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Contingent Planning as And/Or forward Search with Disjunctive Representation

Outline

- Contingent planning
- Approach overview
  - Employed **DNF representation**
  - **PrAO**: a new And/Or forward search with **novel pruning techniques**
- DNF representation: review & **extension**
- **PrAO** And/Or forward search algorithm
- Experimental evaluation
- Conclusion and future work

Outline

- Contingent planning
  - An example & formulation
  - And/Or search for solutions
- Approach overview
  - Employed DNF representation
  - **PrAO**: an And/Or forward search
- DNF representation: review & extension
- And/Or forward search algorithm: PrAO
- Experimental evaluation
- Conclusion and future work

Contingent Planning: An Example

at-same-room
¬bug-is-dead

¬at-same-room
¬bug-is-dead

Contingent Planning Problem

- Problem $P = \langle F, A, \Omega, I, G \rangle$
  - **Fluents**: $F = \{bug\text{-}is\text{-}dead, at\text{-}same\text{-}room\}$
  - **Actions**: $A = \{move, kill\text{-}bug\}$
    - $pre(move) = \emptyset$
      $move: at\text{-}same\text{-}room \rightarrow \neg at\text{-}same\text{-}room$
      $move: \neg at\text{-}same\text{-}room \rightarrow at\text{-}same\text{-}room$
    - $pre(kill\text{-}bug) = at\text{-}same\text{-}room$
      $kill\text{-}bug: \emptyset \rightarrow bug\text{-}is\text{-}dead$
  - **Sensing**: $\Omega = \{sense\text{-}bug\}$, $pre(sense\text{-}bug) = \emptyset$
    - $l(sense\text{-}bug) = at\text{-}same\text{-}room$
  - **Initial State**: $I = \neg bug\text{-}is\text{-}dead$ (? $at\text{-}same\text{-}room$)
  - **Goal**: G = bug-is-dead

- The initial *Belief State:* set of states satisfying I:
  $BS(I) = \{ \{\neg bug\text{-}is\text{-}dead, at\text{-}same\text{-}room\}$,
  $\{\neg bug\text{-}is\text{-}dead, \neg at\text{-}same\text{-}room\} \}$

Outline

- Contingent planning
  - ✓Formulation
  - ➢And/Or search for solutions
- Approach overview
  - ▪Employed DNF representation
  - ▪**PrAO**: an And/Or forward search
- DNF representation: review & extension
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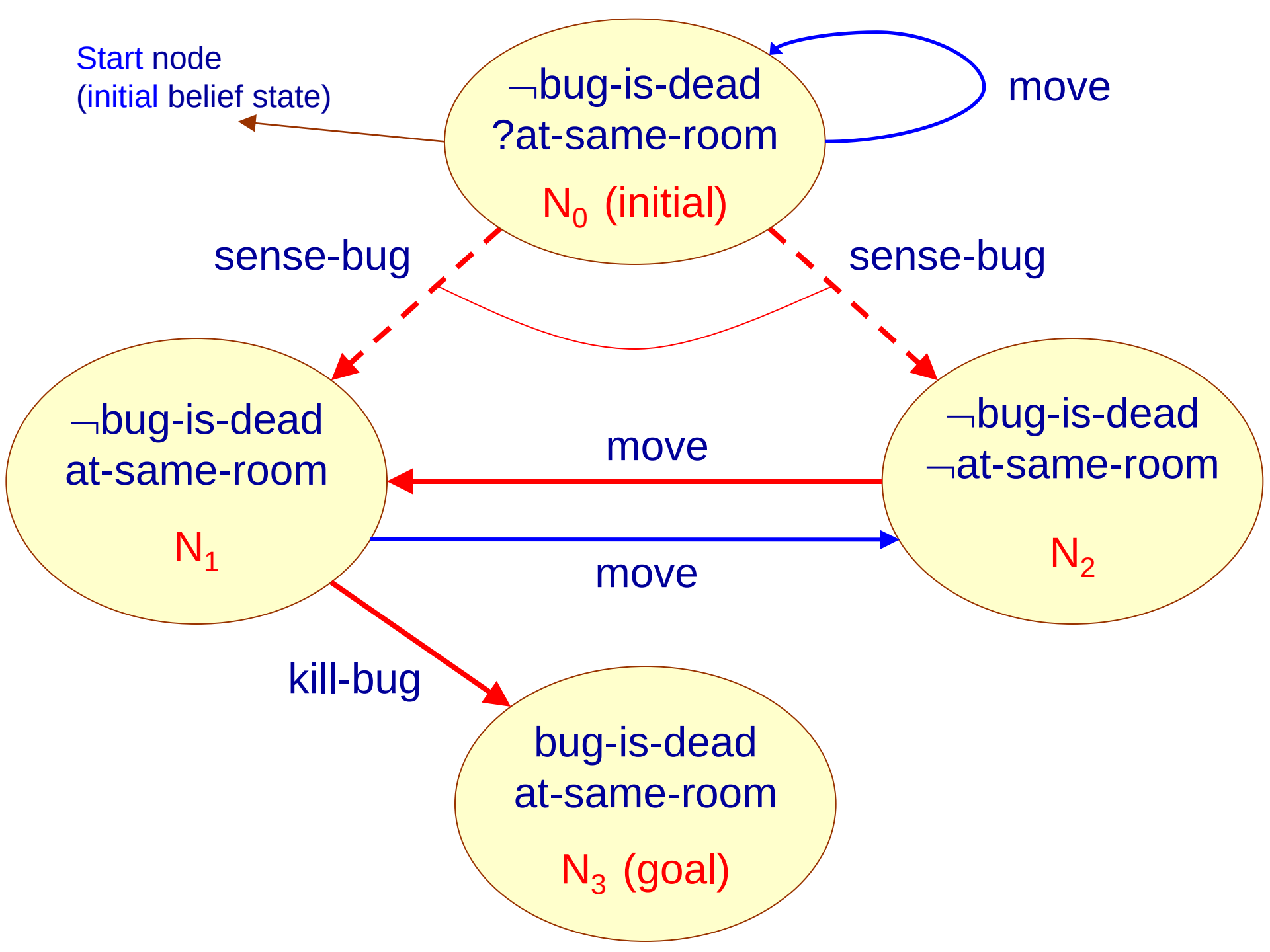

Start node
(initial belief state)
¬bug-is-dead
?at-same-room
N0 (initial)
move
sense-bug
sense-bug
¬bug-is-dead
at-same-room
N1
move
¬bug-is-dead
¬at-same-room
N2
move
kill-bug
bug-is-dead
at-same-room
N3 (goal)

Overview of Our Approach

- **Extend DNF representation** for conformant planning (ICAPS-2009) to handle
  - Non-deterministic actions
  - Sensing actions
- **Develop PrAO**: an And/Or forward search with
  - Novel pruning techniques
  - The remaining search graph when a solution is detected is also the solution

Outline

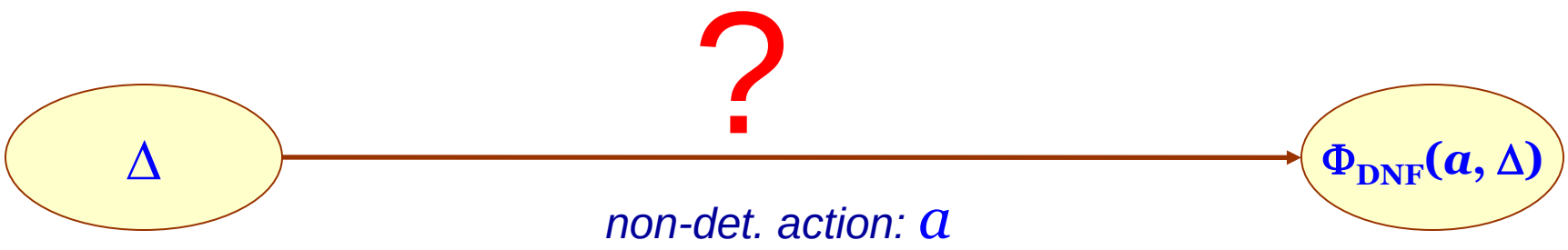
- ✓ Contingent planning
- ✓ Approach overview
- ➢ DNF representation
  - ➢ Brief review (conformant planning)
  - ▪ Extending for contingent planing
- And/Or forward search algorithm: PrAO
- Experimental evaluation
- Conclusion and future work

Outline

- ✓ Contingent planning
- ✓ Approach overview
- DNF representation
  - ✓ Review (conformant planning)
  - ➢ Extending for contingent planning
- And/Or forward search algorithm: PrAO
- Experimental evaluation
- Conclusion and future work

Extending to Non-deterministic action

- A non-deterministic action a contains a set of outcomes: o_1, …, o_n. (a is deterministic if $n = 1$)
- o_i is a set of conditional effects
- a_i : the deterministic action with set of effects o_i



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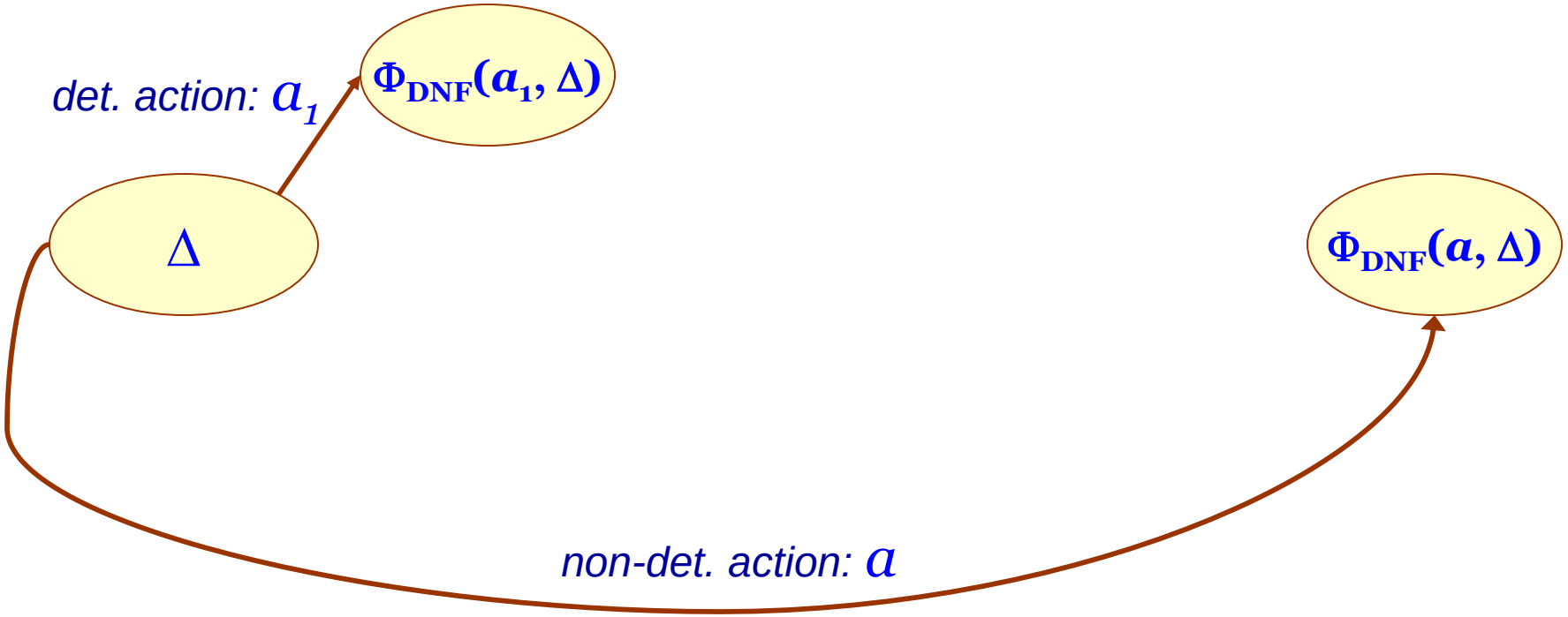

