The Situation Calculus and Cognitive Robotics

The Situation Calculus

- McCarthy and Hayes 1969
- A predicate calculus formalization of states, actions, and effects.
- Reiter 1991

The Situation Calculus (cont)

- A first order language for representing dynamically changing worlds; all changes are the result of named *actions*.
- The world is conceived as being in some situation *s*; this situation can change only in consequence of some agent performing an action.

The Situation Calculus (cont)

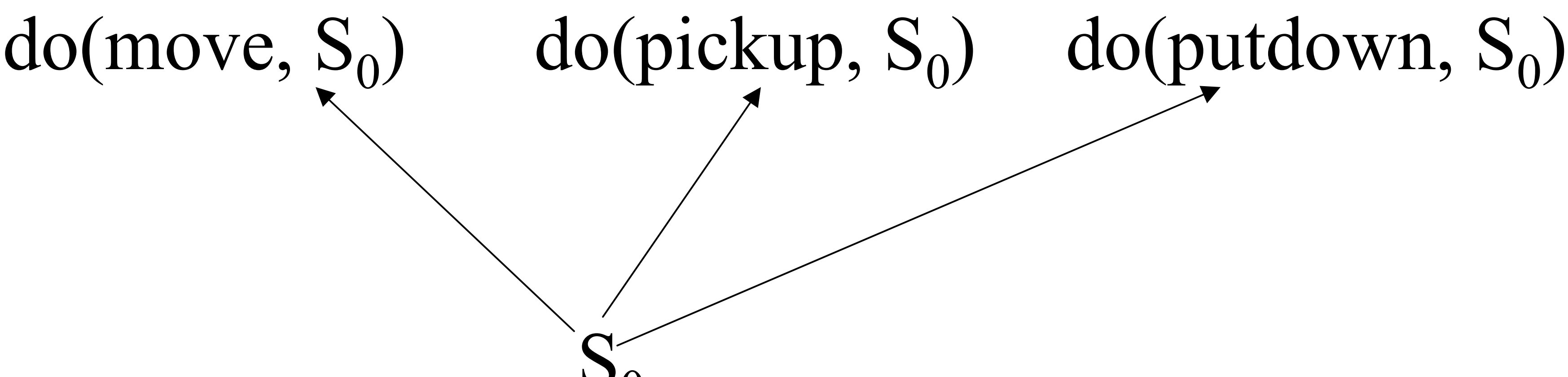
- The constant S_0 denotes the initial situation.
- Actions are denoted by function symbols.
- $Do(\alpha,s)$ denotes the successor situation to s resulting from performing the action α.

