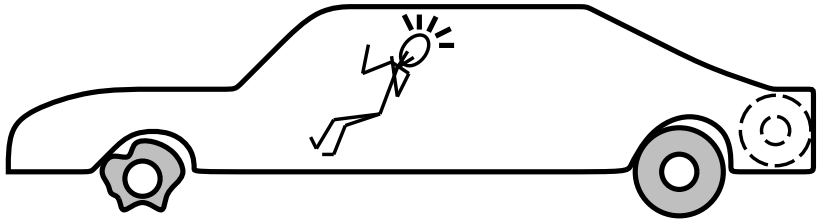
Planning and Search

Planning and acting in non-deterministic domains

Outline

- ♢ Planning in the real world: additional complications
- ♢ Conditional planning
- ♢ Monitoring and replanning

The real world



On(x) ~Flat(x)

START

FINISH

~Flat(Spare) Intact(Spare) Off(Spare)
On(Tire1) Flat(Tire1)

On(x)

Remove(x)

Off(x) ClearHub

Off(x) ClearHub

Puton(x)

On(x) ~ClearHub

Intact(x) Flat(x)

Inflate(x)

~Flat(x)

Things go wrong

Incomplete information

Unknown preconditions, e.g., $Intact(Spare)$?

Disjunctive effects, e.g., $Inflate(x)$ causes

$Inflated(x) \vee SlowHiss(x) \vee Burst(x) \vee BrokenPump \vee \ldots$

Incorrect information

Current state incorrect, e.g., spare NOT intact

Missing/incorrect postconditions in operators

Qualification problem:

can never finish listing all the required preconditions and possible conditional outcomes of actions

Solutions

Conformant or sensorless planning

Devise a plan that works regardless of state or outcome

Such plans may not exist

Conditional planning

Plan to obtain information (**observation actions**)

Subplan for each contingency, e.g.,

$[Check(Tire1), \textbf{if}\ Intact(Tire1)\ \textbf{then}\ Inflate(Tire1)\ \textbf{else}\ CallAAA$

Expensive because it plans for many unlikely cases

Monitoring/Replanning

Assume normal states, outcomes

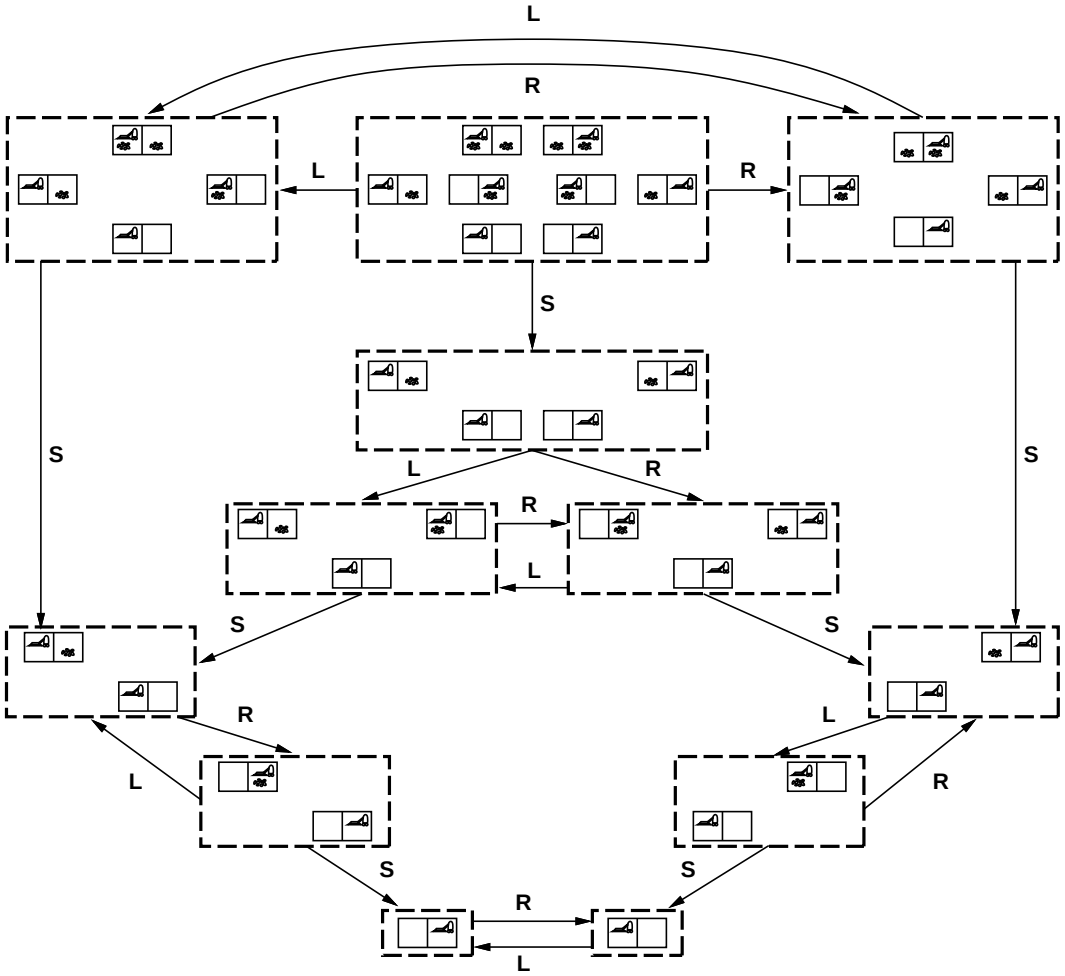
Check progress *during execution*, replan if necessary

Unanticipated outcomes may lead to failure (e.g., no AAA card)

(Really need a combination; plan for likely/serious eventualities,
deal with others when they arise, as they must eventually)

Conformant planning

Search in space of belief states (sets of possible actual states)