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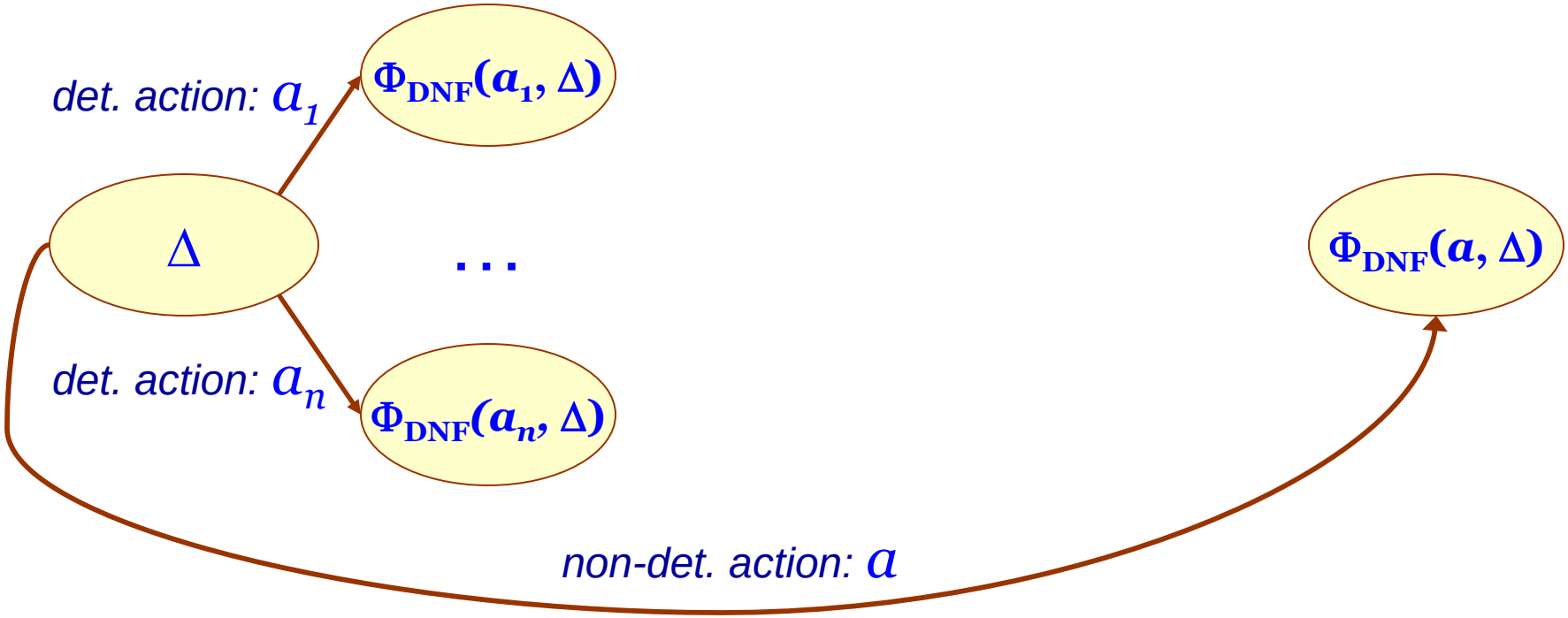

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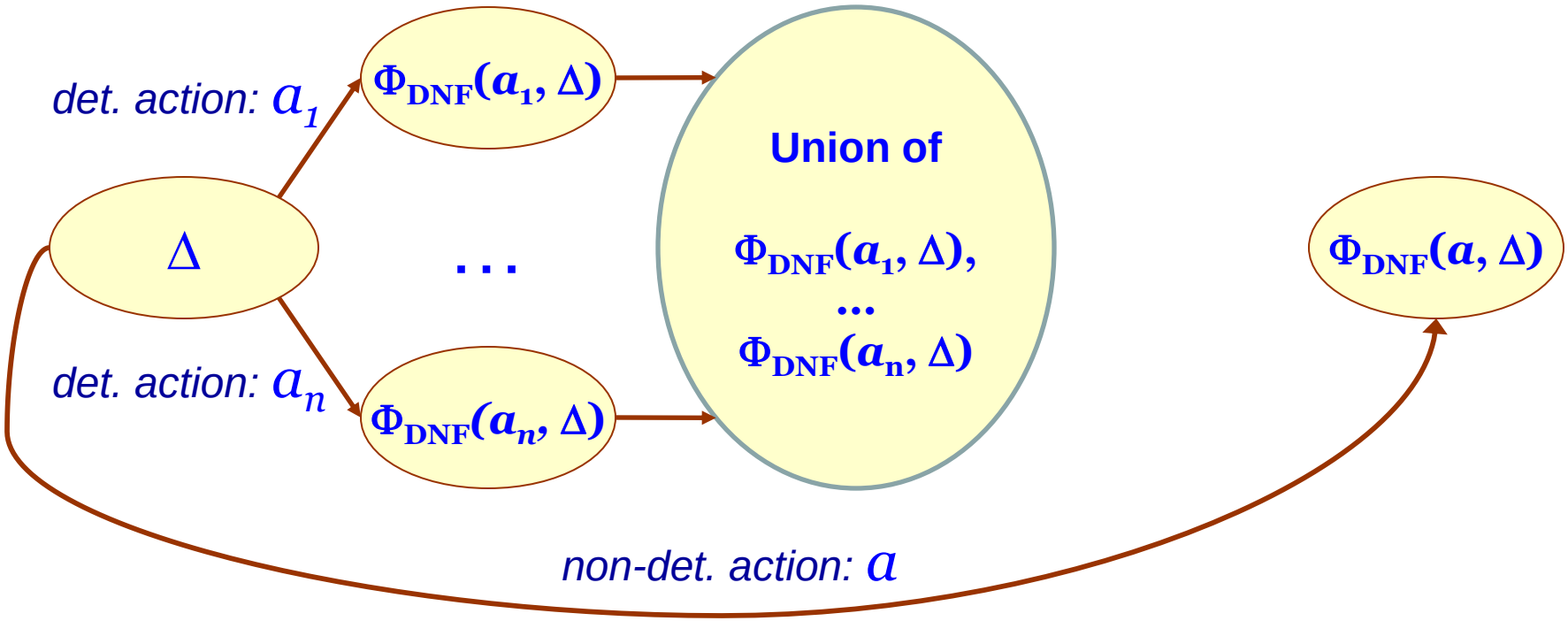

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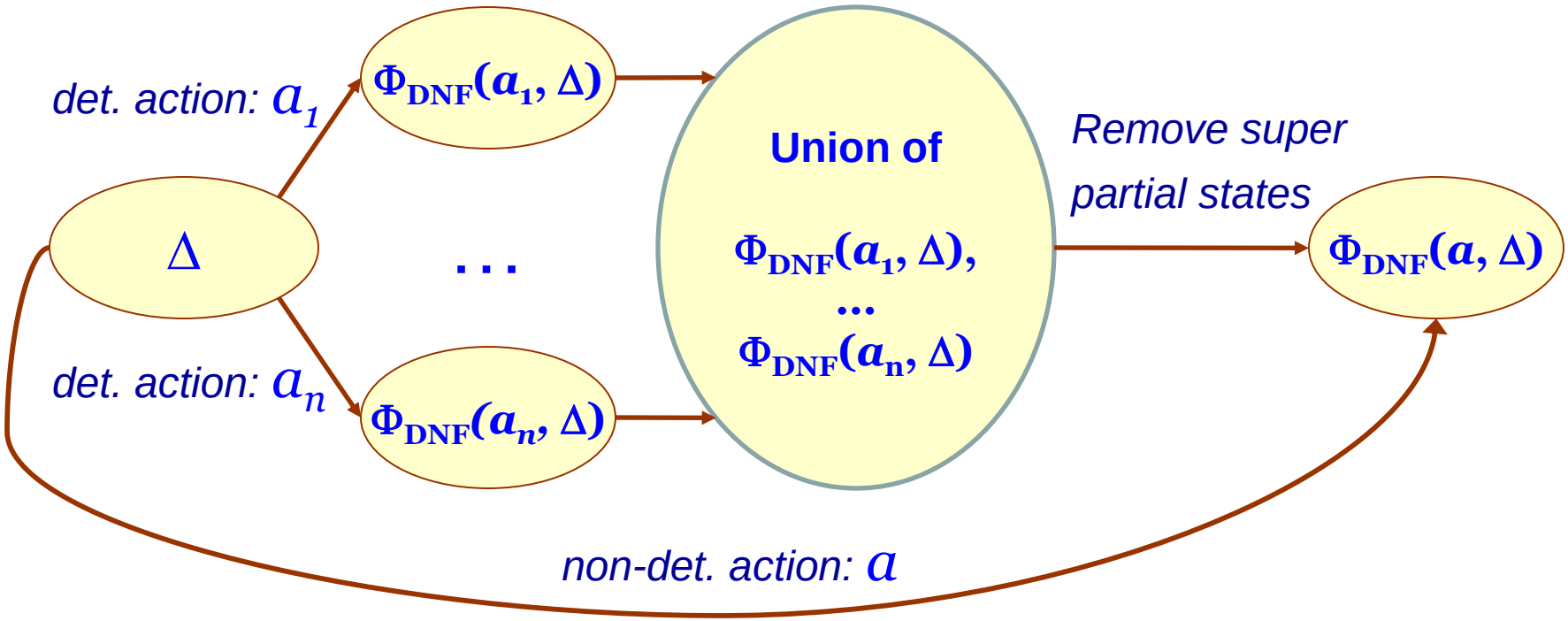


Successor states for Sensing Actions

- Sensing action ω:
  - $(\omega, S) \rightarrow (S^+, S^-)$
    - $S^+ = \{s \mid s \in S, s \models l(\omega)\}$
    - $S^- = \{s \mid s \in S, s \models \neg l(\omega)\}$
  - $(\omega, \Delta) \rightarrow (\Delta^+, \Delta^-)$: $\Delta^+ \equiv S^+$ $\Delta^- \equiv S^-$ $(\Delta^+ \models l(\omega)$ $\Delta^- \models \neg l(\omega))$
  - Initially: $\Delta^+ = \Delta^- = \varnothing$
  - For every $\delta \in \Delta$:
    - If $\delta \models l(\omega)$ then: $\Delta^+ = \Delta^+ \cup \{ \delta \}$
    - Else if $\delta \models \neg l(\omega)$ then: $\Delta^- = \Delta^- \cup \{ \delta \}$
    - Else:

      $\Delta^+ = \Delta^+ \cup \{ \delta^+ \}$ $\delta^+ = \delta \cup \{ l(\omega) \}$

      $\Delta^- = \Delta^- \cup \{ \delta^- \}$ $\delta^- = \delta \cup \{ \neg l(\omega) \}$

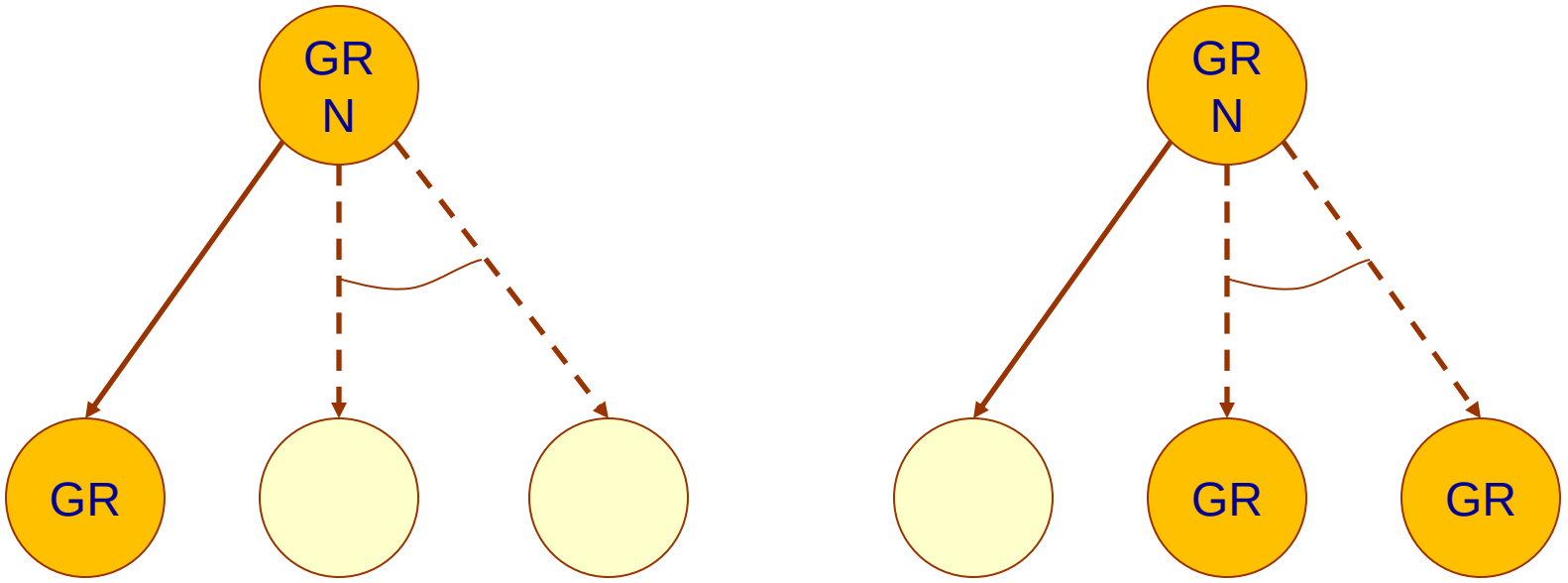
      Intuitively: $\delta \equiv \delta^+ \cup \delta^-$ $\Delta^+ \equiv S^+$ $\Delta^- \equiv S^-$