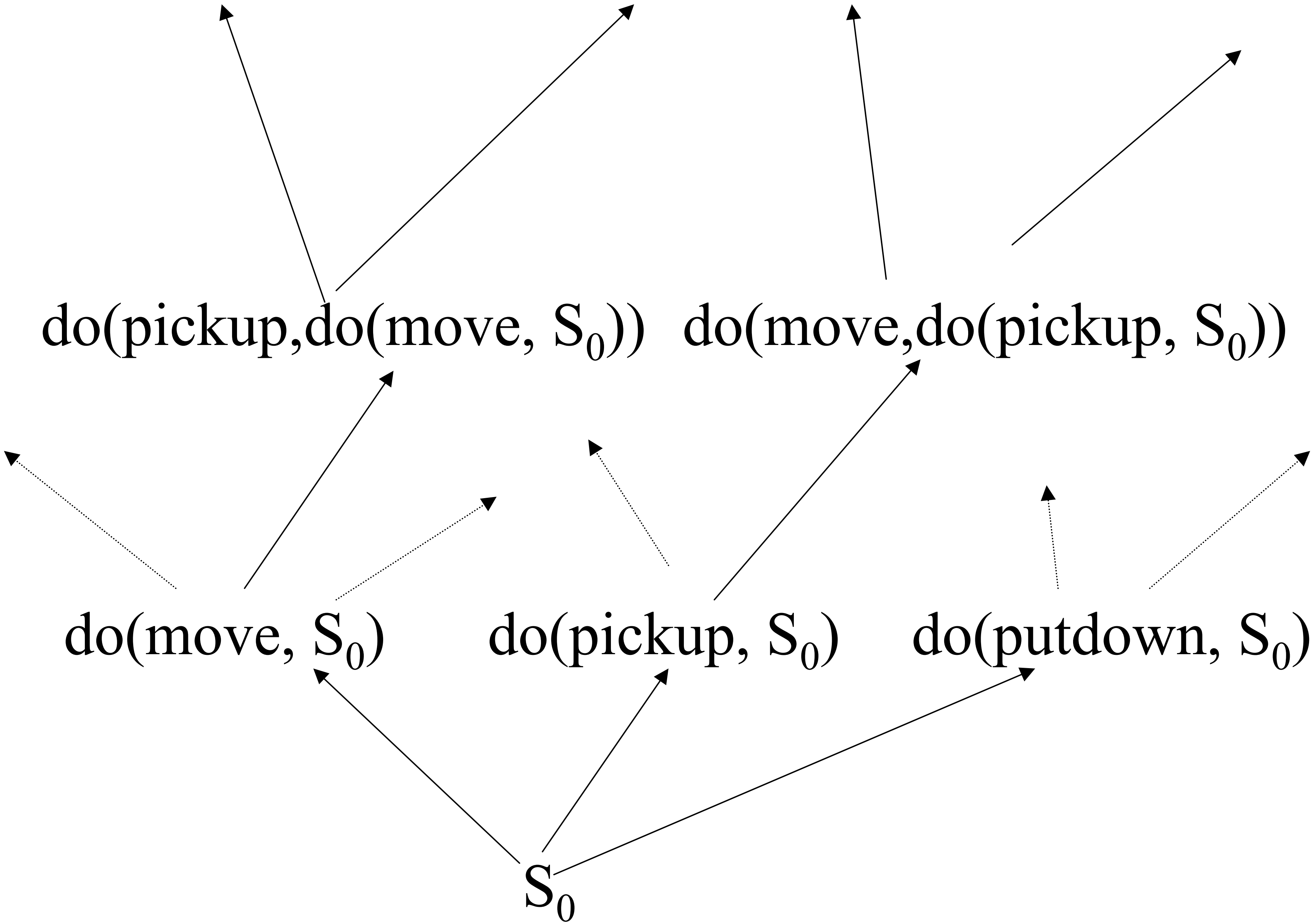
S_0

$do(move, S_0)$

S_0

$$
\begin{tikzcd}
do(move, S_0) & & do(pickup, S_0) \\
& S_0 \arrow[ul] \arrow[ur] &
\end{tikzcd}
$$


do(move, S_0)
do(pickup, S_0)
do(putdown, S_0)
S_0



do(pickup,do(move, S_0))
do(move,do(pickup, S_0))
do(move, S_0)
do(pickup, S_0)
do(putdown, S_0)
S_0

The Situation Calculus

- Actions may be parameterized: *put(x,y)* might stand for the action of putting object *x* on object *y*; *do(put(A,B),s)* denotes that situation resulting from placing *A* on *B* when the world is in situation *s*.

The Situation Calculus (Cont)