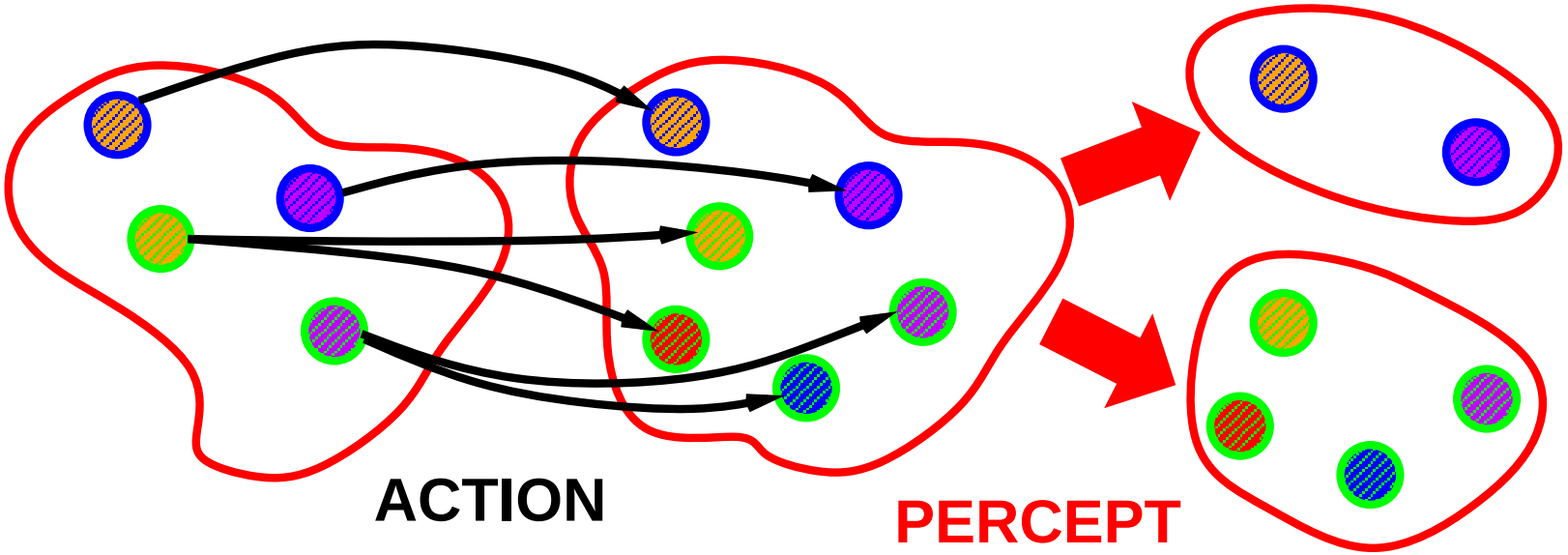


Conditional planning

If the world is nondeterministic or partially observable

then percepts usually *provide information*,

i.e., *split up* the belief state



Conditional planning contd.

Conditional plans check (any consequence of KB +) percept

$[\ldots, \textbf{if } C \textbf{ then } Plan_A \textbf{ else } Plan_B, \ldots]$

Execution: check C against current KB, execute "then" or "else"

Need *some* plan for *every* possible percept

(Cf. game playing: *some* response for *every* opponent move)

And-or-search

Recall search with non-deterministic actions from lecture 6...

function AND-OR-GRAPH-SEARCH(*problem*) **returns** a conditional plan, or failure

    OR-SEARCH(*problem*.INITIAL-STATE,*problem*,[])

---

function OR-SEARCH(*state, problem, path*) **returns** a conditional plan, or failure

    if *problem*.GOAL-TEST(*state*) **then return** the empty plan
    if *state* is on *path* **then return** failure
    for each *action* **in** *problem*.ACTIONS(*state*) **do**
        plan ← AND-SEARCH(RESULTS(*state, action*), *problem*,[*state* | *path*])
        if *plan* ≠ *failure* **then return** [*action* | *plan*]
    return *failure*

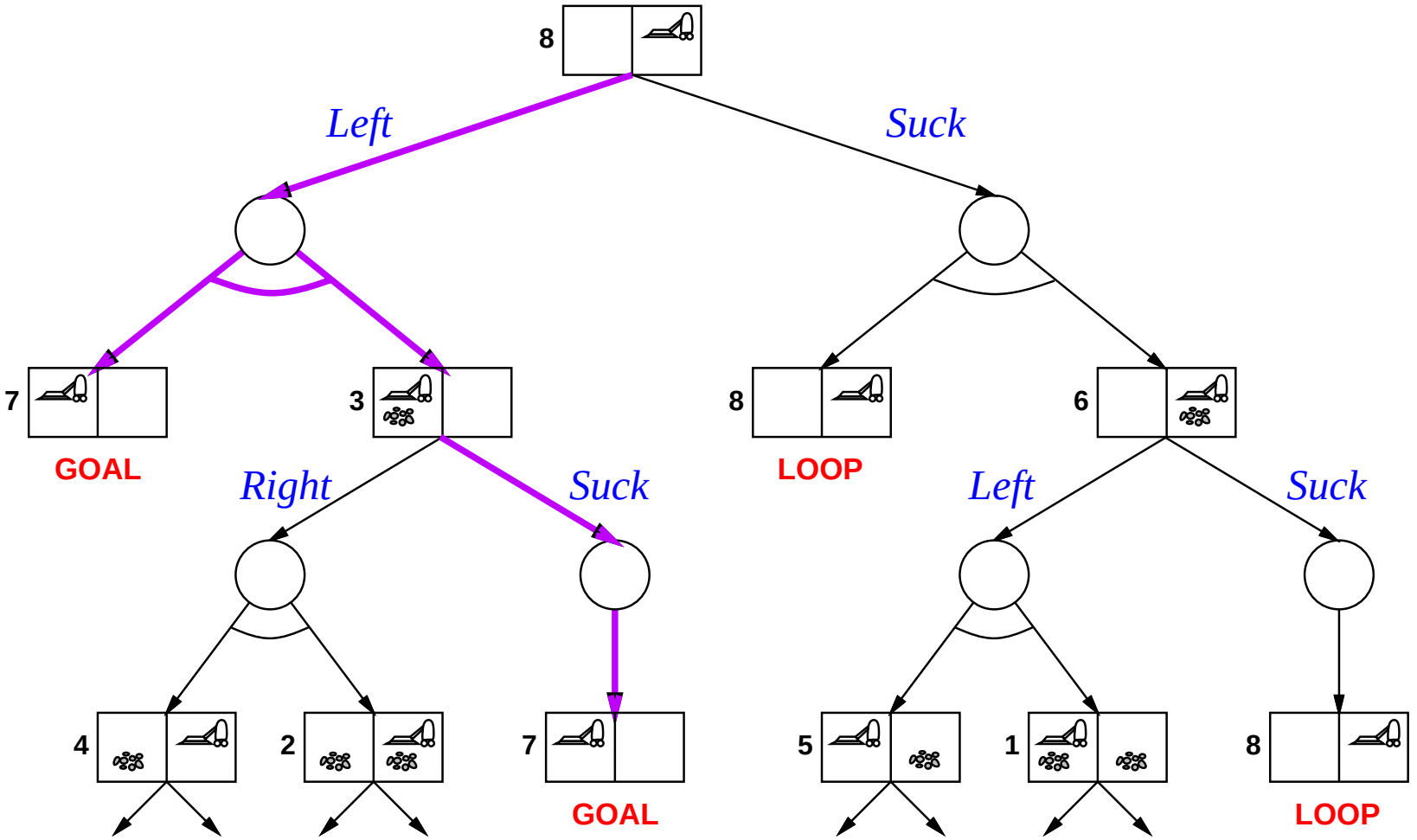
---

function AND-SEARCH(*states, problem, path*) **returns** a conditional plan, or failure