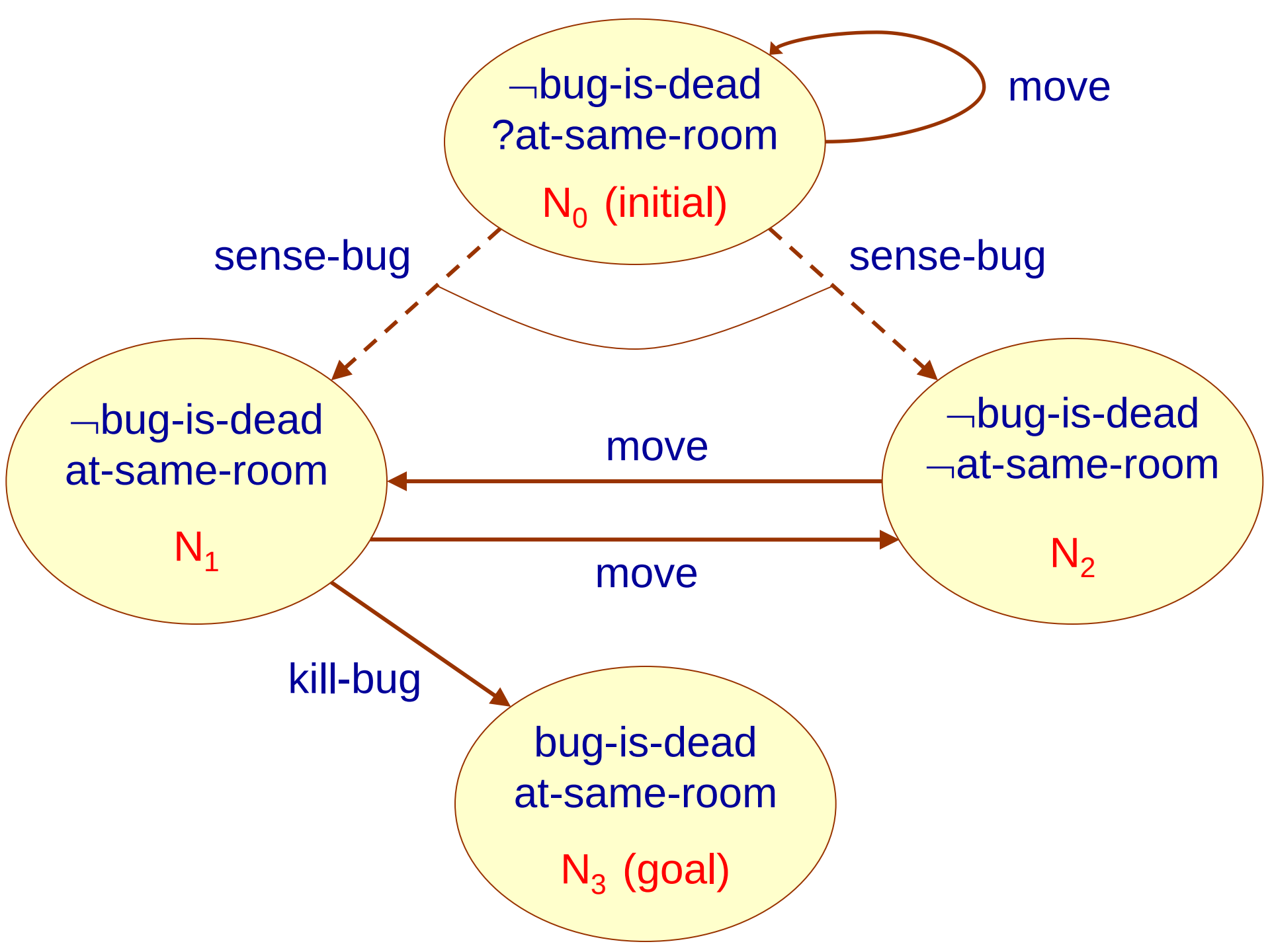
Outline

- ✓ Contingent planning
- ✓ Approach overview
- ✓ DNF representation: review & extension
- ➢ PrAO: a new And/Or forward search:
  - ➢ Search space is a **directed graph**
  - ➢ **Novel pruning techniques**
- • Experimental evaluation
- • Conclusion and future work

Goal Reachability

- Node N is ***goal reachable*** (GR) if:
  - Goal node (satisfies the goal), or
  - Has a goal-reachable or-child, or
  - Both dual and-children are goal-reachable

