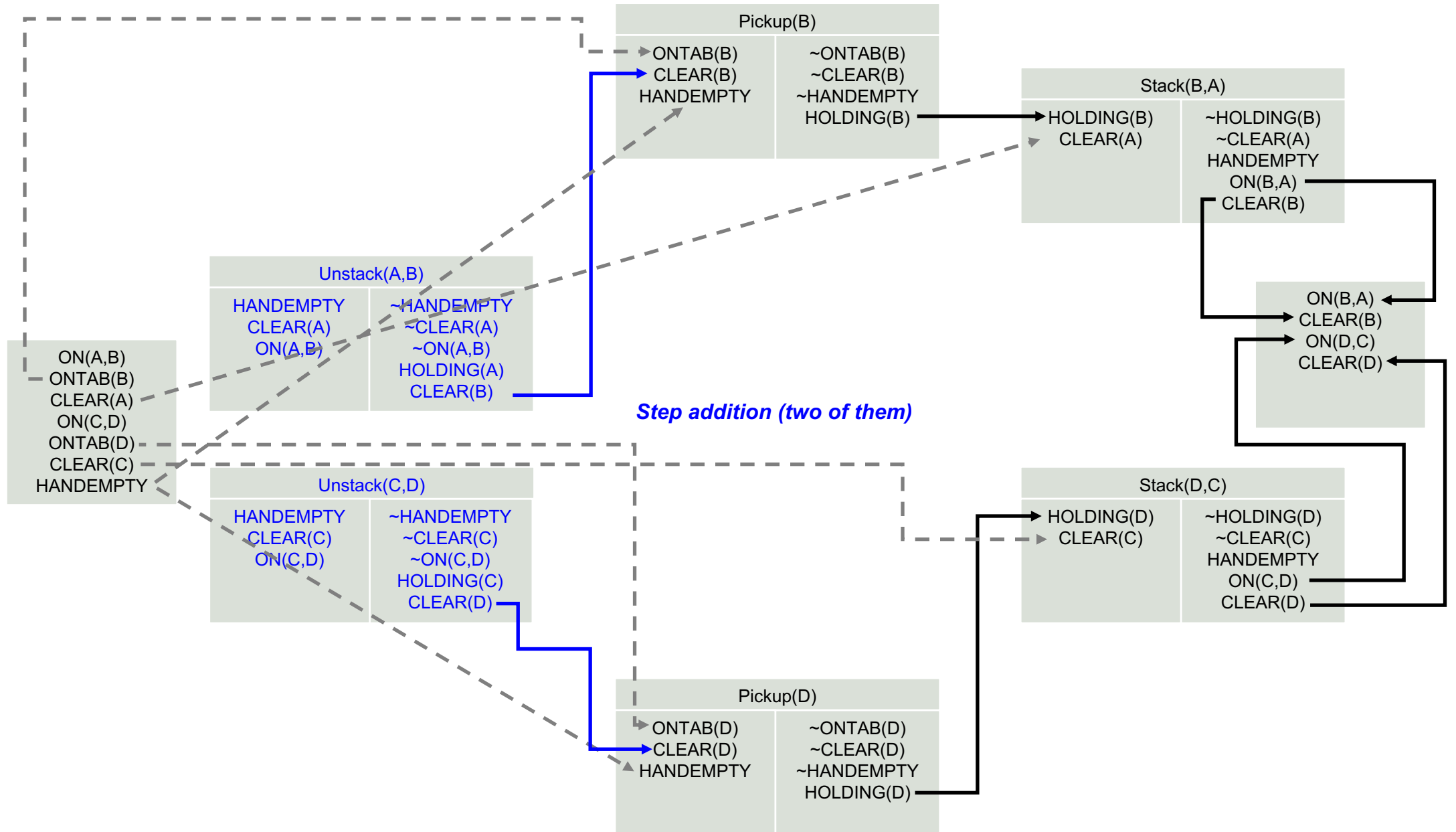
*Step addition + Establishment*

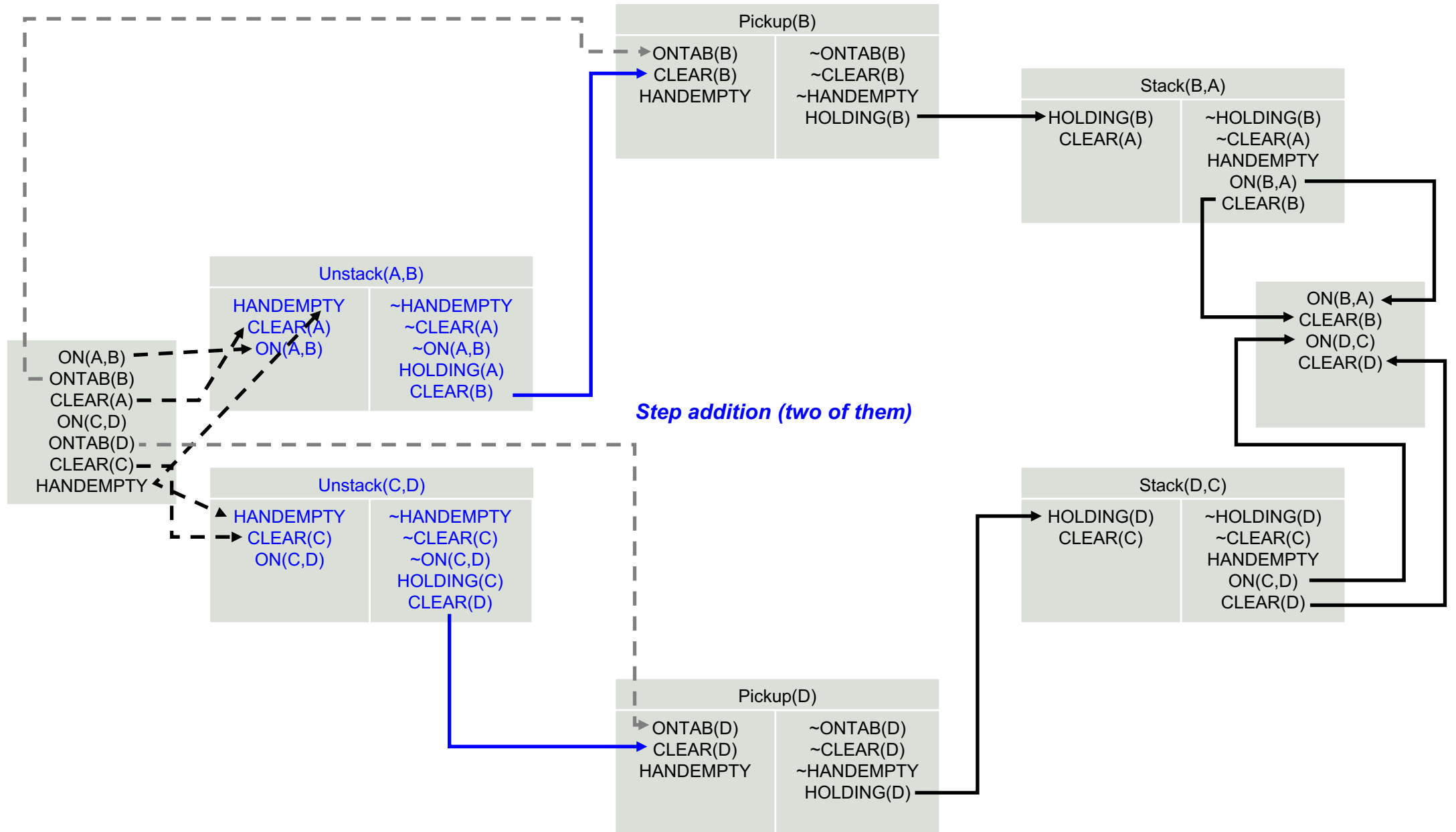