    for each s_i in *states* **do**
        $plan_i$ ← OR-SEARCH(s_i,*problem, path*)
        if *plan* = *failure* **then return** *failure*
    return [**if** s_1 **then** $plan_1$ **else if** s_2 **then** $plan_2$ **else** . . . **if** s_{n-1} **then** $plan_{n-1}$ **else** $plan_n$]

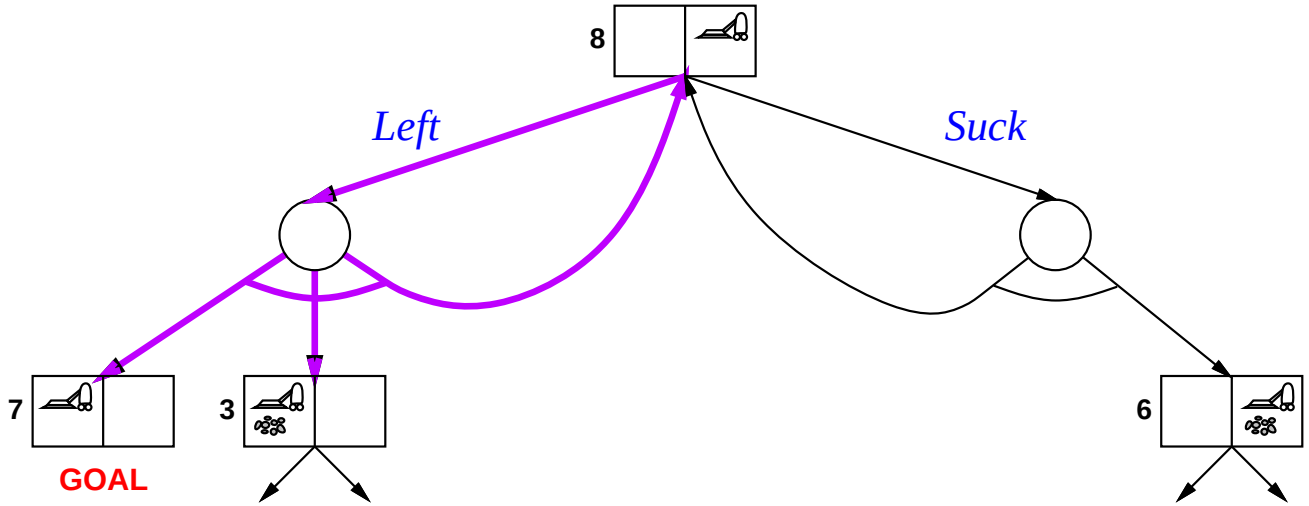
Non-deterministic vacuum cleaner

Sucking or arriving may dirty a clean square



Non-deterministic vacuum cleaner 2

Even worse: also sometimes stays put instead of moving



$[L_1 : \ Left, \textbf{if } AtR \textbf{ then } L_1 \textbf{ else } [\textbf{if } CleanL \textbf{ then } [\,] \textbf{ else } Suck]]$

or $[\textbf{while } AtR \textbf{ do } [Left], \textbf{if } CleanL \textbf{ then } [\,] \textbf{ else } Suck]$

"Infinite loop" but will eventually work unless action always fails

Execution Monitoring

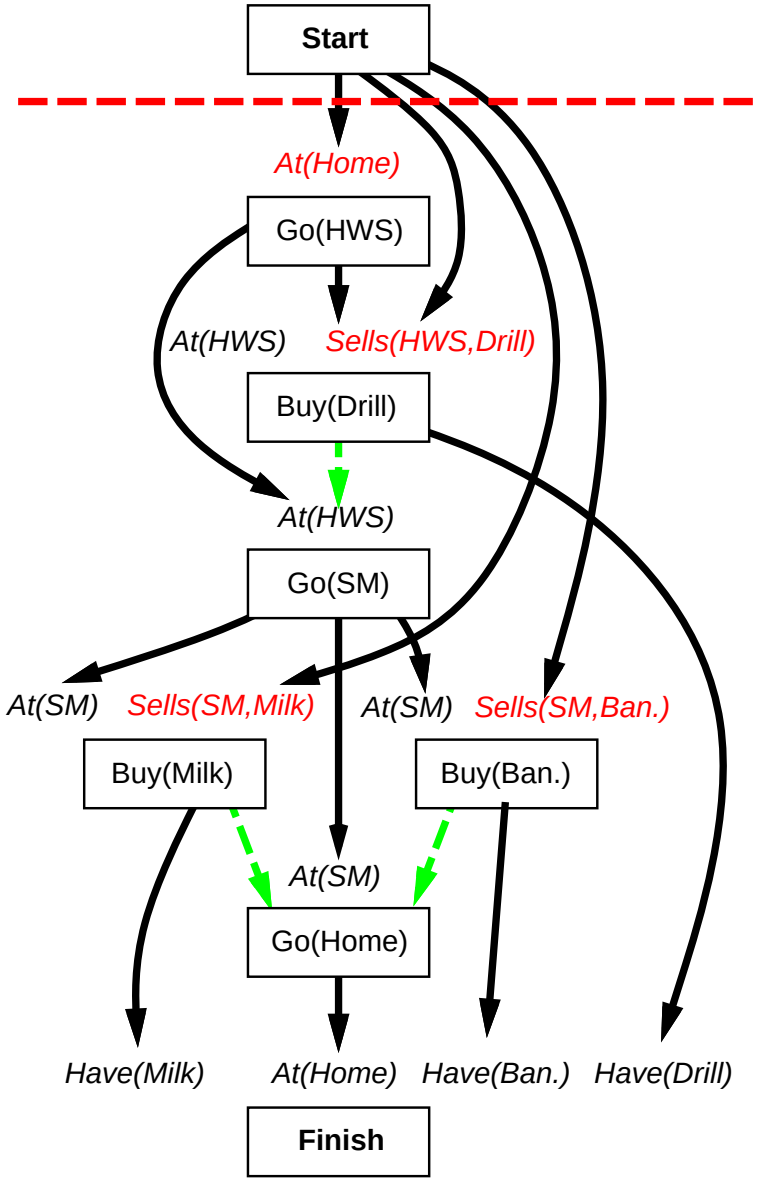
"Failure" = preconditions of *remaining plan* not met