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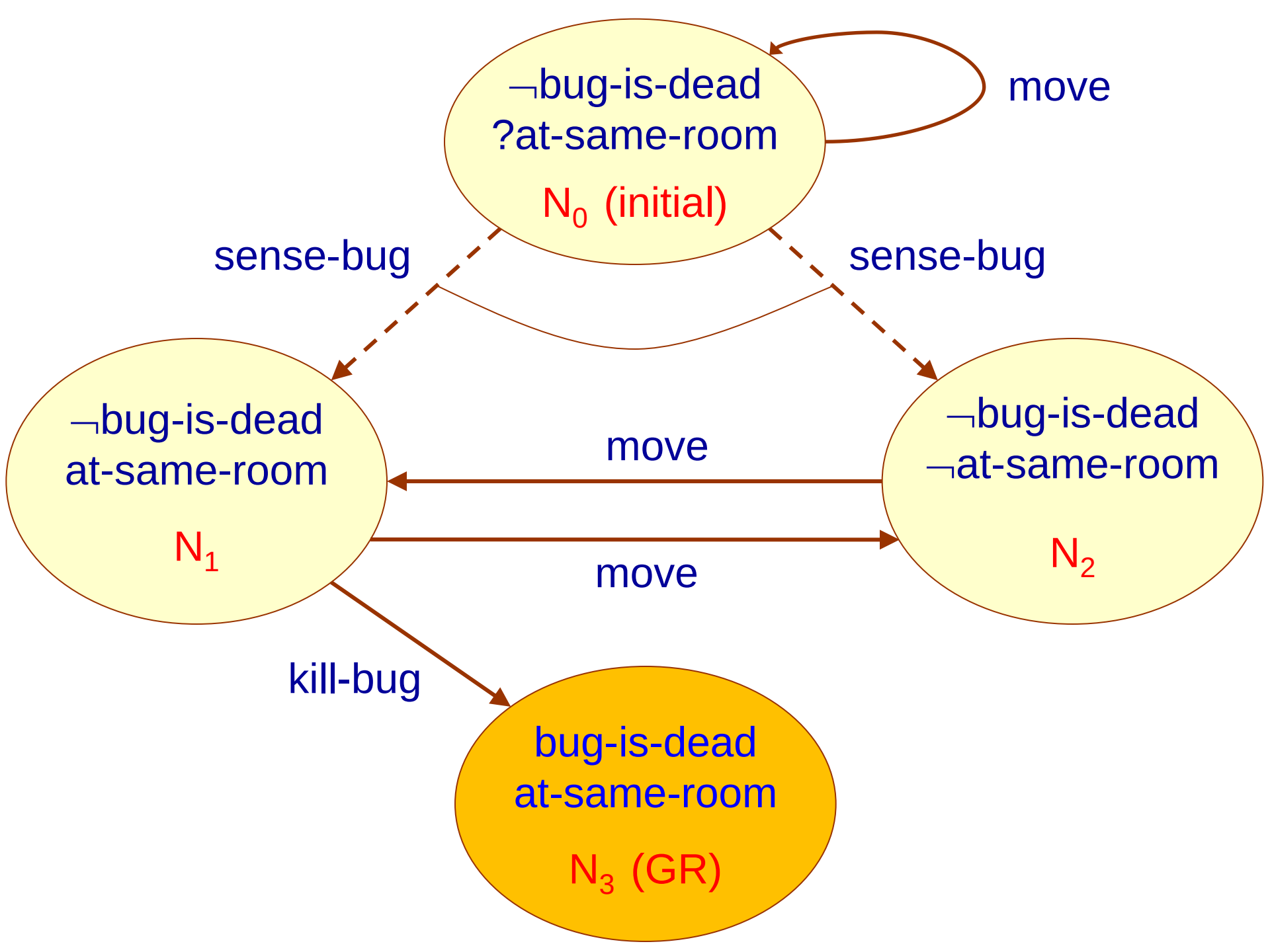
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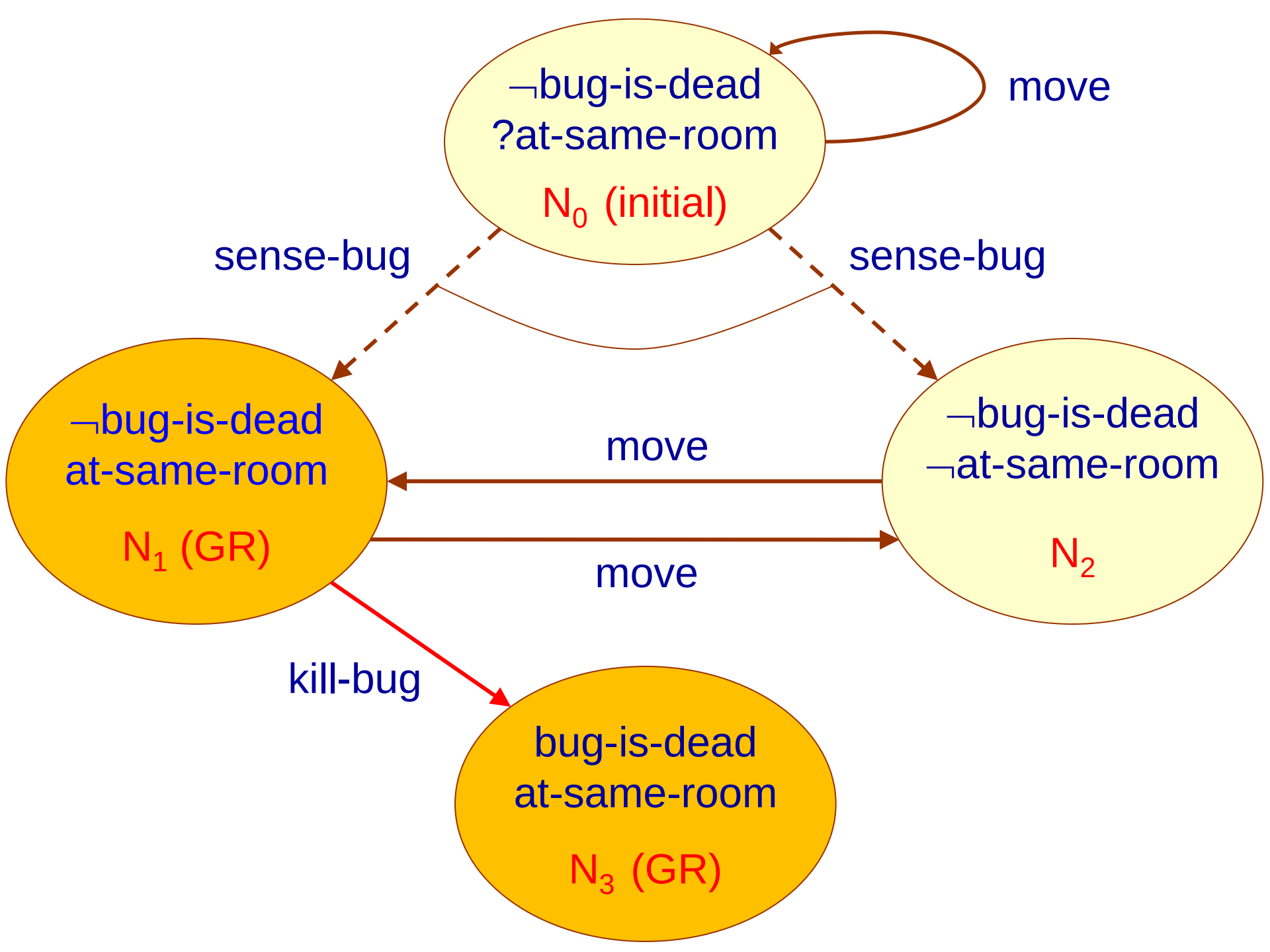
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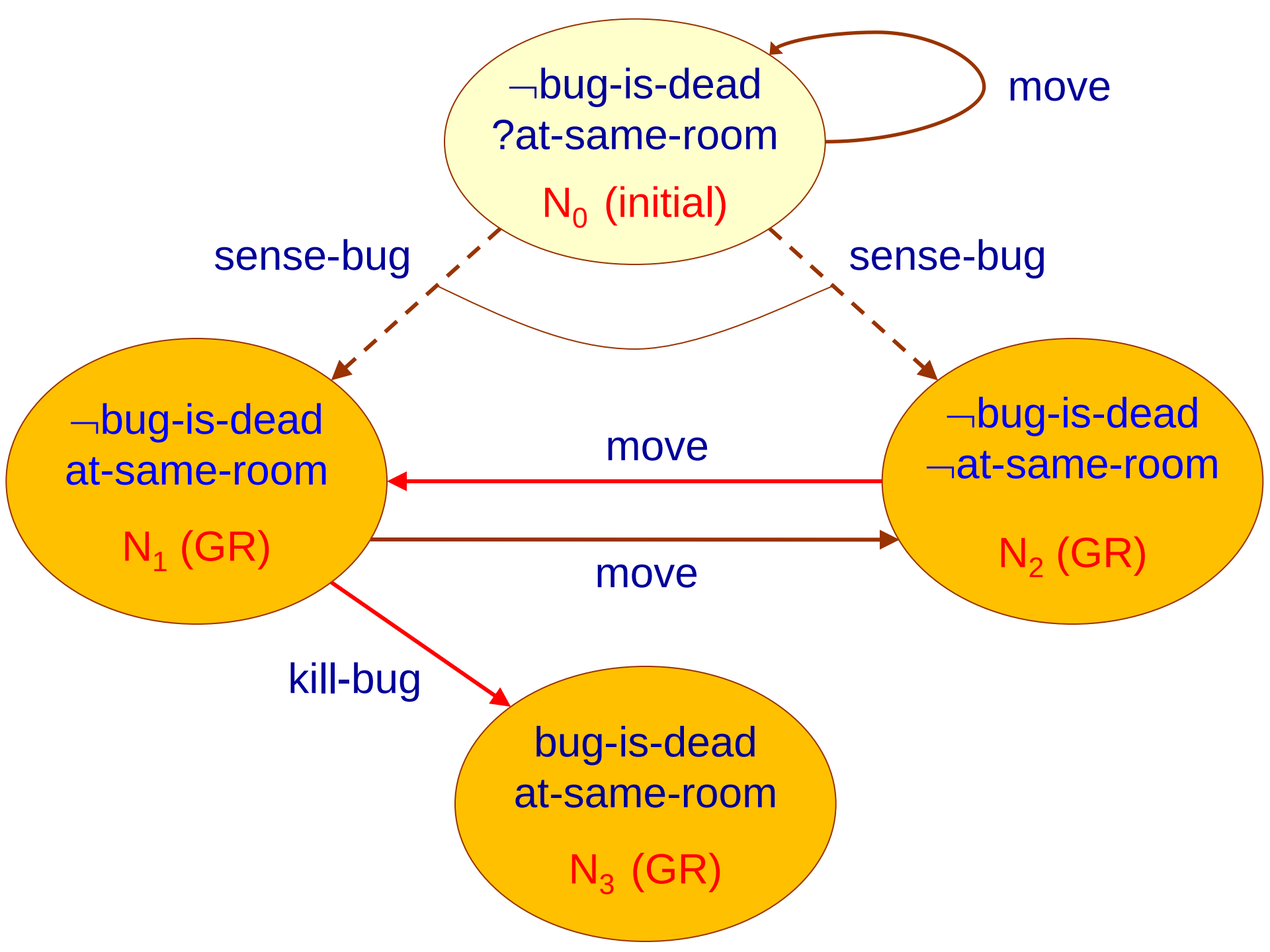
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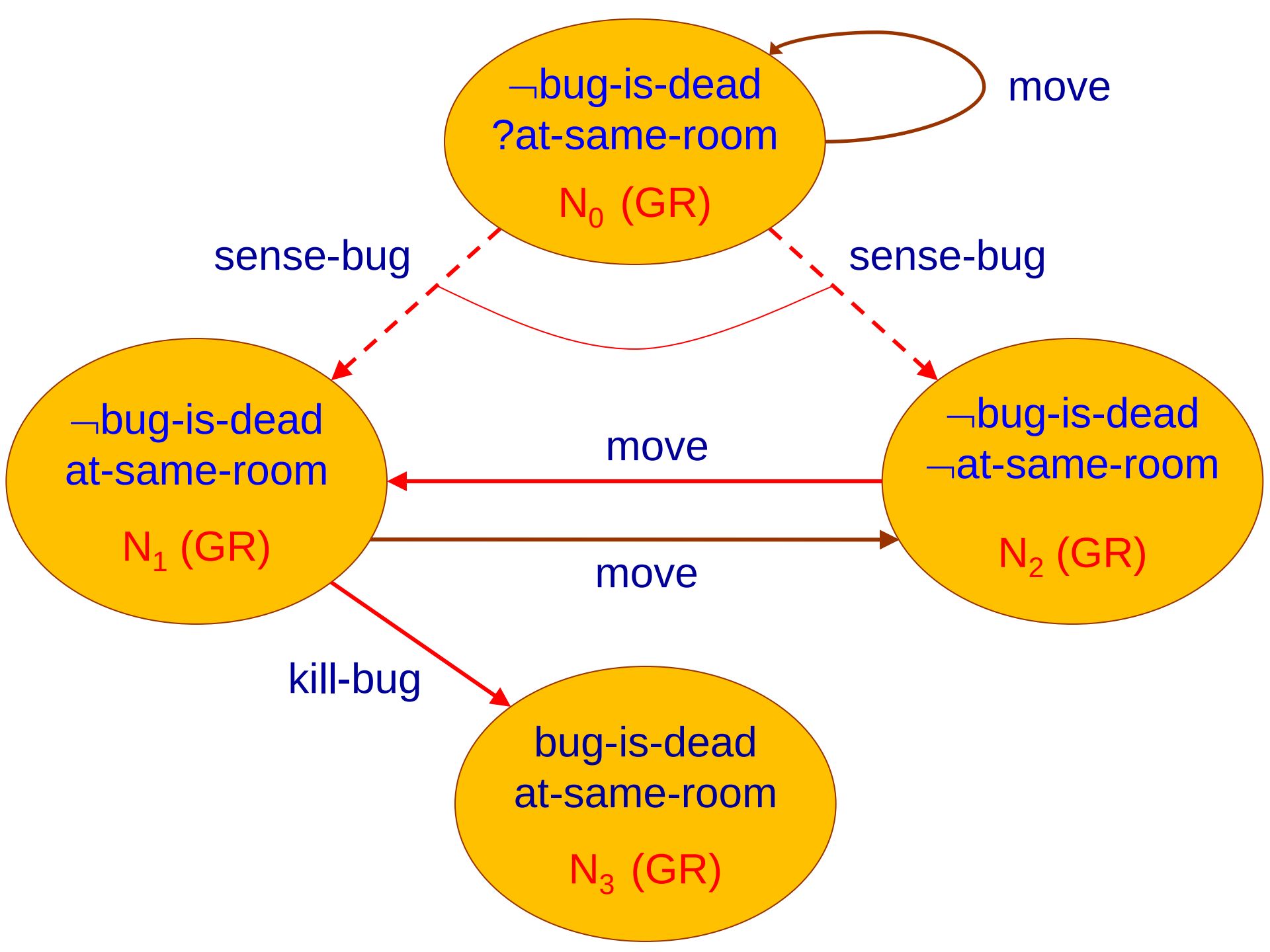
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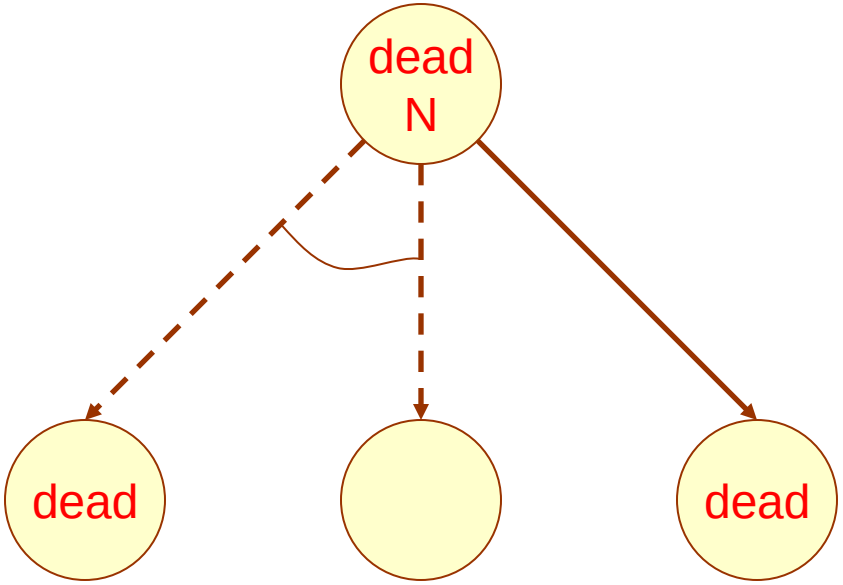
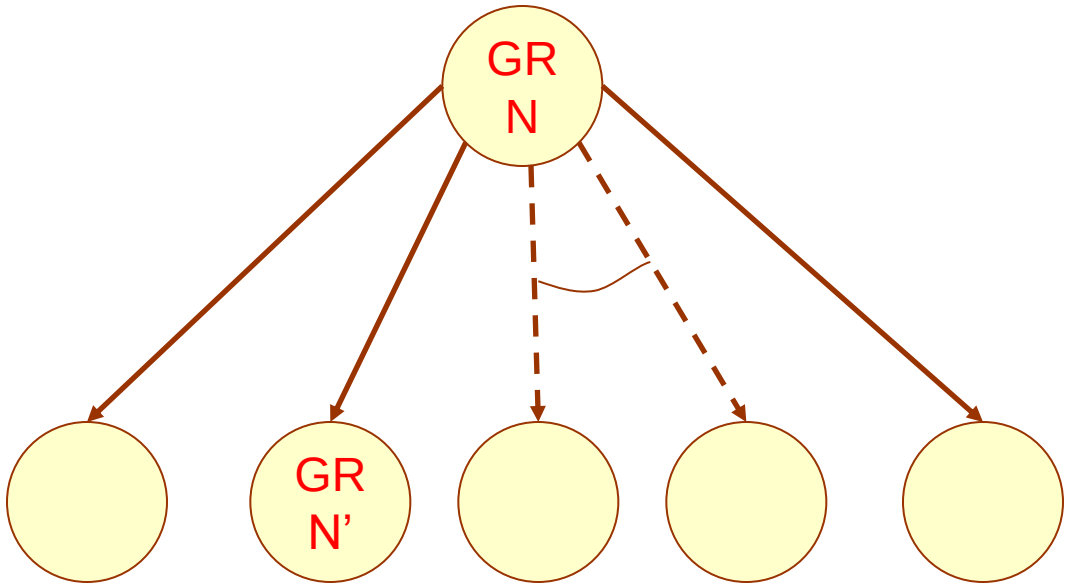
Dead Node Propagation

- Node *N* is **dead** if *N* ≠ goal and either:
  - N has no outgoing edges; or
  - Every or-child is dead, and for every pair of dual and-children, at least one is dead