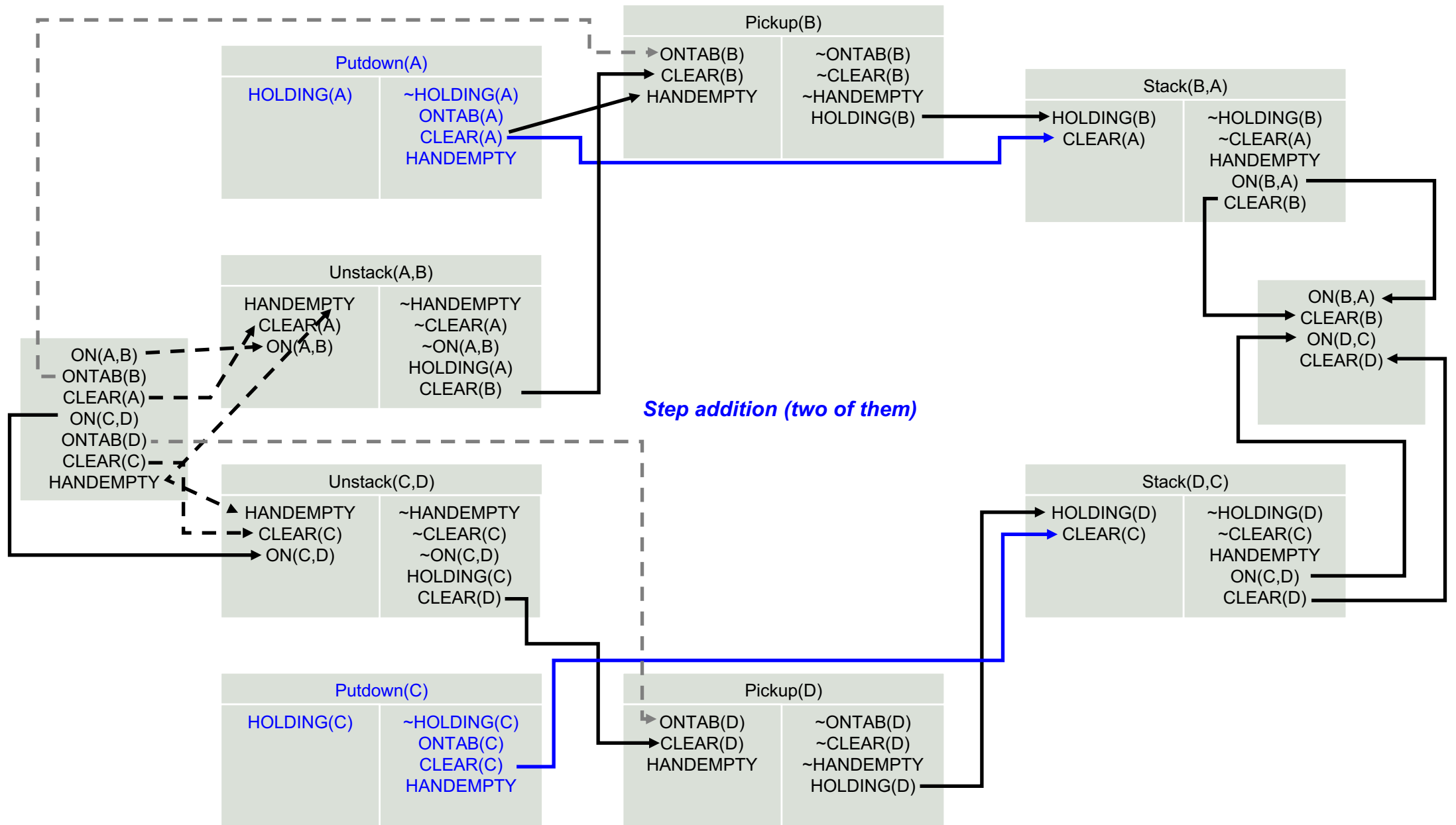
Study these slides offline and confirm your understanding. The font may be too small to study in real time.