Preconditions of remaining plan
= all preconditions of remaining steps not achieved by remaining steps
= all causal links *crossing* current time point

On failure, resume POP to achieve open conditions from current state

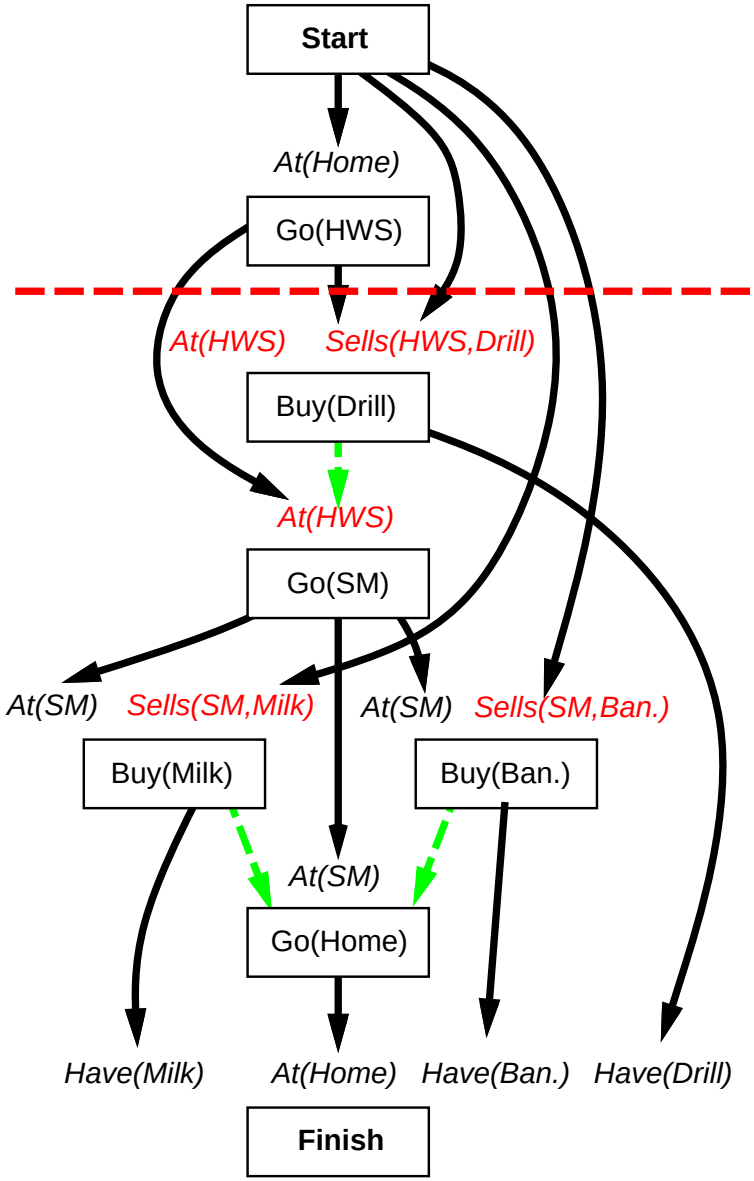
IPEM (Integrated Planning, Execution, and Monitoring):
keep updating $Start$ to match current state
links from actions replaced by links from $Start$ when done

Example



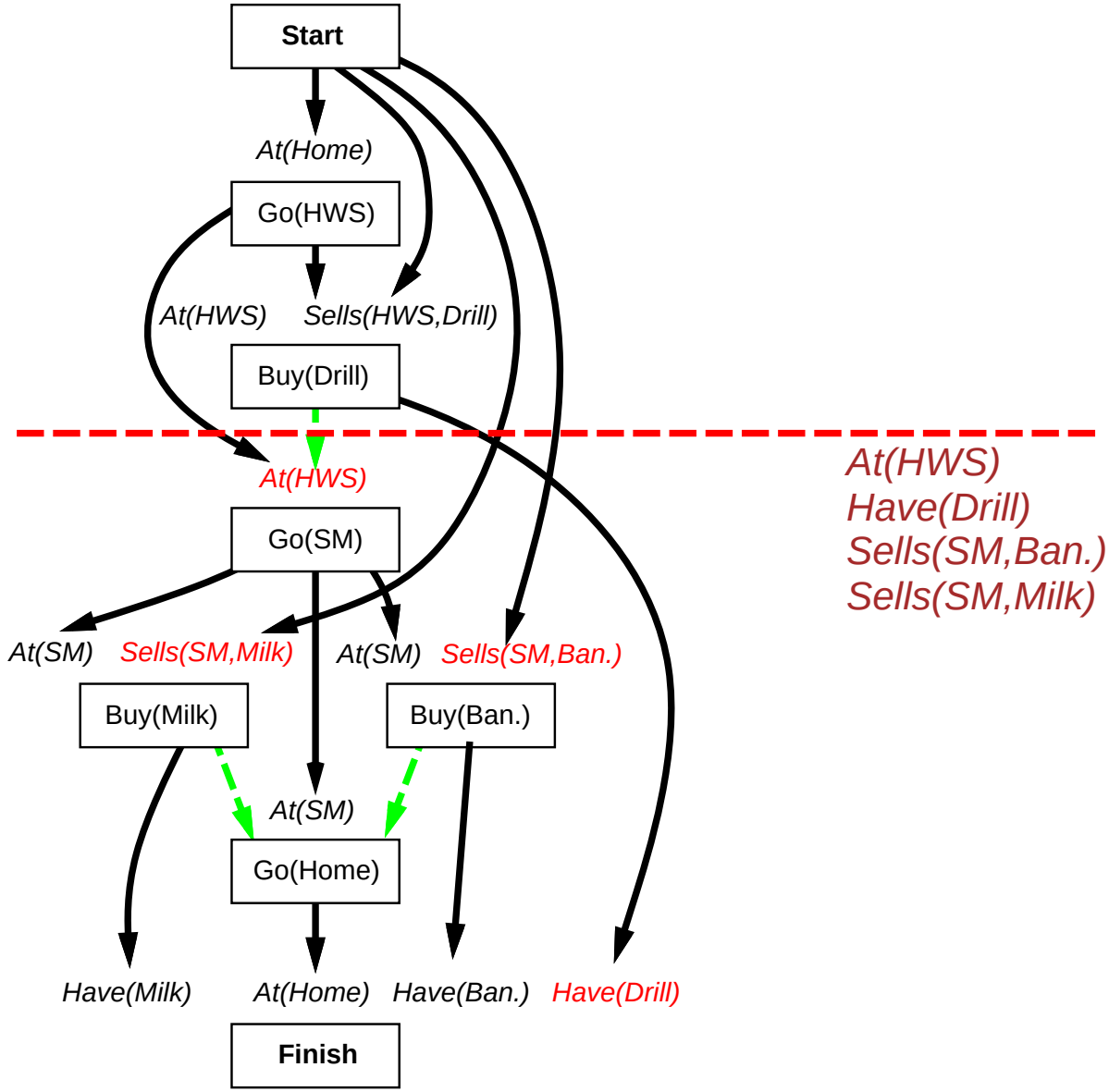
At(Home)
Sells(HWS,Drill)
Sells(SM,Ban.)
Sells(SM,Milk)