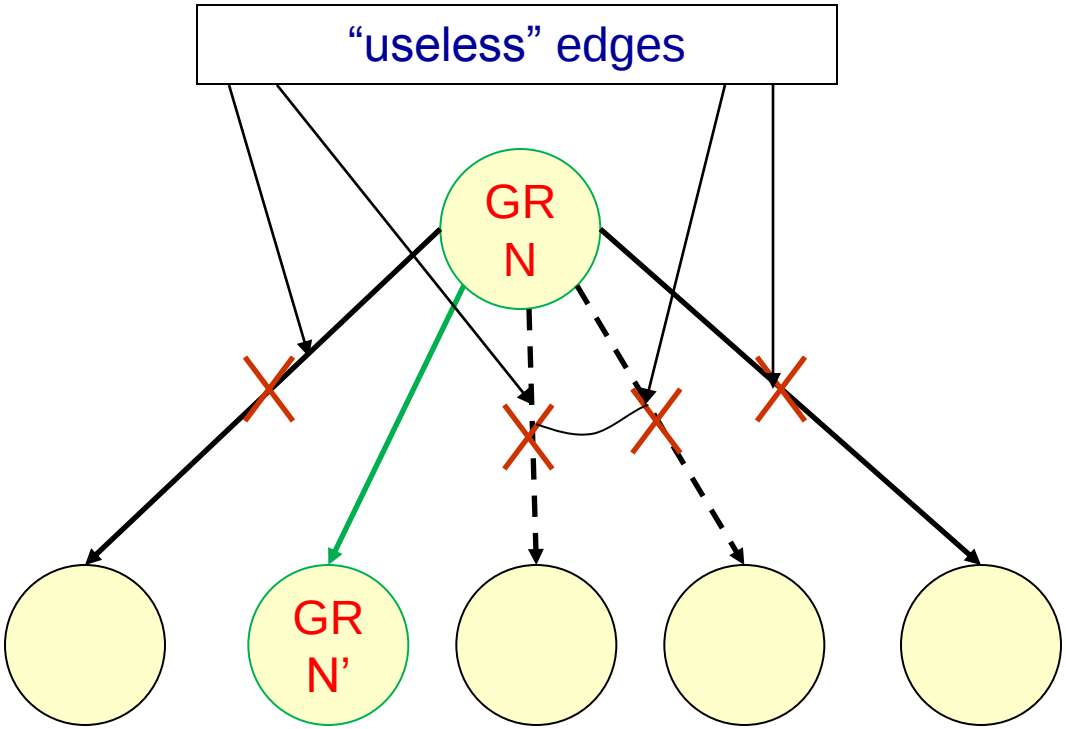


Pruning

- Observation 1:
  - Some edges may become “useless” due to goal-reachable path



PrAO Algorithm: Pruning Technique



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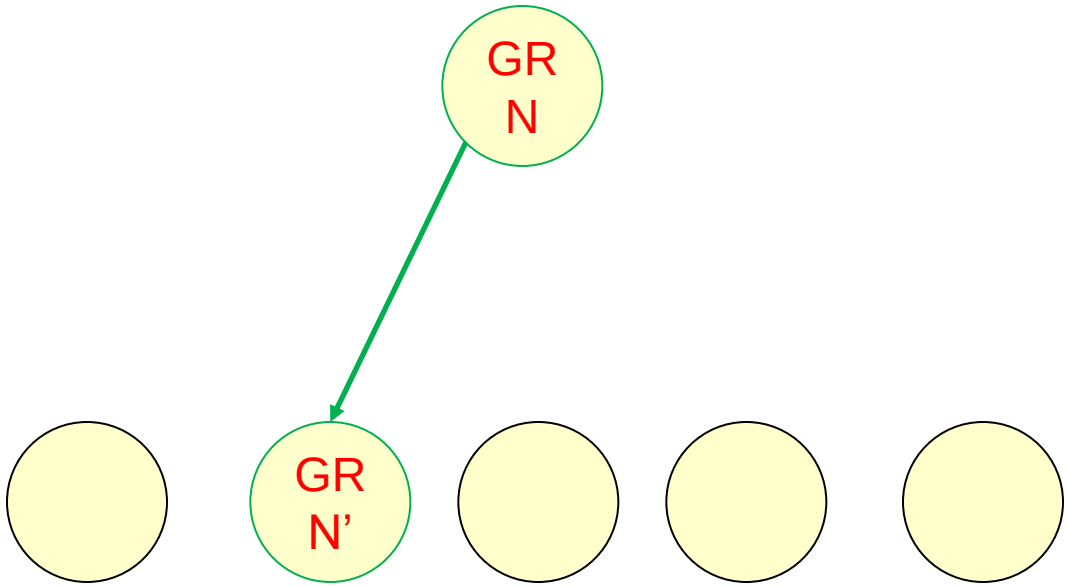

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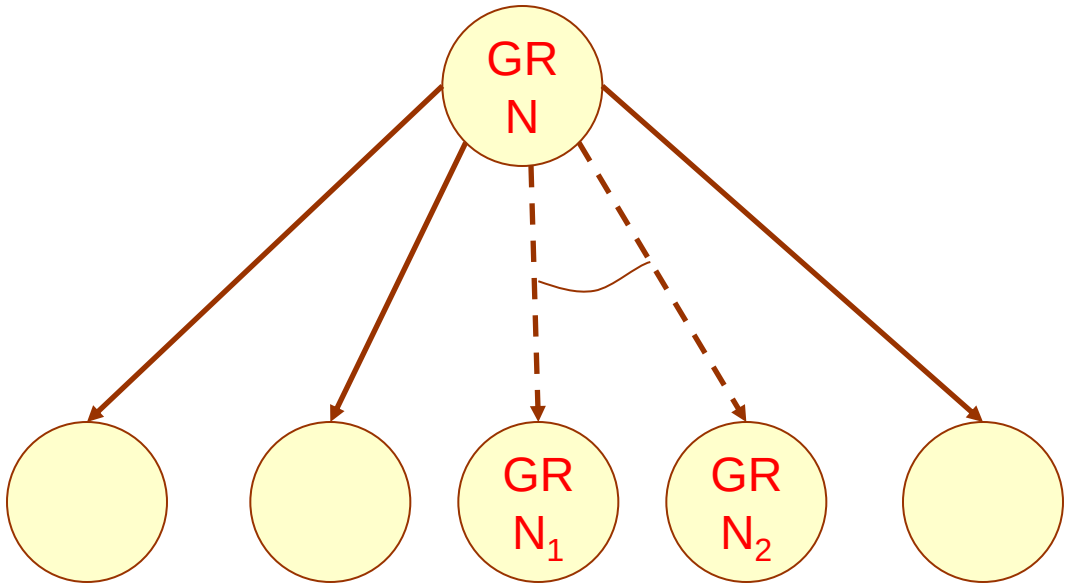

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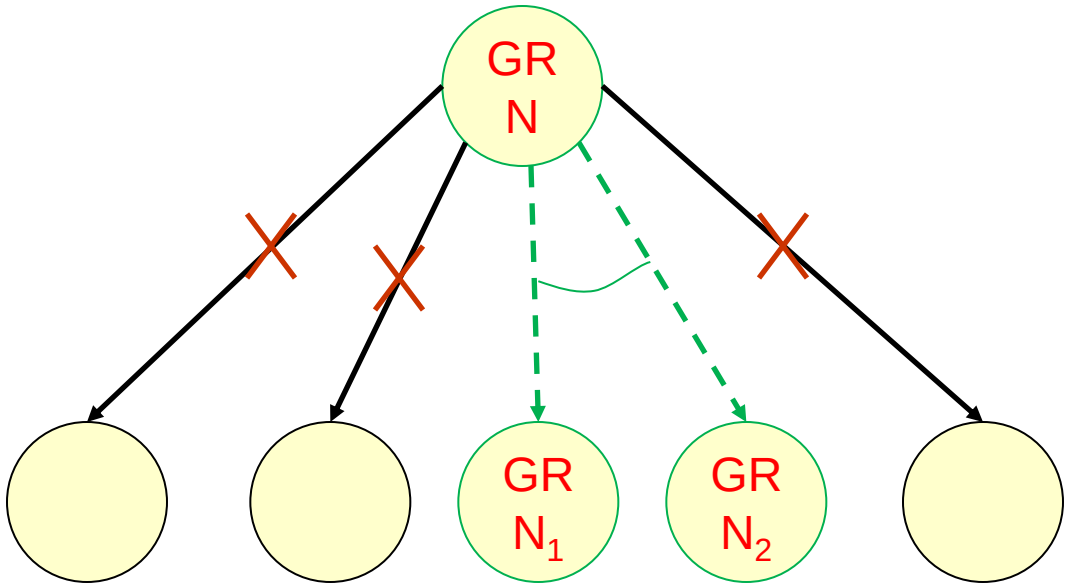

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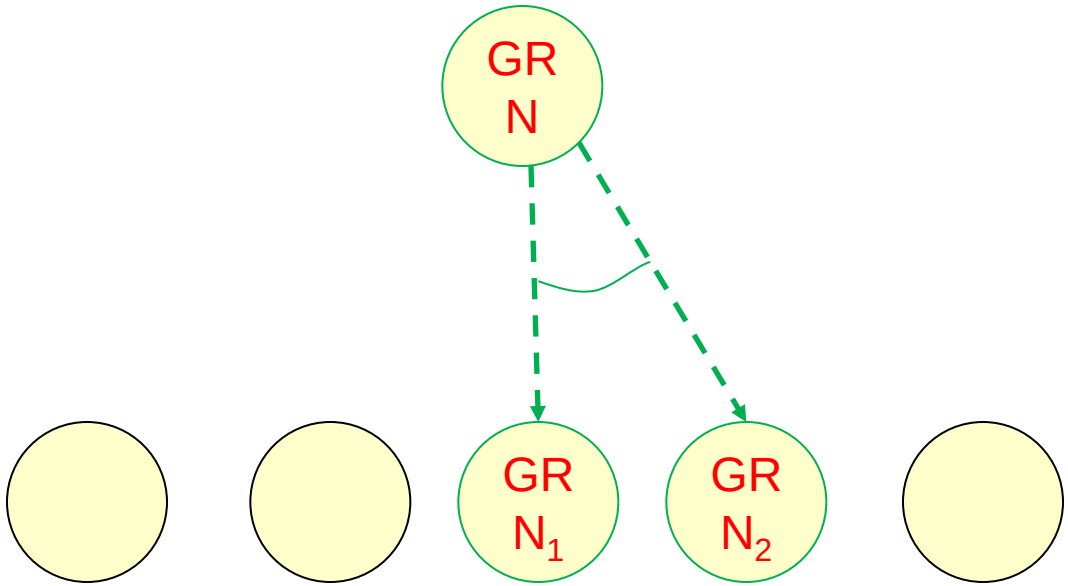
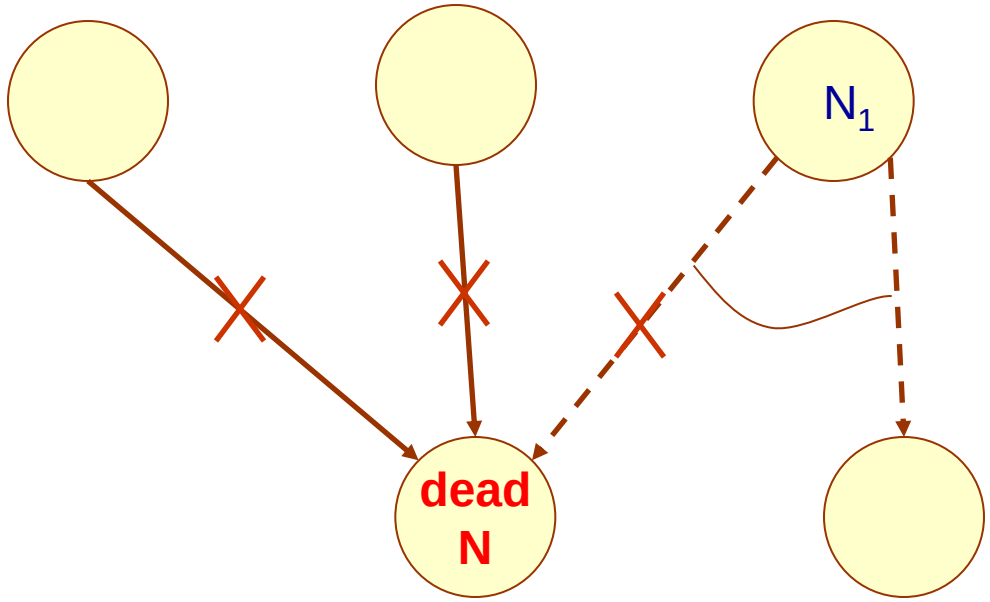