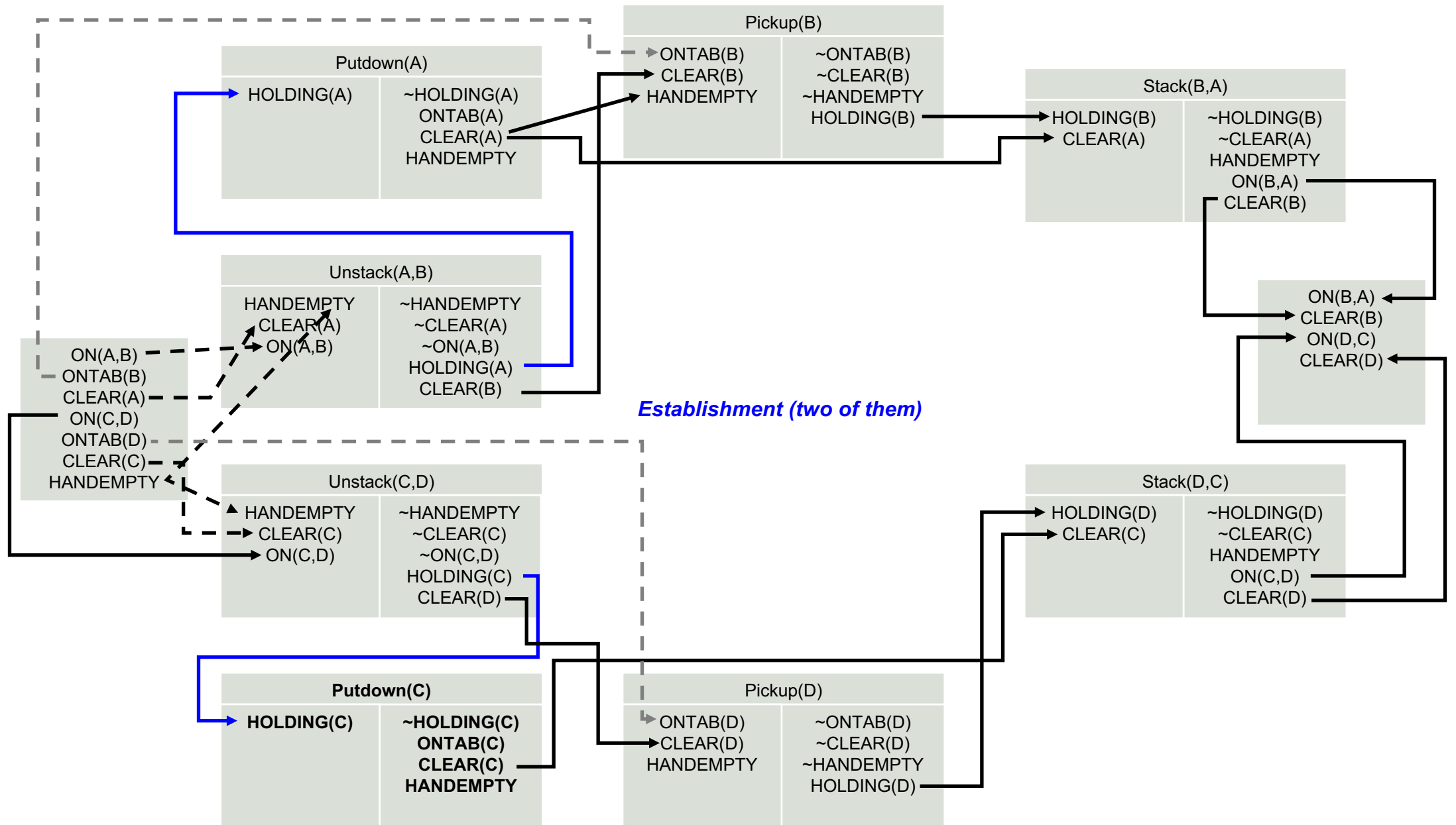


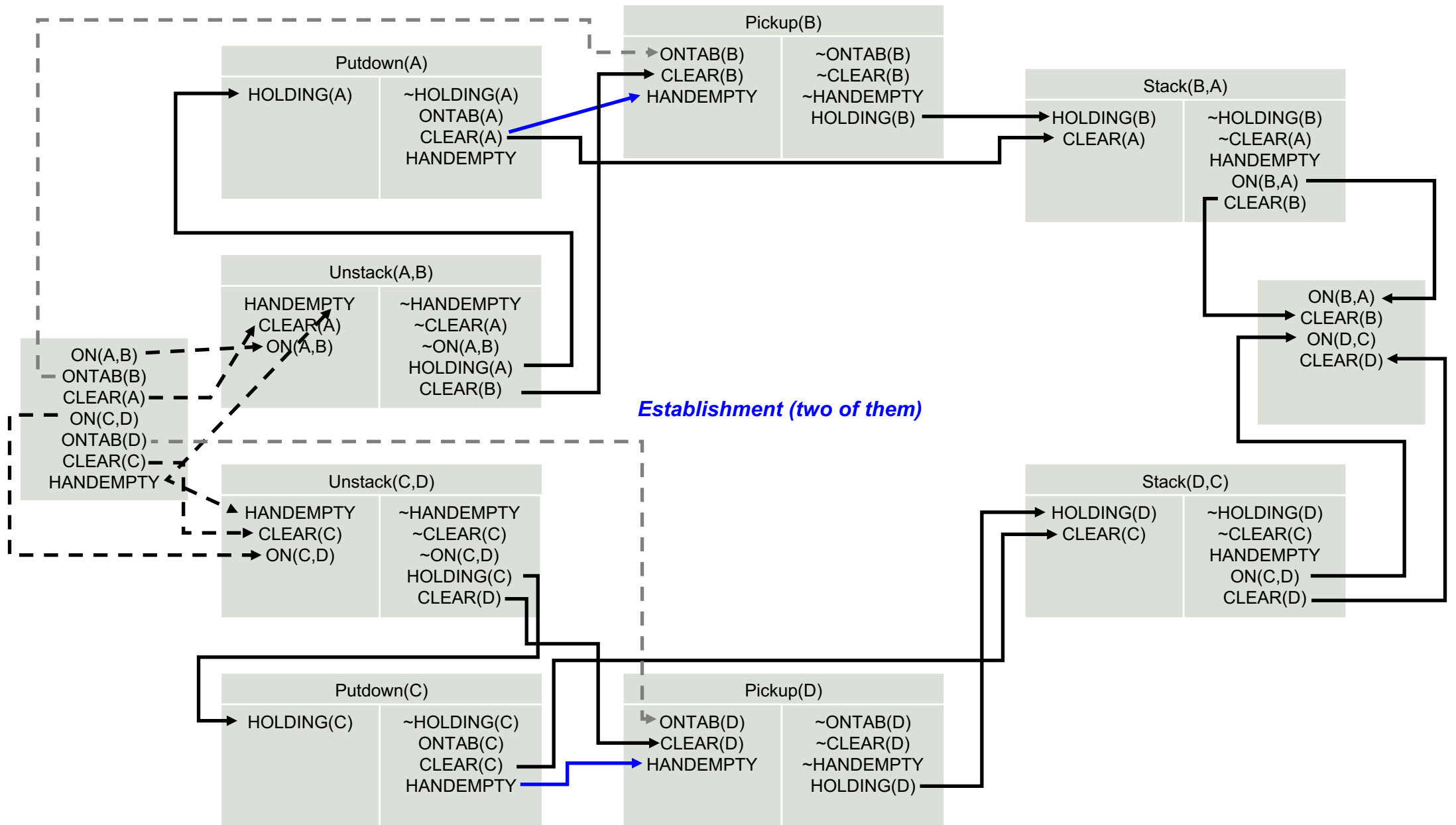


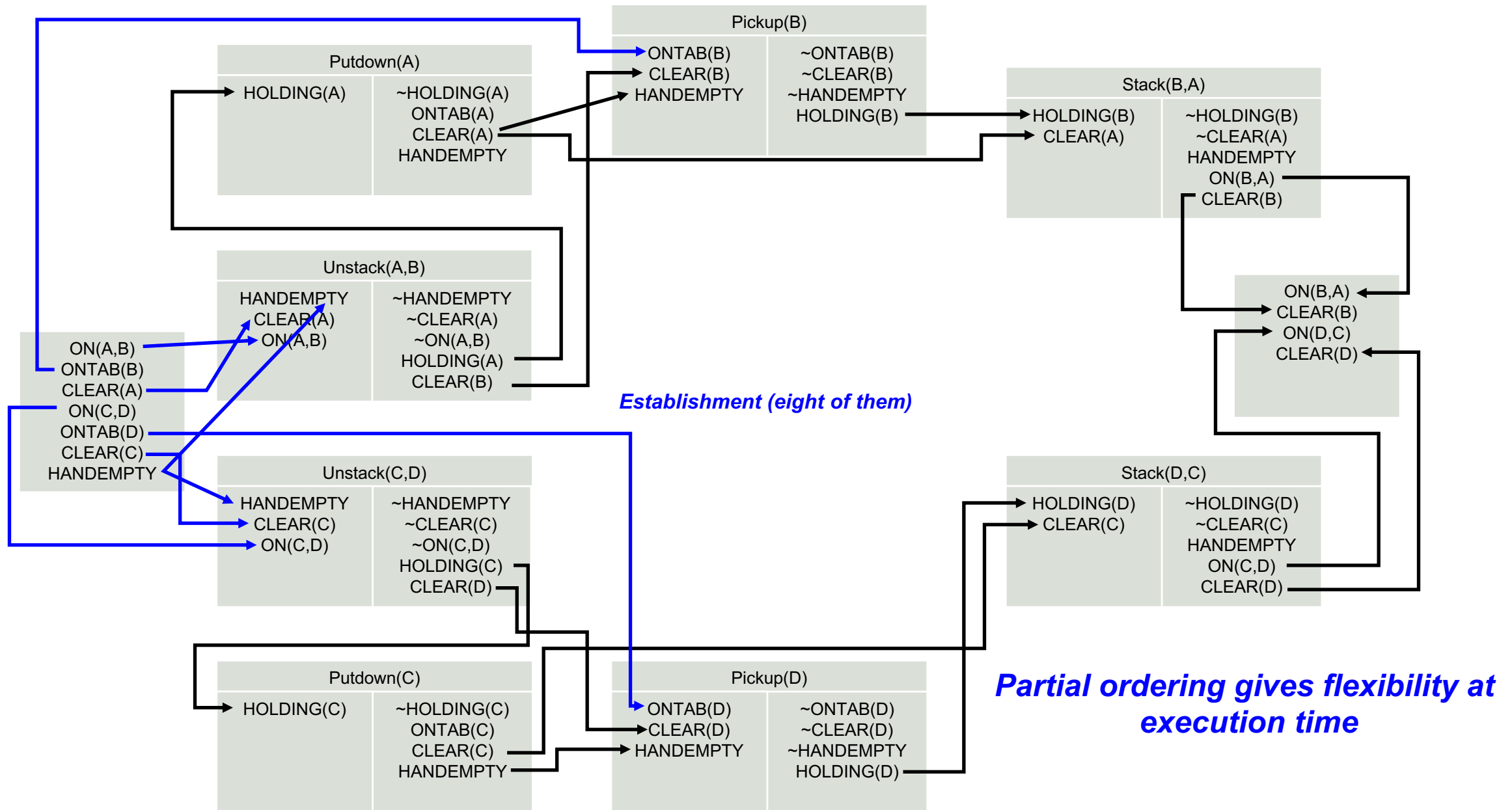




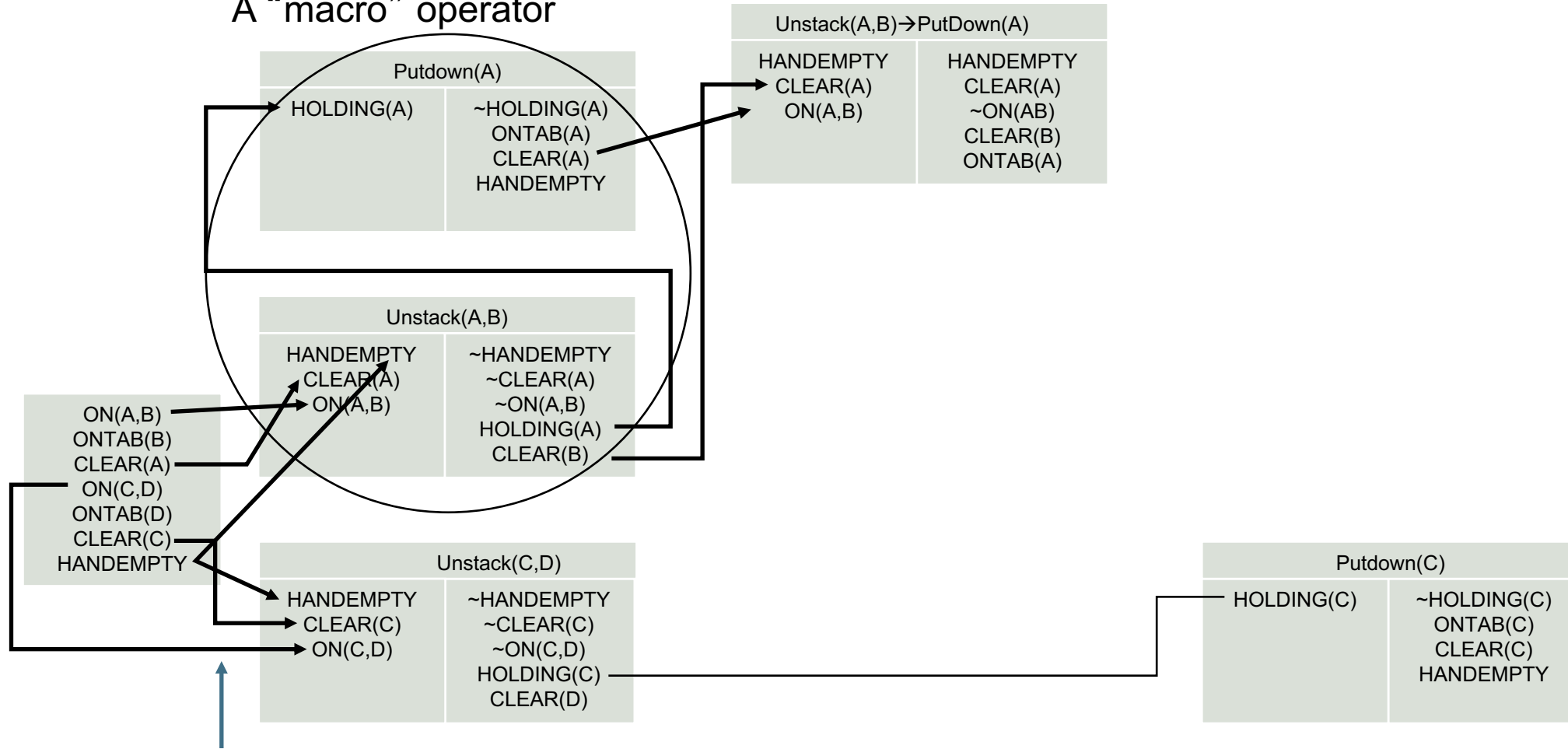








# A "macro" operator



No "operator" is inserted in here that will negate the protected conditions, however when viewed as a "macro" operator,  $Unstack(A,B) \rightarrow PutDown(A)$  does not clobber