Example

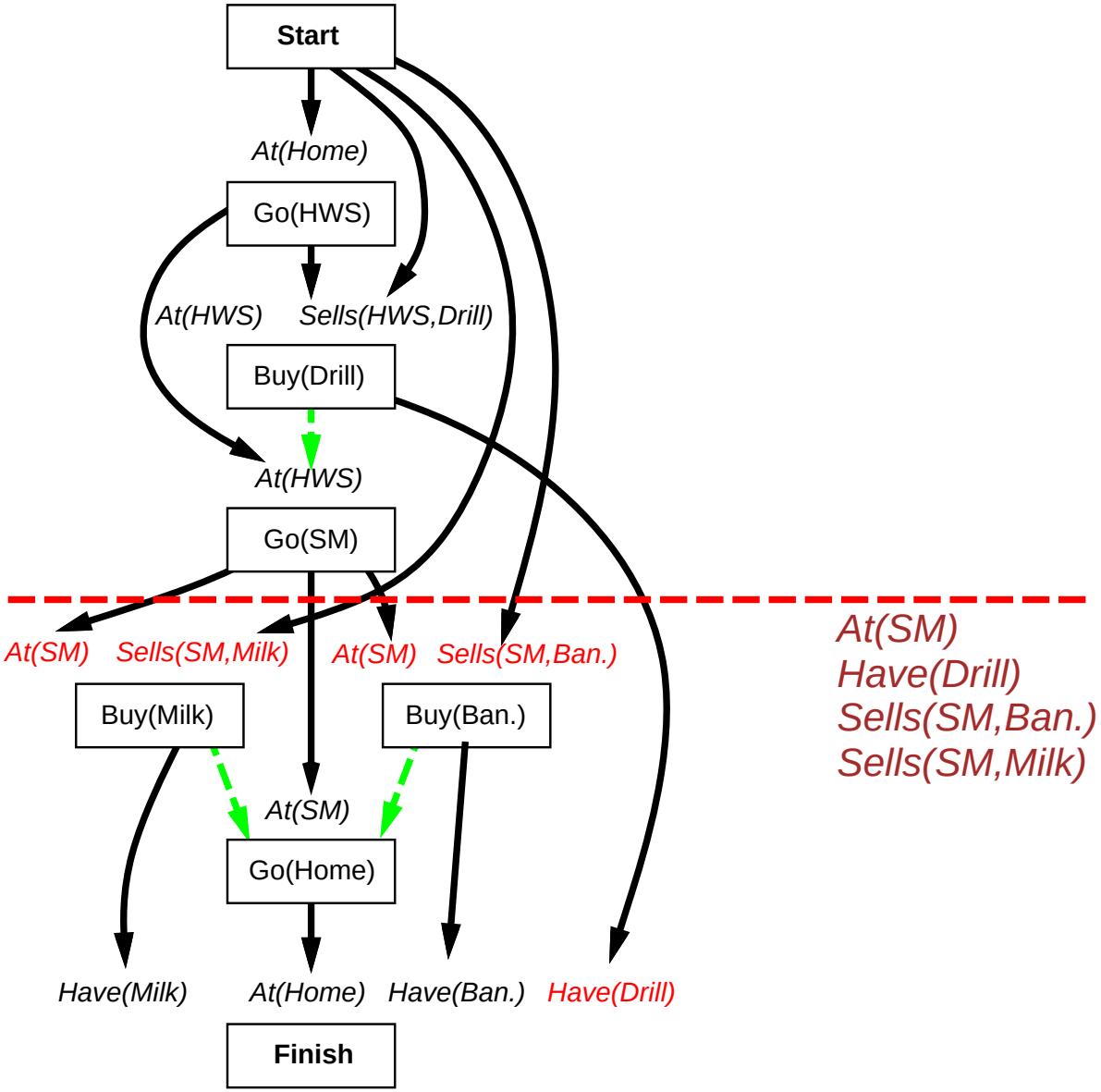


At(HWS)
Sells(HWS,Drill)
Sells(SM,Ban.)
Sells(SM,Milk)