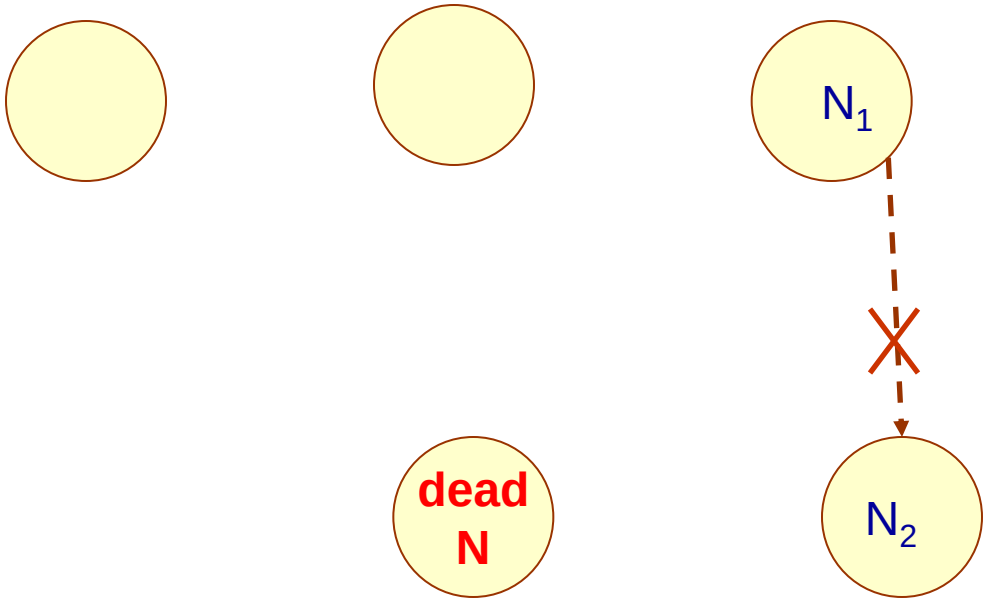
PrAO Algorithm: Pruning Technique

- Observation 2:
  - Edges can be removed due to a dead-node



PrAO Algorithm: Pruning Technique

- Observation 2:
  - Edges can be removed by dead-nodes



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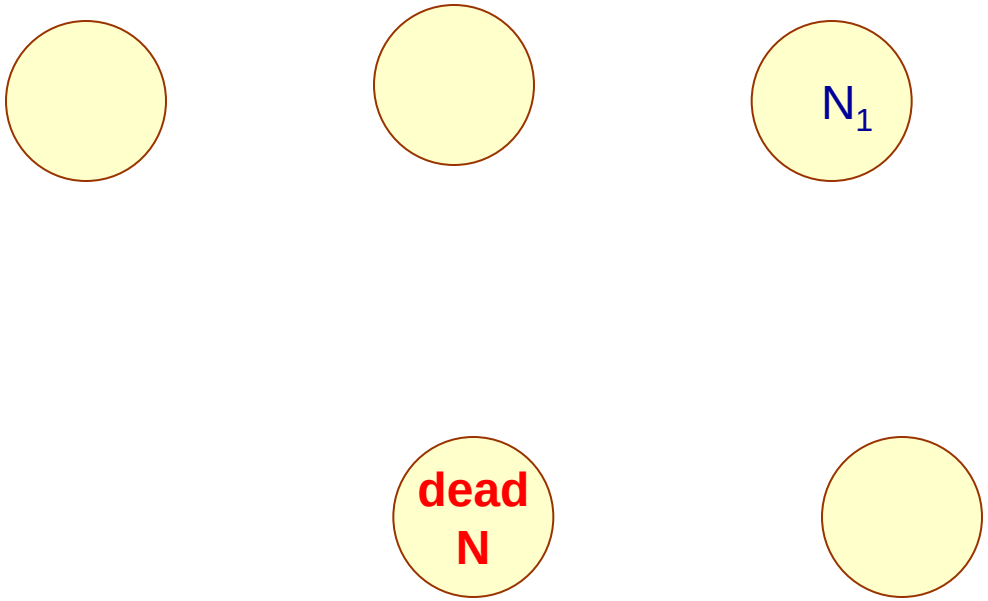
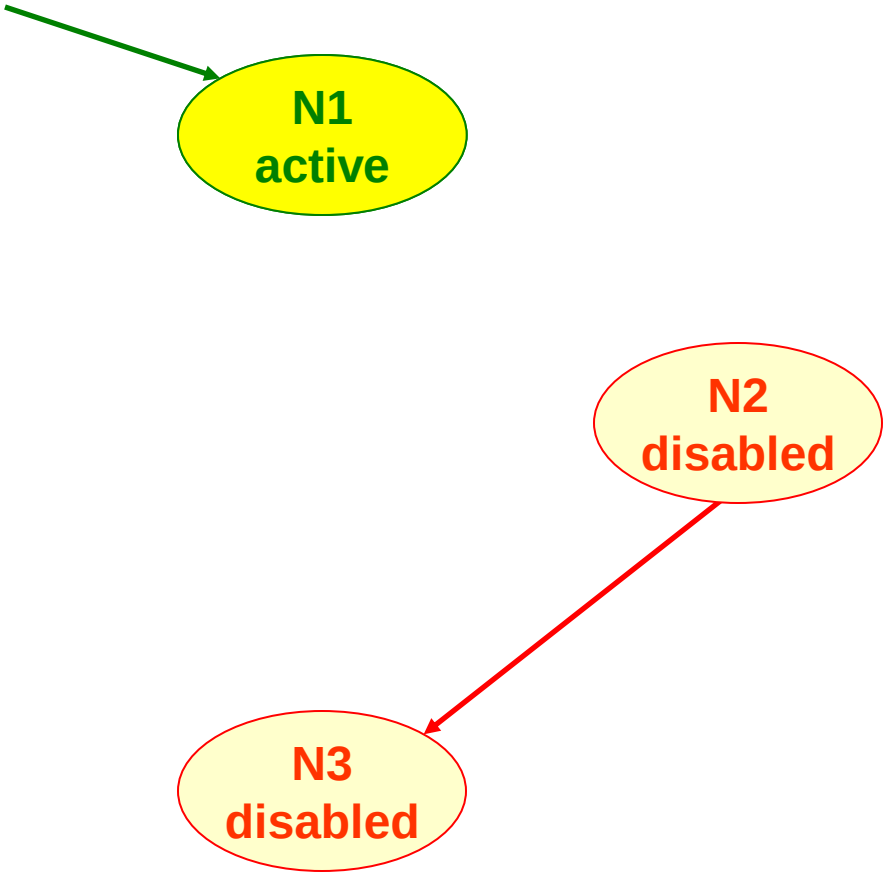


PrAO Algorithm: Pruning Technique

- Active nodes: can be reached from the start node
- Some nodes (and their descendants if exist) may become disabled (inactive) after removing useless edges
- Expand only active nodes
- A disabled node *N* may become active again if it is a child of being expanded node. If *N* is active then so are its descendants (*reactivate-propagation*).

PrAO: Reactivate Disabled Nodes



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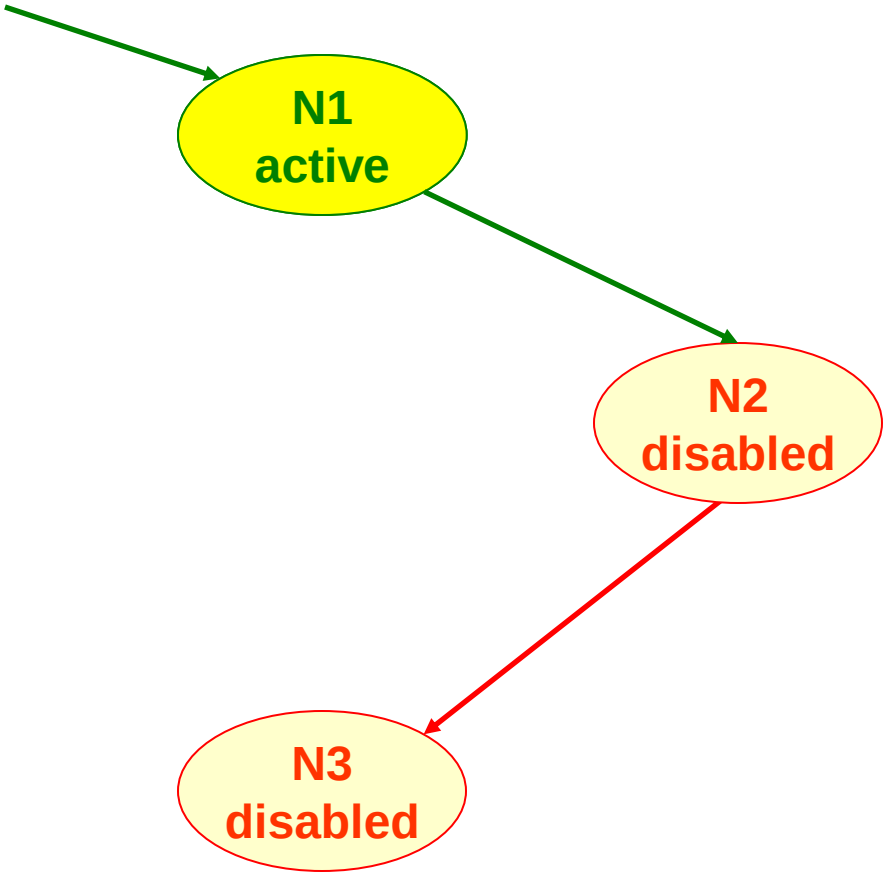

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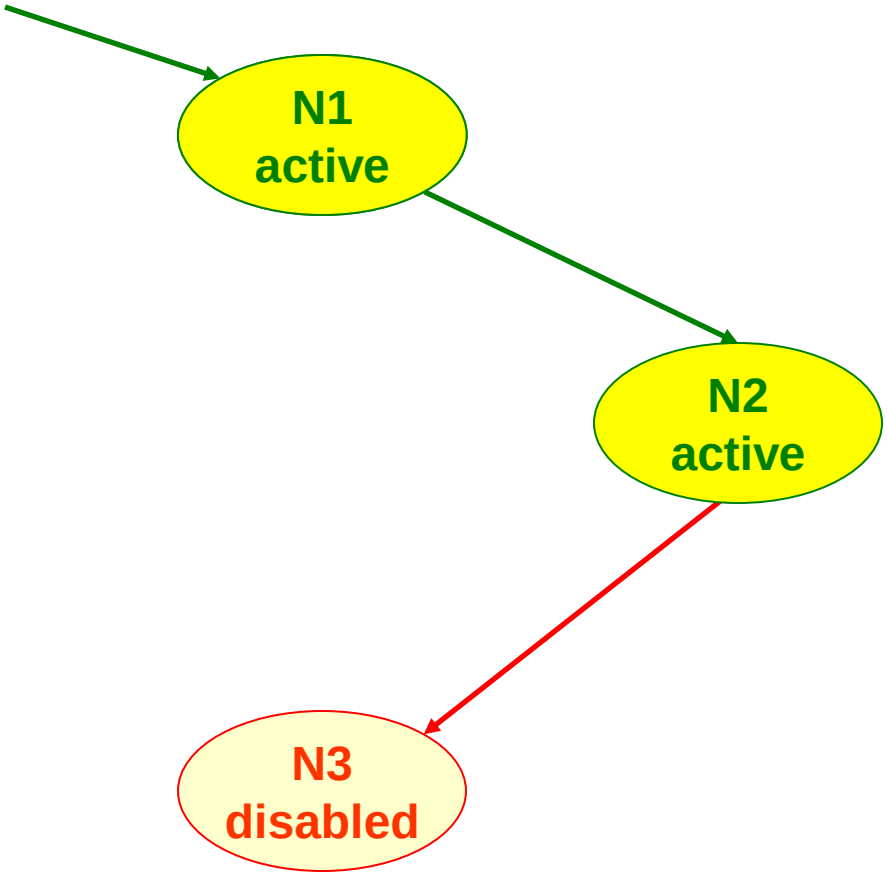