any protected subgoals (or more exactly, it restores any subgoals (e.g., handempty) that are temporally "clobbered")

Planning With First-Order Representations

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**The End**



# Relational Learning

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# Relational Learning

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Relational (e.g., first-order) representations, such as:

**IF**  $R(?c1, ?r1) \wedge R(?c2, ?r1) \wedge R(?c3, ?r2) \wedge R(?c4, ?r2) \wedge R(?c5, ?r2)$   
 $\wedge \neq(?c1, ?c2) \wedge \neq(?c3, ?c4) \wedge \neq(?c3, ?c5) \wedge \neq(?c4, ?c5)$   
**THEN** FullHouse(?c1, ?c2, ?c3, ?c4, ?c5)



# Relational Learning (cont.)

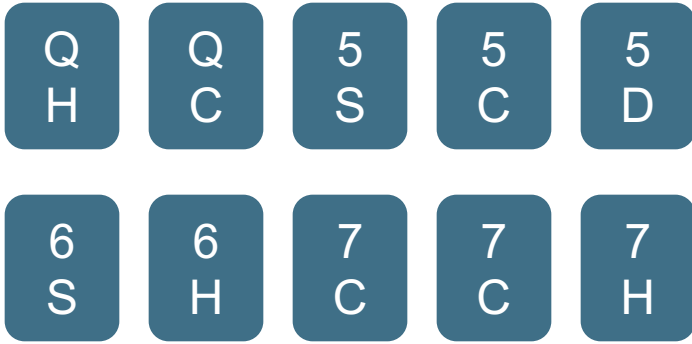