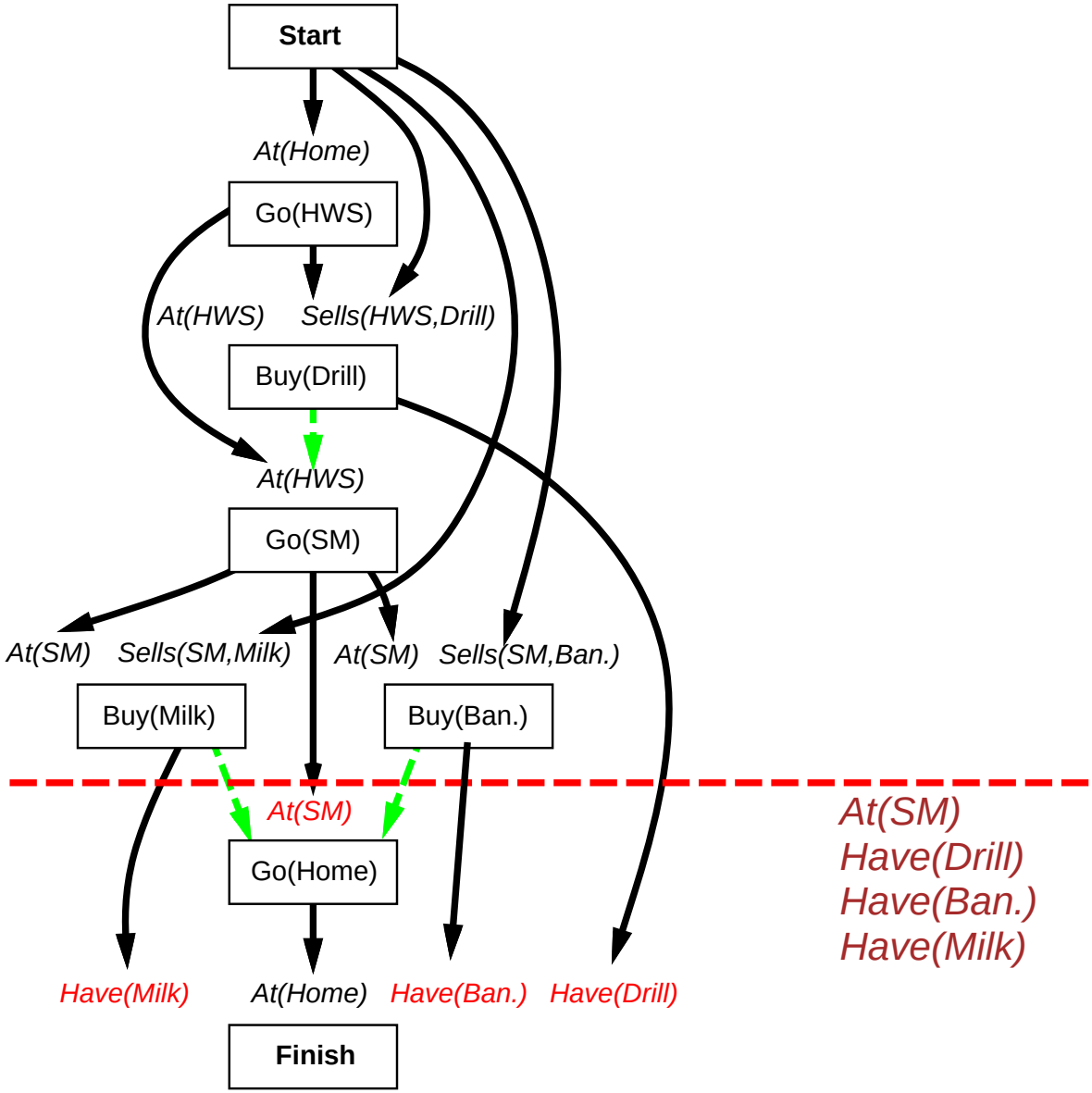
Example


Start
At(Home)
Go(HWS)
At(HWS)
Sells(HWS,Drill)
Buy(Drill)
At(HWS)
Go(SM)
At(SM)
Sells(SM,Milk)
At(SM)
Sells(SM,Ban.)
Buy(Milk)
Buy(Ban.)
At(SM)
Go(Home)
Have(Milk)
At(Home)
Have(Ban.)
Have(Drill)
Finish
At(HWS)
Have(Drill)
Sells(SM,Ban.)
Sells(SM,Milk)