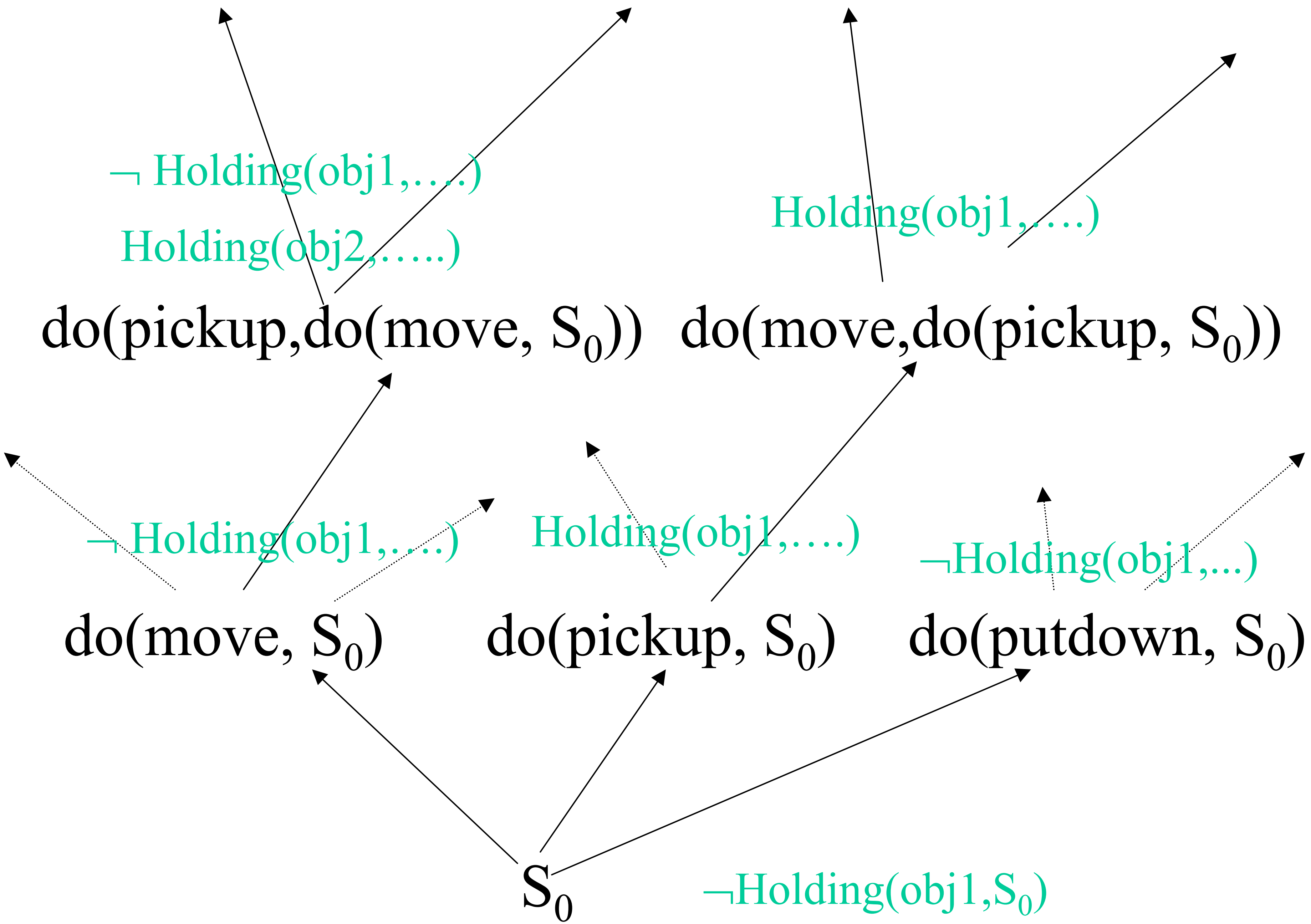
- Fluents = those relations whose truth values may vary from situation to situation. Denoted by predicate symbols taking a situation term as one of their arguments
- --- $Color(x, c, s)$
- Functional Fluents.
- -- $Pos(x, s)$

Fluents

- Holding(x,s)
- $\neg$ Holding(x,s)
- Color(x,c,s)
- Pos(x,s) = i

Axiomatization of Initial Situation

- $\neg$ Holding(obj1,S_0)
- Pos(robot,S_0) = 0
- Pos(obj1,S_0) = 1
- $\neg$Holding(obj1,S_0)
- Pos(obj2,S_0) =2
- Color(obj1, red,S_0)

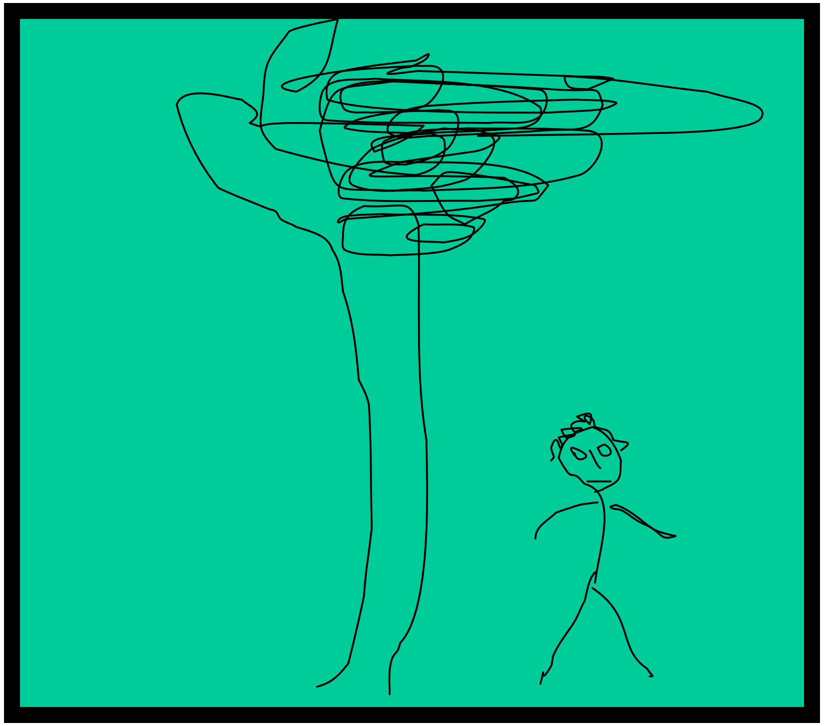

¬ Holding(obj1,….)
Holding(obj2,…..)
Holding(obj1,….)
do(pickup,do(move, S0))
do(move,do(pickup, S0))
¬ Holding(obj1,….)
Holding(obj1,….)
¬Holding(obj1,...)
do(move, S0)
do(pickup, S0)
do(putdown, S0)
S0
¬Holding(obj1,S0)