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Relational (e.g., first-order) representations, such as:

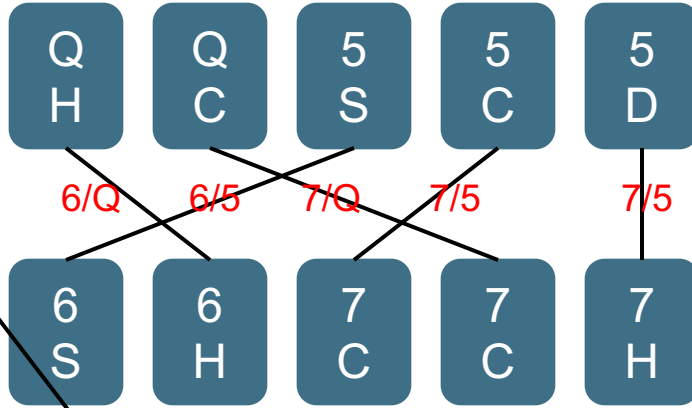
**IF**  $R(?c1, ?r1) \wedge R(?c2, ?r2) \wedge R(?c3, ?r3) \wedge R(?c4, ?r4) \wedge R(?c5, ?r5)$   
 $\wedge +1(?r1, ?r2) \wedge +1(?r2, ?r3) \wedge +1(?r3, ?r4) \wedge +1(?r4, ?r5)$   
**THEN**  $Straight(?c1, ?c2, ?c3, ?c4, ?c5)$