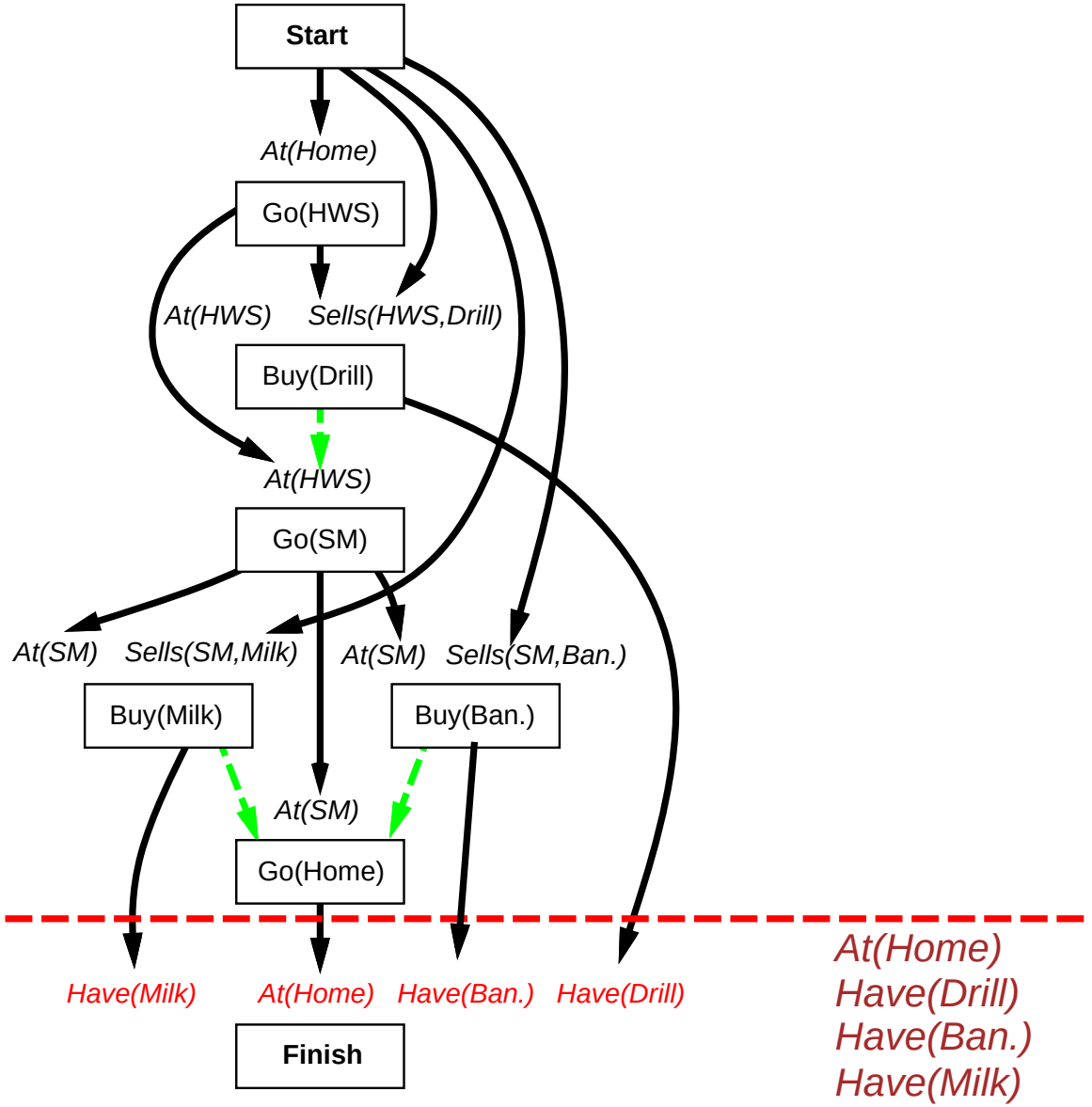
Example


Start
At(Home)
Go(HWS)
At(HWS)
Sells(HWS,Drill)
Buy(Drill)
At(HWS)
Go(SM)
At(SM)
Sells(SM,Milk)
At(SM)
Sells(SM,Ban.)
Buy(Milk)
Buy(Ban.)
At(SM)
Go(Home)
Have(Milk)
At(Home)
Have(Ban.)
Have(Drill)
Finish
At(SM)
Have(Drill)
Sells(SM,Ban.)
Sells(SM,Milk)

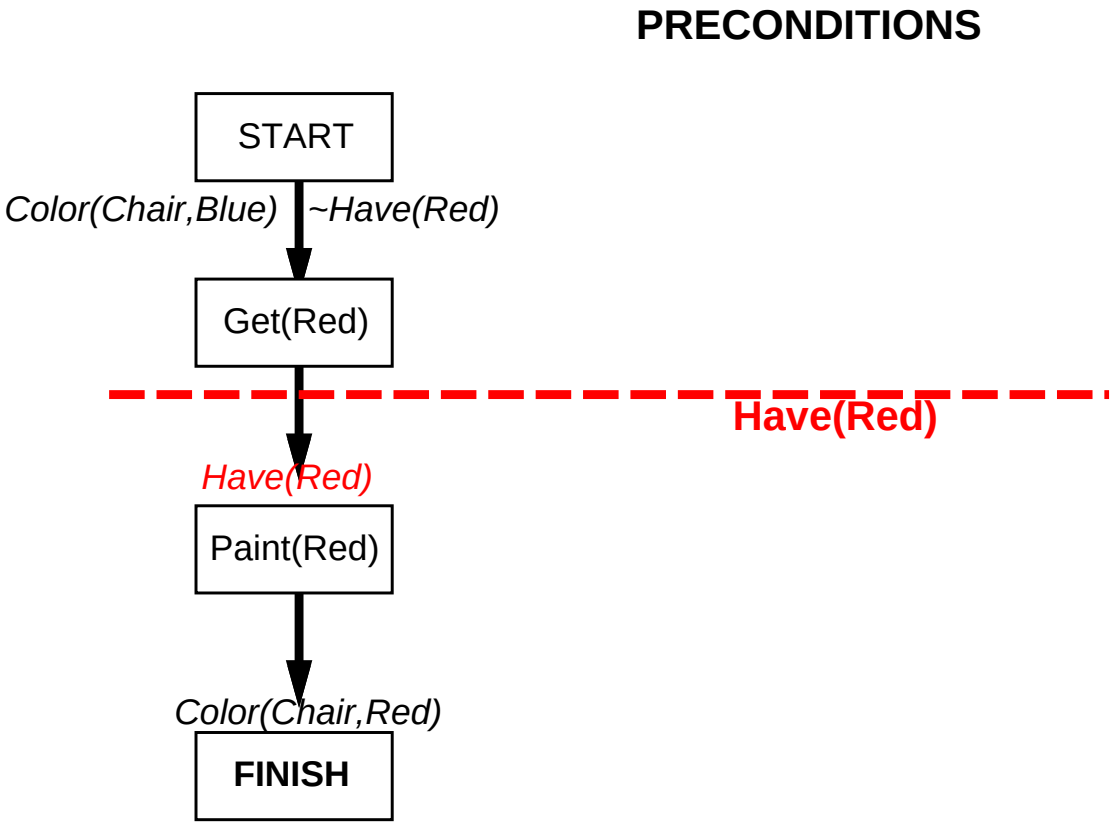
Example


Start
At(Home)
Go(HWS)
At(HWS)
Sells(HWS,Drill)
Buy(Drill)
At(HWS)
Go(SM)
At(SM)
Sells(SM,Milk)
At(SM)
Sells(SM,Ban.)
Buy(Milk)
Buy(Ban.)
At(SM)
Go(Home)
Have(Milk)
At(Home)
Have(Ban.)
Have(Drill)
Finish
At(SM)
Have(Drill)
Have(Ban.)
Have(Milk)