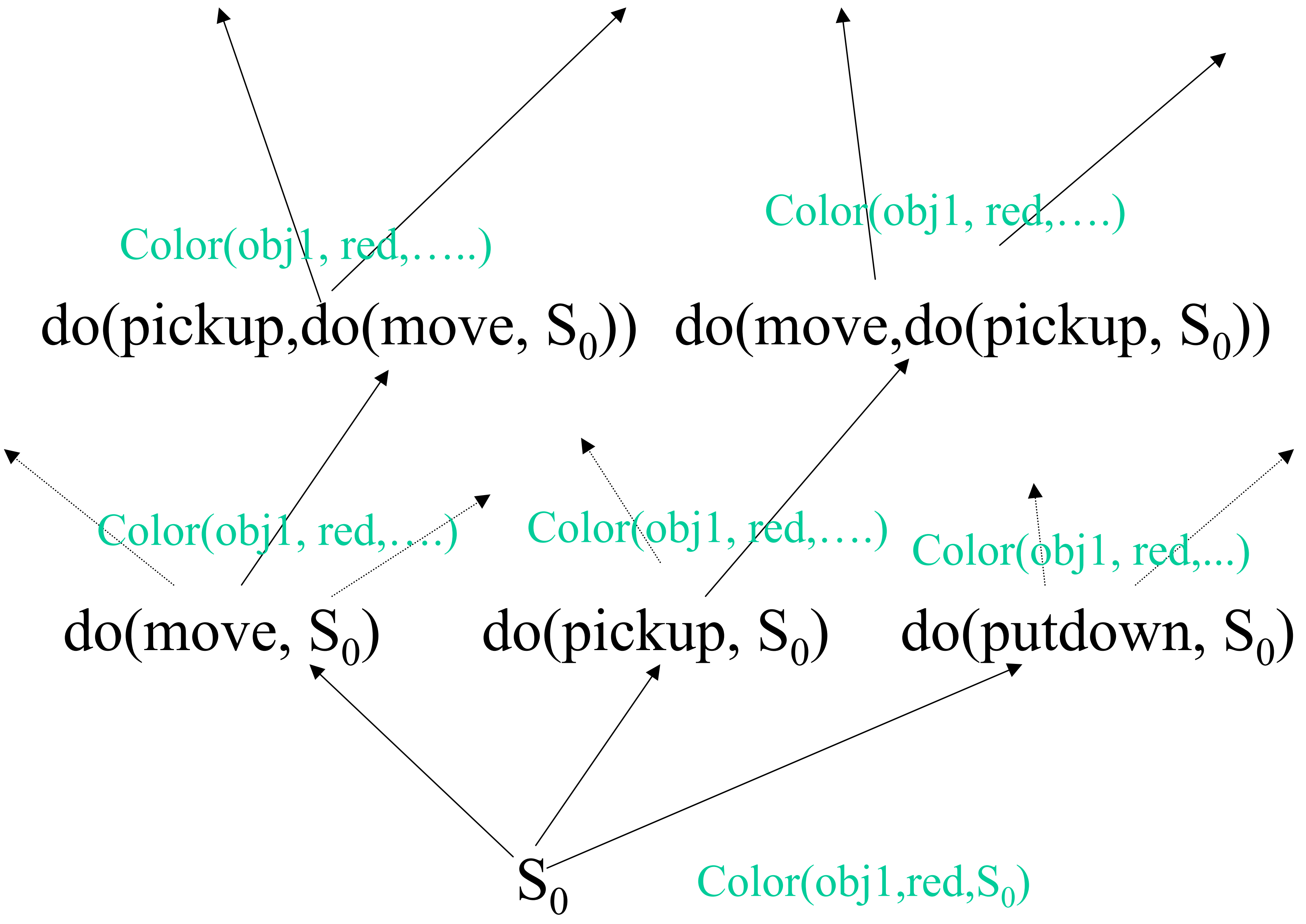
Causal Laws

- $\forall$ x,y,s $\neg$ $\exists$ z Holding(z,s) $\wedge$ Pos(robot,s) = y $\wedge$ Pos(x,s) = y $\Rightarrow$
  Holding(x, do(pickup,s))
- $\forall$ x,y,s Pos(x, s) = y $\Rightarrow$
  Pos(x, do(move, s) = Succ(y)
- $\forall$ x,y,s Color(x, y, do(paint(x,y),s))