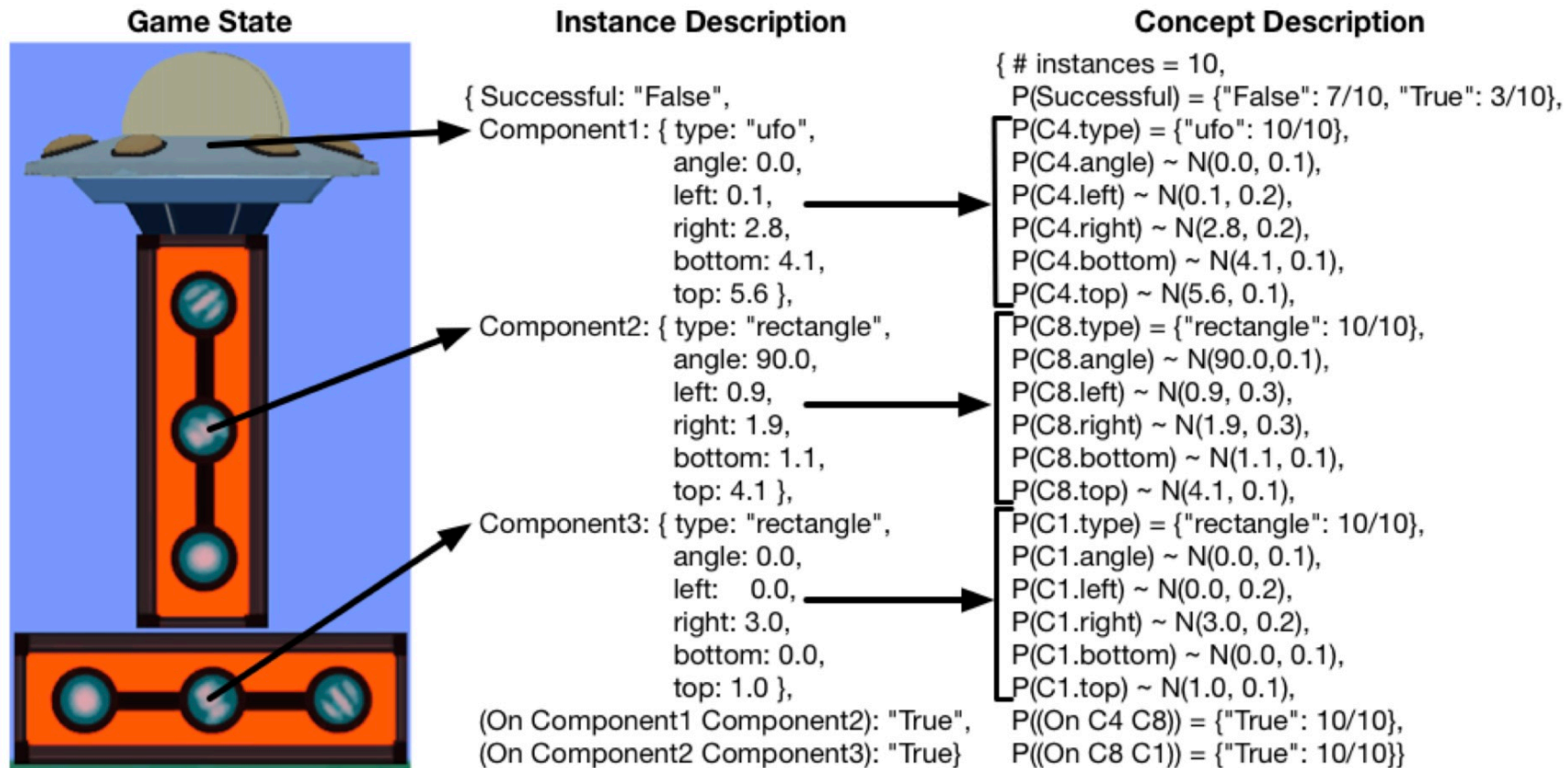
9 H	8 C	7 S	6 C	5 D
6 S	5 H	4 C	3 D	2 H

8 D	9 H	7 C	J H	10 D
4 D	6 H	7 D	5 H	8 D



Q/6 5/7  
H/S C/H



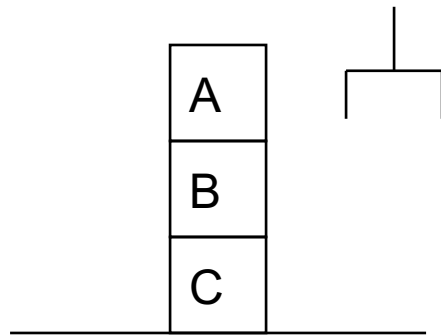


From MacLellan, C. J., Harpstead, E., Aleven, V., Koedinger, K. R. (2016). *TRESTLE: A Model of Concept Formation in Structured Domains*. *Advances in Cognitive Systems*, 4, 131–150. Retrieved from <http://www.cogsys.org/journal/volume4/article-4-10.pdf> (Used with permission)

# Relational Learning, Part I

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- Learning macros: Given a plan, generalize the plan so that the generalized plan can be applied in a greater number of situations.
- Objective: Reusing previously developed generalized plans (aka macro operators) will reduce the cost (improve the “speed”) of subsequent planning.