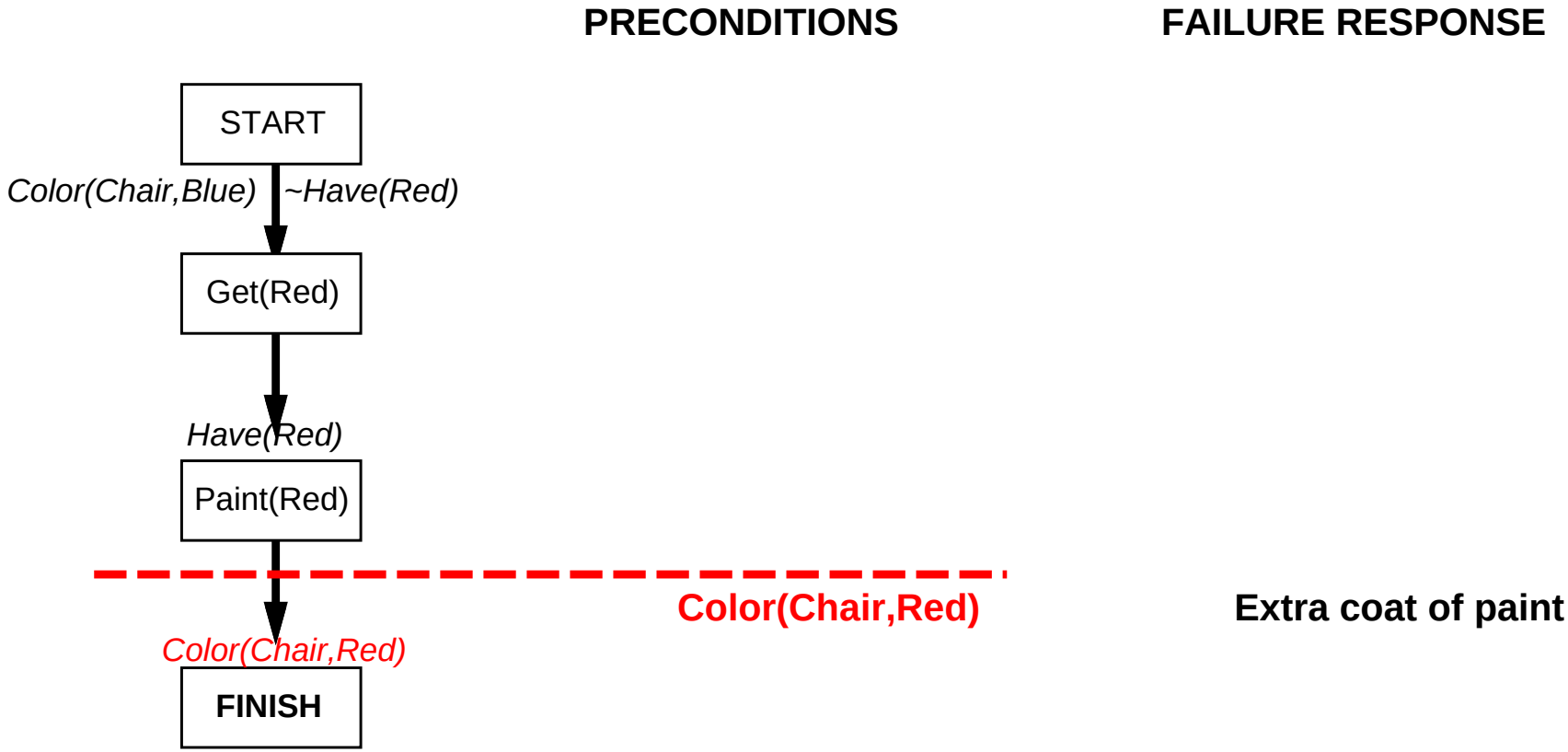
Example


Start
At(Home)
Go(HWS)
At(HWS)
Sells(HWS,Drill)
Buy(Drill)
At(HWS)
Go(SM)
At(SM)
Sells(SM,Milk)
At(SM)
Sells(SM,Ban.)
Buy(Milk)
Buy(Ban.)
At(SM)
Go(Home)
Have(Milk)
At(Home)
Have(Ban.)
Have(Drill)
Finish
At(Home)
Have(Drill)
Have(Ban.)
Have(Milk)

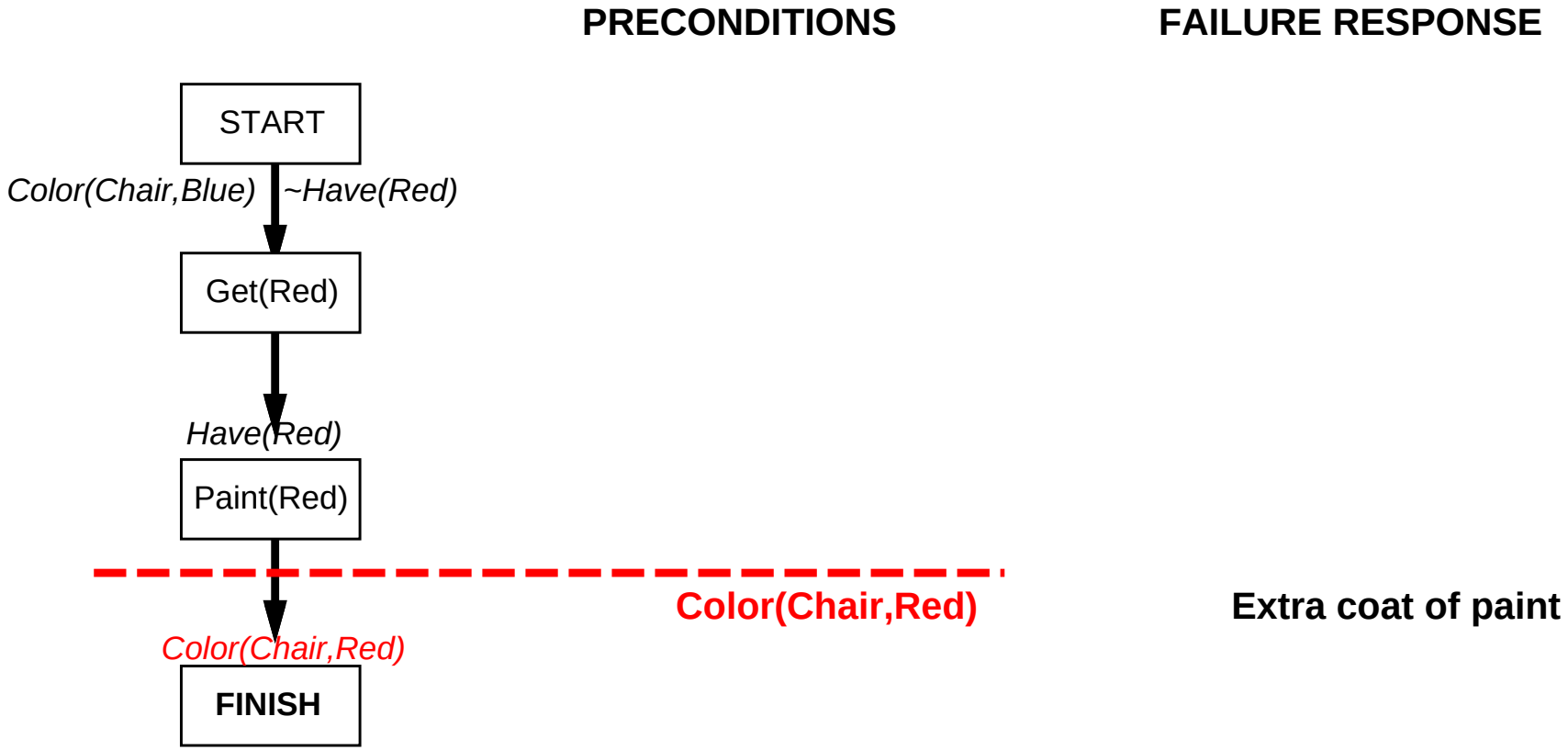
Emergent behaviour



Emergent behaviour



Emergent behaviour



"Loop until success" behaviour *emerges* from interaction between monitor/replan agent design and uncooperative environment

Next lecture

Revision