Frame Problem

- McCarthy and Hayes





Color(obj1, red,…..)
Color(obj1, red,….)
do(pickup,do(move, S0))
do(move,do(pickup, S0))
Color(obj1, red,….)
Color(obj1, red,….)
Color(obj1, red,...)
do(move, S0)
do(pickup, S0)
do(putdown, S0)
S0
Color(obj1,red,S0)

Frame Axioms

- $\forall$ x,y,s Color(x, y, s) $\Rightarrow$
  Color(x, y, do(move,s))
- $\forall$ x,y,s $\neg$ Color(x, y, s) $\Rightarrow$
  $\neg$ Color(x, y, do(move,s))
- Need ~ 2 $*$ F $*$ A Frame Axioms

Cognitive Robotics

- Most current work in robotics emphasizes basic-level tasks like sensory processing, path planning, manipulator design and control, reactive agents, artificial insects etc. In contrast, research in cognitive robotics is concerned with the theory and the implementation of robots that reason, act and perceive in changing, incompletely known, unpredictable environments.

Cognitive Robotics (cont)

- Such robots must have higher level cognitive functions that involve reasoning, for example, about goals, actions, when to perceive and what to look for, the cognitive states of other agents, time, collaborative task execution, etc.

Cognive Robotics (cont)

- In short, Cognitive Robotics is concerned with integrating reasoning, perception and action within a uniform theoretical and implementation framework.
- From Description of 1998 AAAI Fall Symposium on Cognitive Robotics

Reasoning about Actions: Logics of Actions

- Situation Calculus
- “A” Language
- Event Calculus
- Temporal Logics
- Dynamic Logics
- Fluent Calculus

Toronto Approach to Cognitve Robotics

- Based on the Situation Calculus.
- Agent Theory
- Agent Programming Language -- GOLOG
- University of Toronto -- Hector Levesque and Raymond Reiter

Characteristics of the Toronto Approach

- Theory of Agents that act, perceive, and reason in changing, incompletely known, and unpredictable environments.
- Agent Goals
- Action effects and preconditions
- Time, Continuous events, and concurrency
- When to perceive and what to look for

Characteristics of the Toronto Approach (Cont)

- Cognitive States of other agents.
- Implementation ---- a uniform theoretical and implementation framework integrating perception, action, and reasoning.

Theory of Actions

- Frame, ramification, and qualification problem.
- Exogeneous Actions
- Probabilistic action occurrences and effects
- Complex actions
- Ability
- Time

Theory of Actions (cont)

- Concurrency
- Hypothetical and Counterfactual Reasoning
- Perceptual Actions
- Deciding when to act, when to think, what to do, and what to look for.
- Agent beliefs, desires, and intentions.

Theory of Actions (cont)

- Real time, resource bounded behavior
- Belief Revision
- Execution Monitoring and Failure Recovery

GOLOG

- GOLOG -- AlGol in LoGic
- Sequences, nondeterministic choice of actions.
- Conditions,
- While loops
- Recursion

Do(putdown, do(move,do(pickup,S0)))

$\Downarrow\Downarrow$

[pickup, move, putdown]

Incomplete Knowledge

- Generally, agents do not have complete knowledge of the world.
- Formalism must distinguish between what is true in the world and what the agent knows.

Incomplete Knowledge (cont)

- Agents must reason about:
- Actions that produce knowledge --- perception, reading, comunicative acts.
- The knowledge prerequisites of actions.

Plans vs Computer Programs

- There is a long tradition of viewing plans as computer programs. (Green, Manna and Waldinger)
- There are many problems with this view of plans.
- An agent may not know whether a test is true.
- Agents may not know enough to execute the action.

Knolwedge and Action

- McCarthy and Hayes 1969, McCarthy 1963
- Moore 1980, Moore 1985
- If John is at the same place as SF_1 and he knows the combination of the safe, he can open the safe by dialing the combination.

Knowledge and Action (cont)

- If John is at the same place as SF_1 and the piece of paper PPR_1, and he knows that the combination of SF_1 is the only thing written on PPR_1, he can open SF_1 by reading the piece of paper and dialing the combination.

Knowledge and Action (cont)

- If C_1 is the combination of SF_1, and if John tries to open SF_1 by dialing C_1, he will then know that C_1 is the combination of SF_1.

Sensing Actions

- An Epistemic Fluent -- *Knows(P,s)*
- Effects of Sensing Actions -- changes in knowledge of agent.
- Reasoning

Applications

- Robots
- Hypertext
- Animated Characters
- Software Agents

More Information

- http://www.cis.njit.edu/~scherl
- http://www.cs.toronto.edu/cogrobo