**Start state**



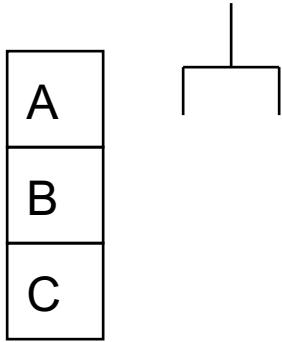
**Goal spec**

Unstack(A,B) → Putdown(A) → Unstack(B,C) → Stack(B,A)

(Generalize) →

Unstack(?x1, ?y1) → Putdown(?x1) → Unstack(?y1, ?z1) → Stack(?y1, ?x1)

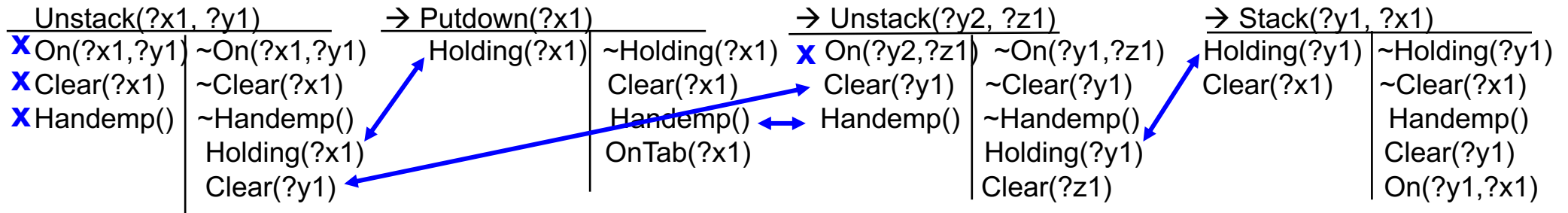
# Relational Learning, Part VII



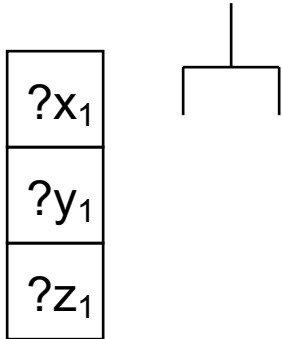
**Start state**



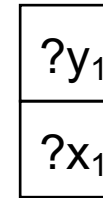
**Goal spec**



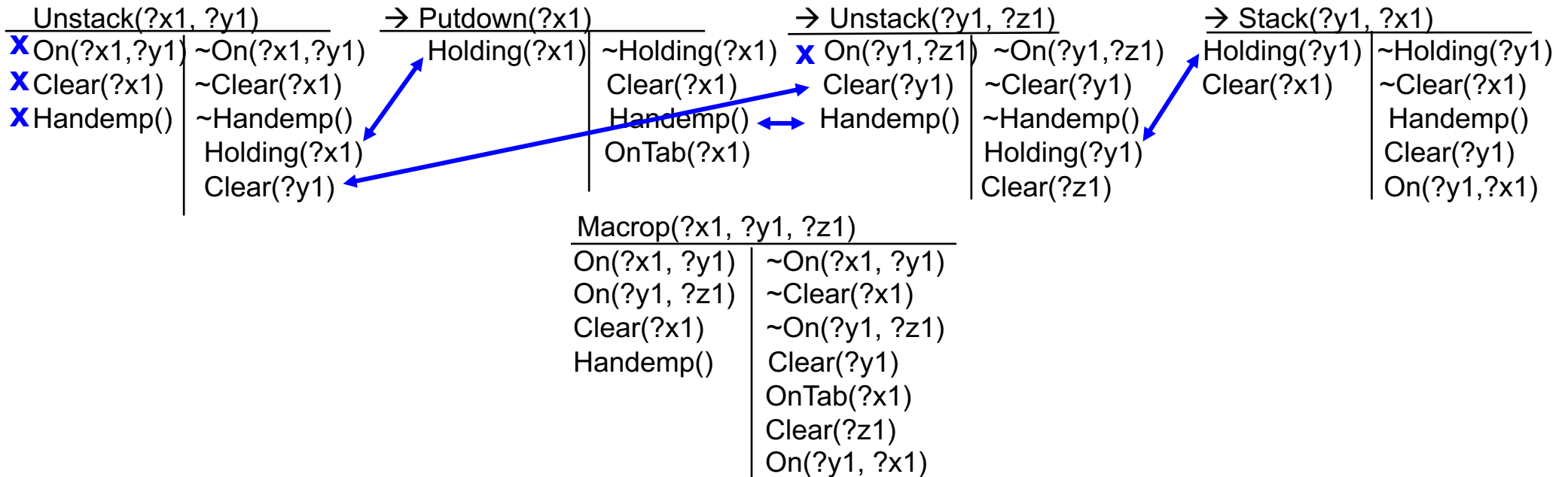
# Relational Learning, Part VII



**Start state**



**Goal spec**





Relational Learning

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**The End**