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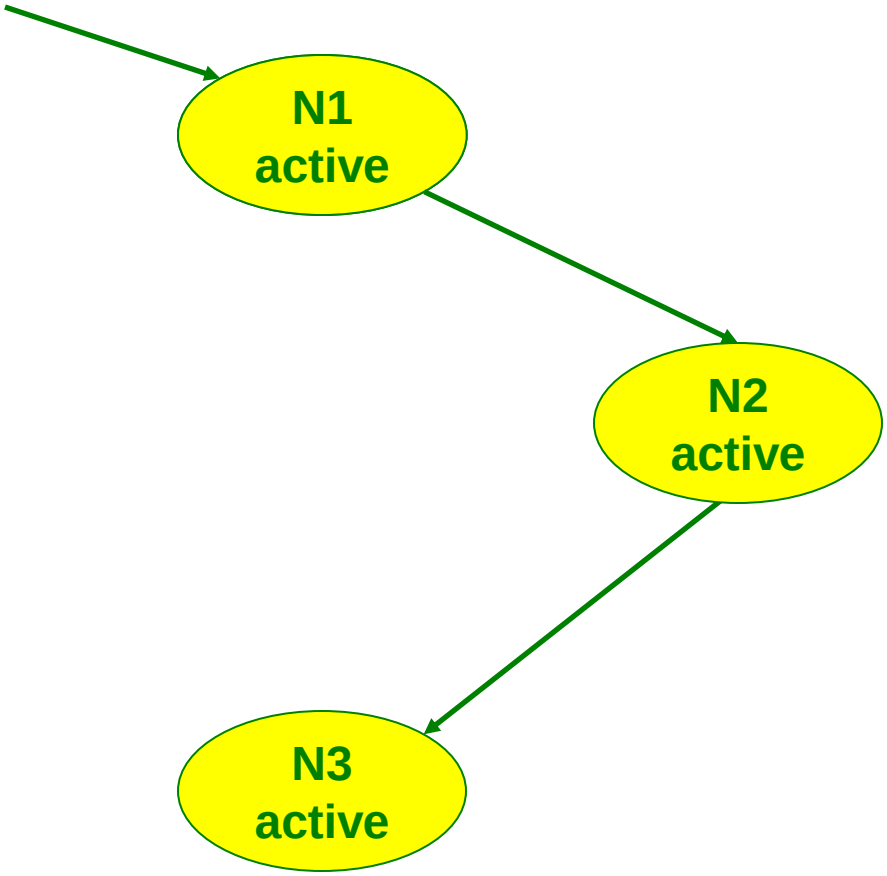


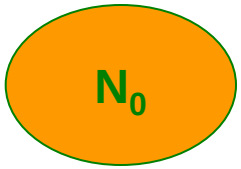
PrAO Algorithm

1. Initialize the front queue Q with the start node n_o (initial belief state).
2. Iteratively perform the following steps:
    3. Pick an active node n from Q with the best heuristic
    4. If no such node n exists, terminate the search
    5. Expand node n
    6. If n is goal-reachable, then
        7. Execute *goal-propagation(n)*
        8. If n_o is goal-reachable then extract and return the solution.
    9. Else if n is dead, then
        10. Execute *dead-end-propagation(n)*
        11. If n_o is a dead node then terminate the search
    10. Else for every disabled child n' of n, activate n' and execute *reactivate-propagation(n')*

PrAO Algorithm

- Incorporate the pruning techniques in:
  - goal-propagation
  - dead-end-propagation
- Expand only active unexpanded nodes: avoid redundant expansion and reduce numbers of expanded/generated nodes
- PrAO is complete due to *reactivate-propagation*

PrAO Algorithm



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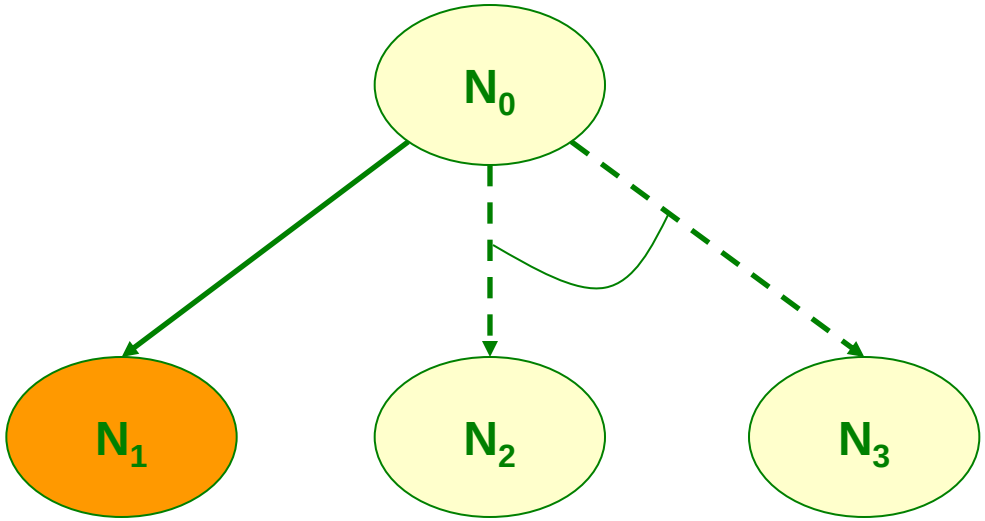

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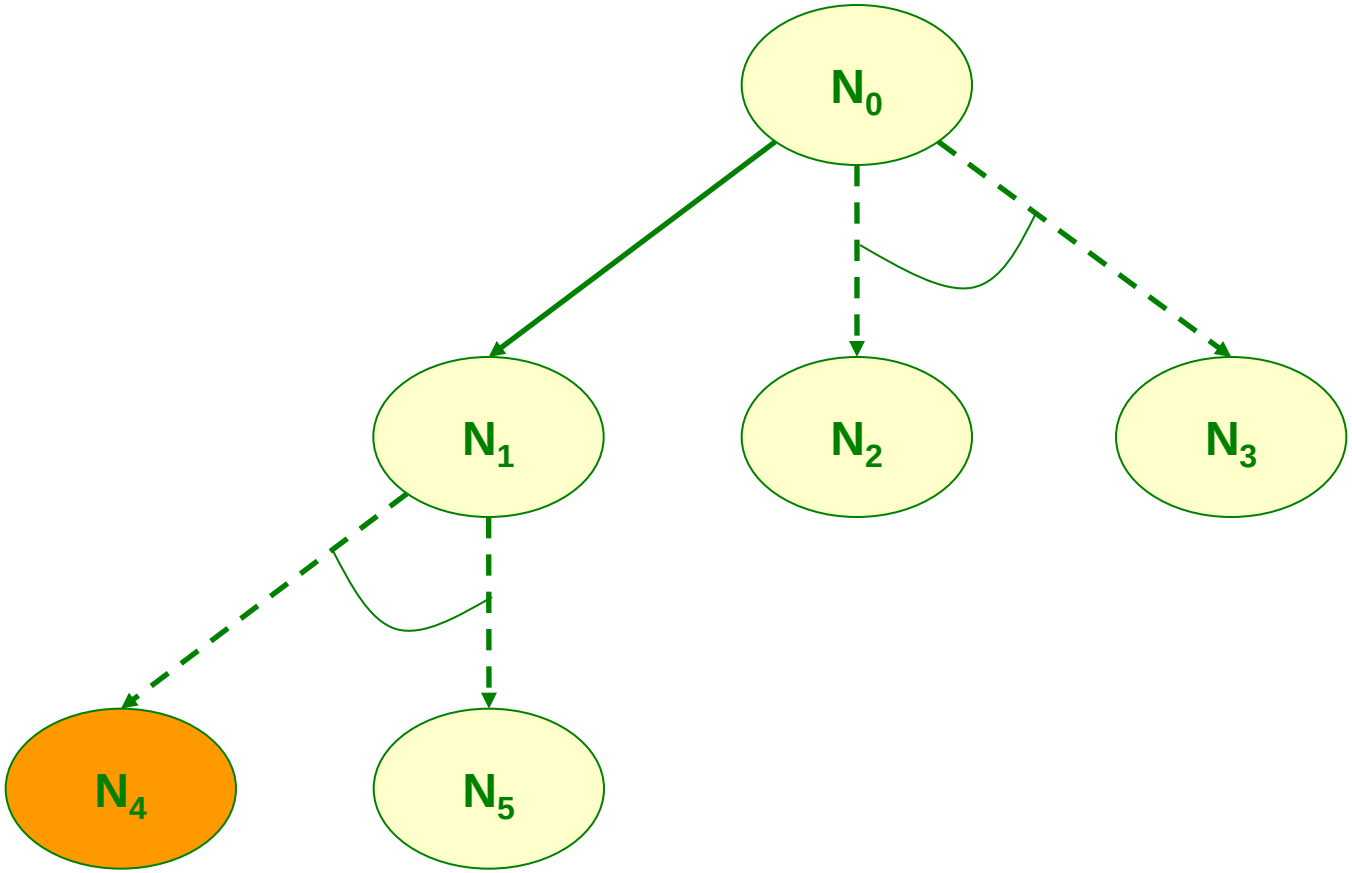

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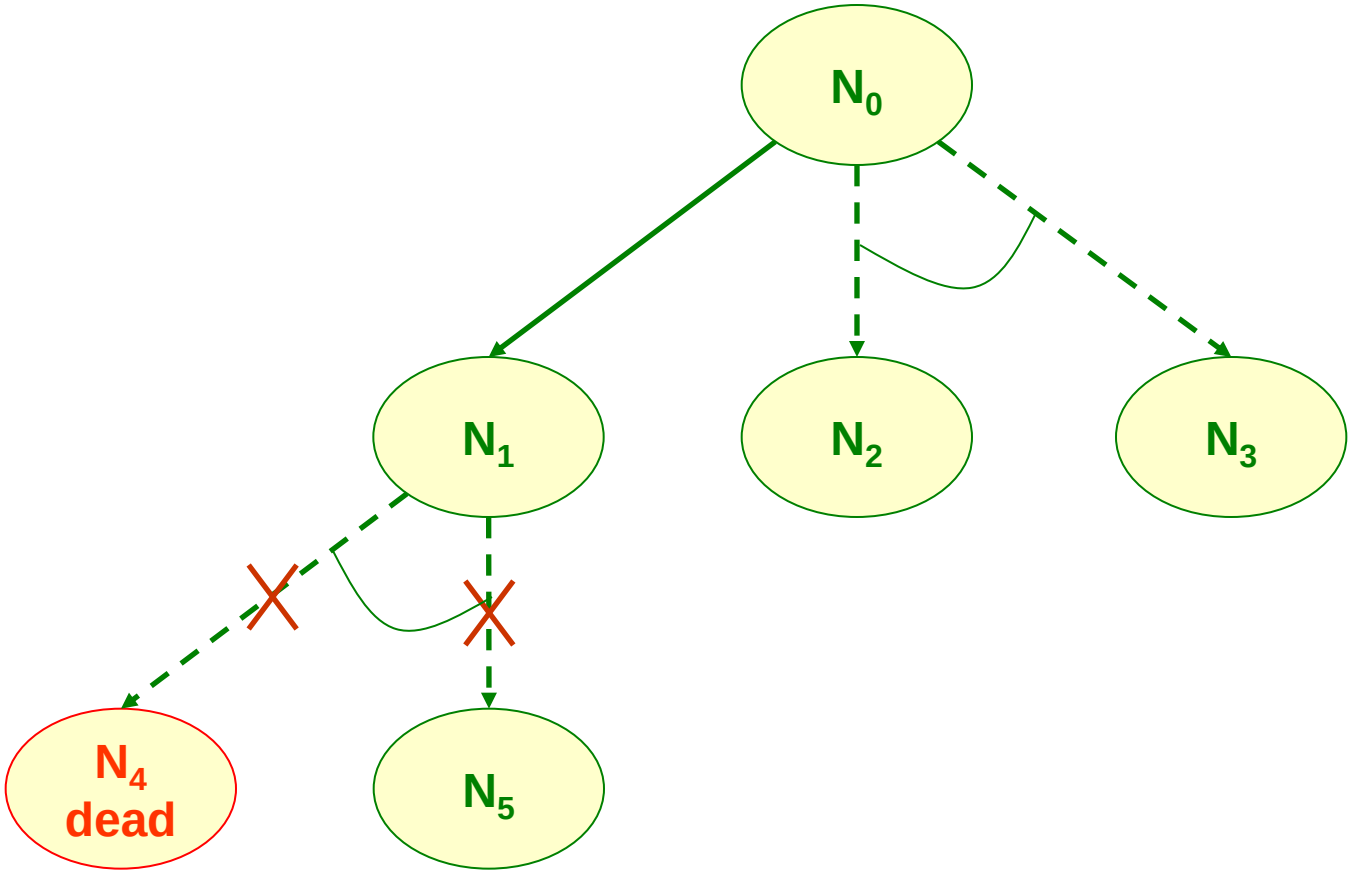

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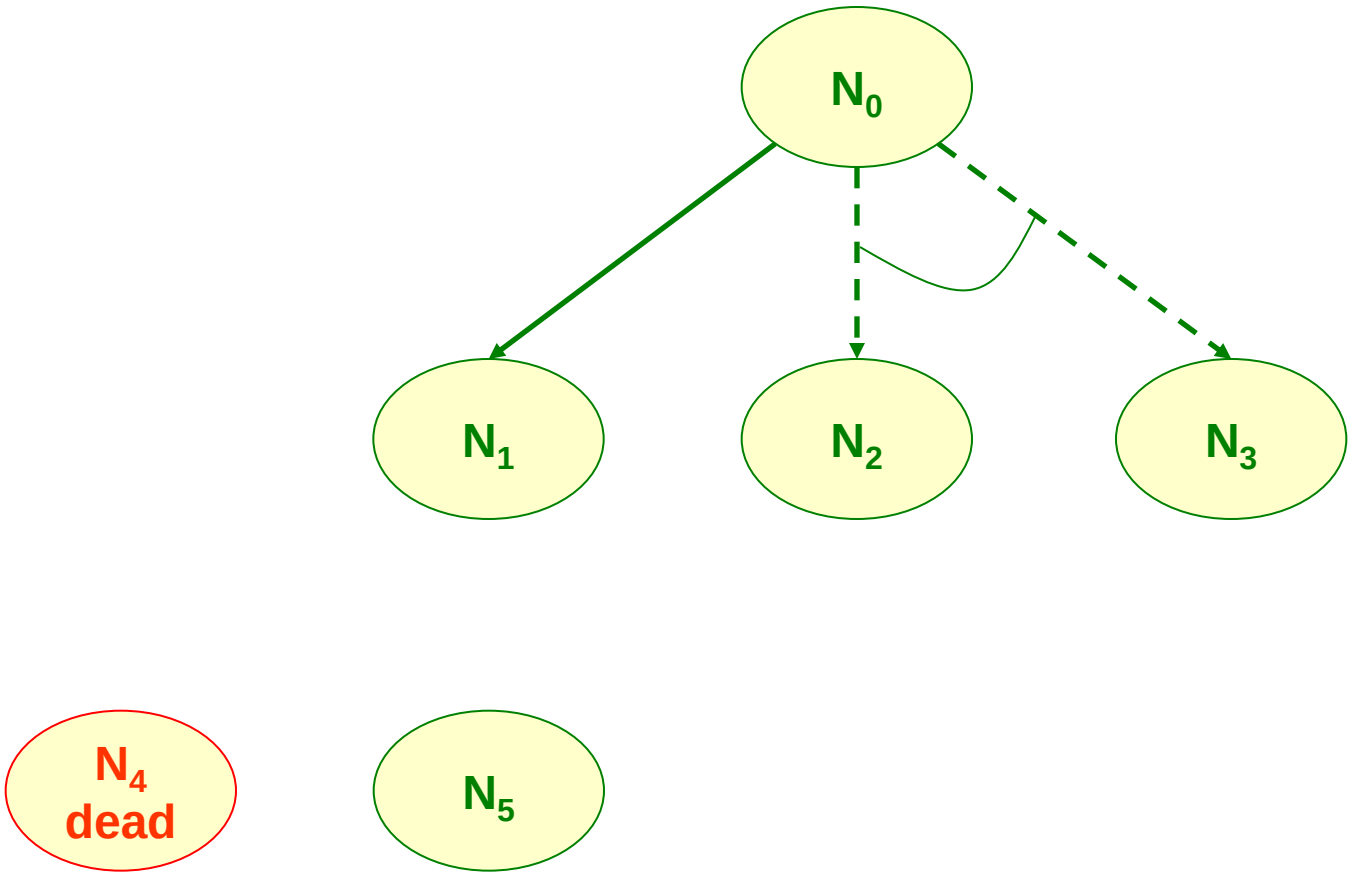

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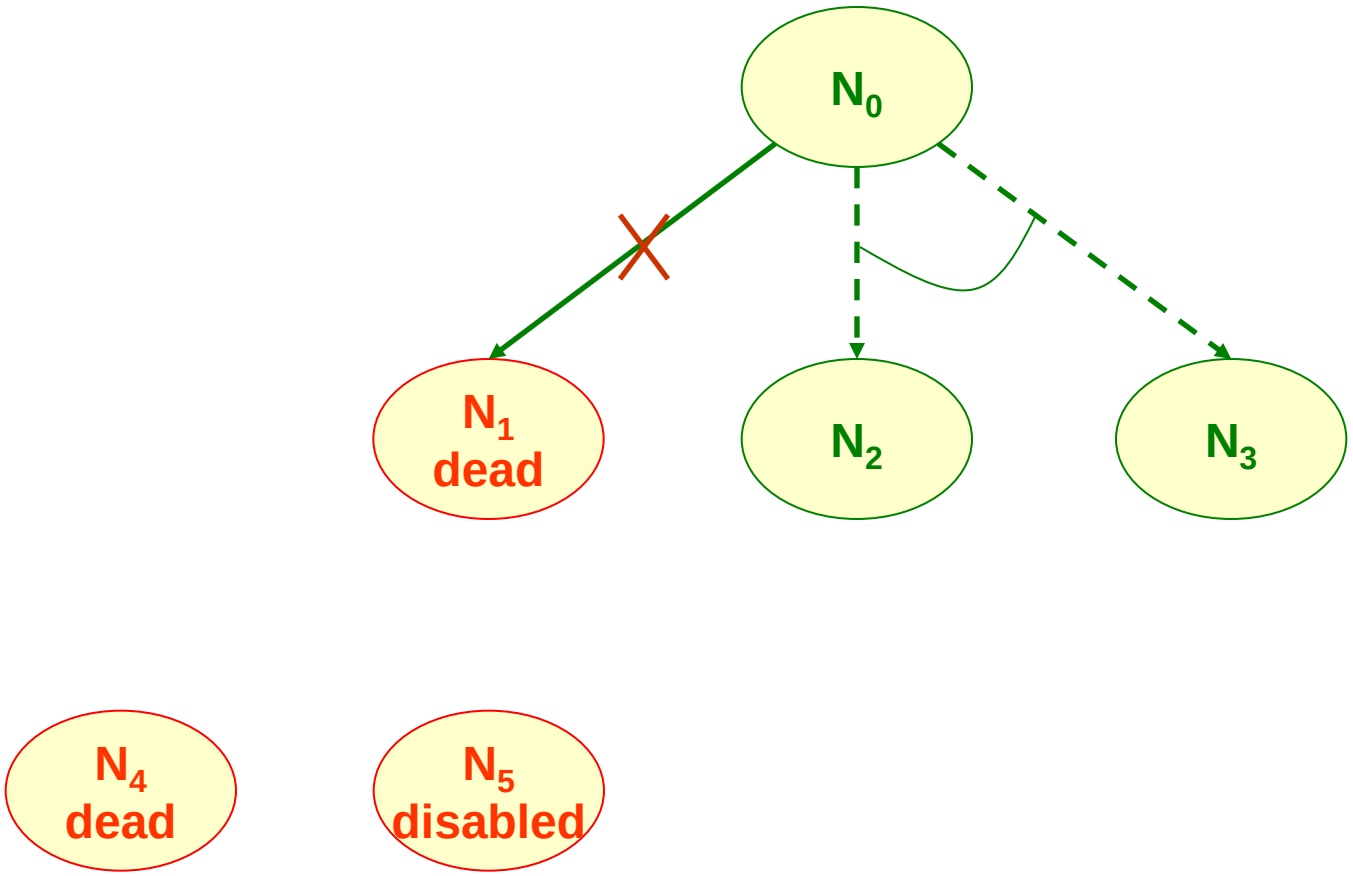

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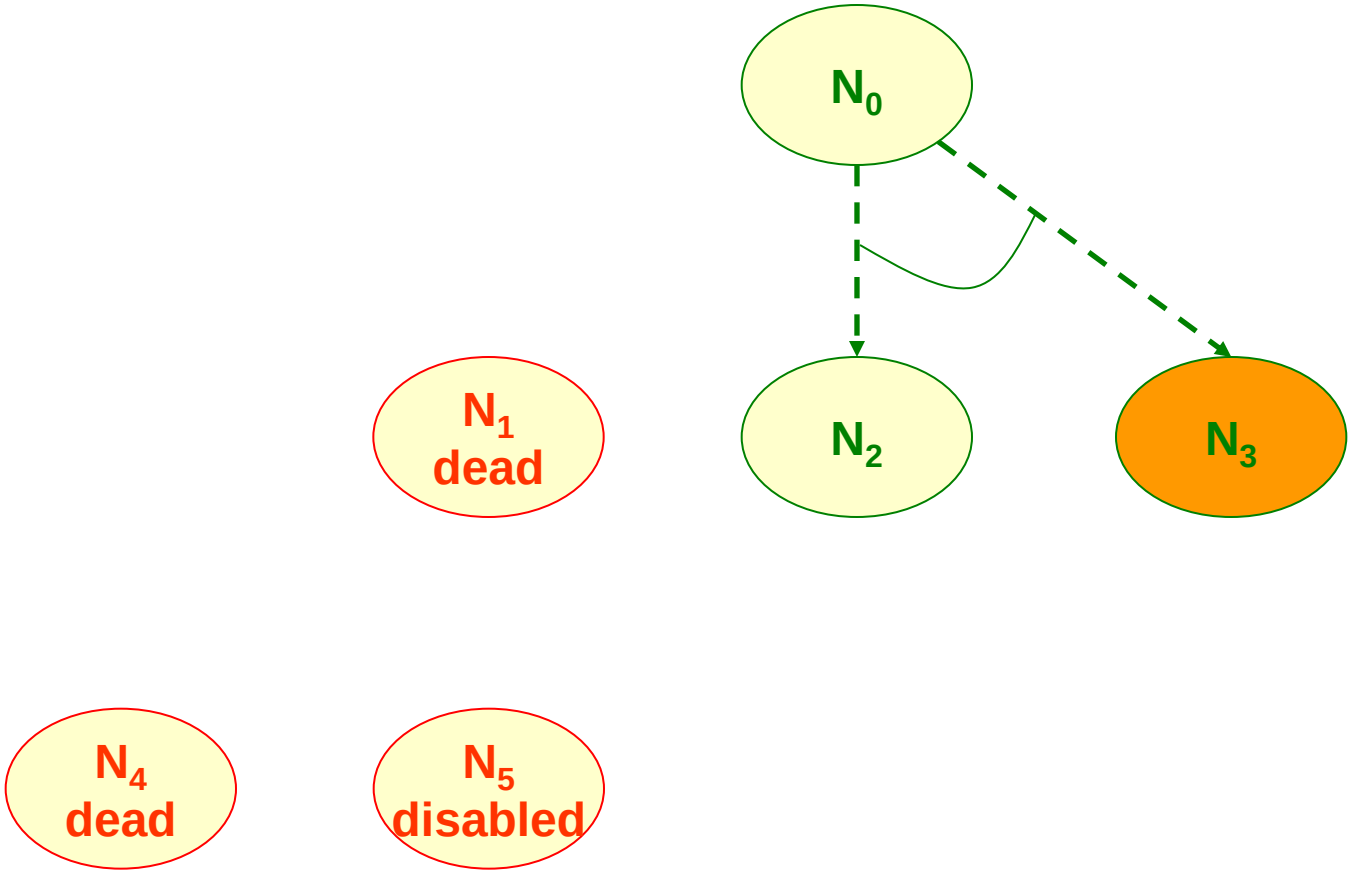

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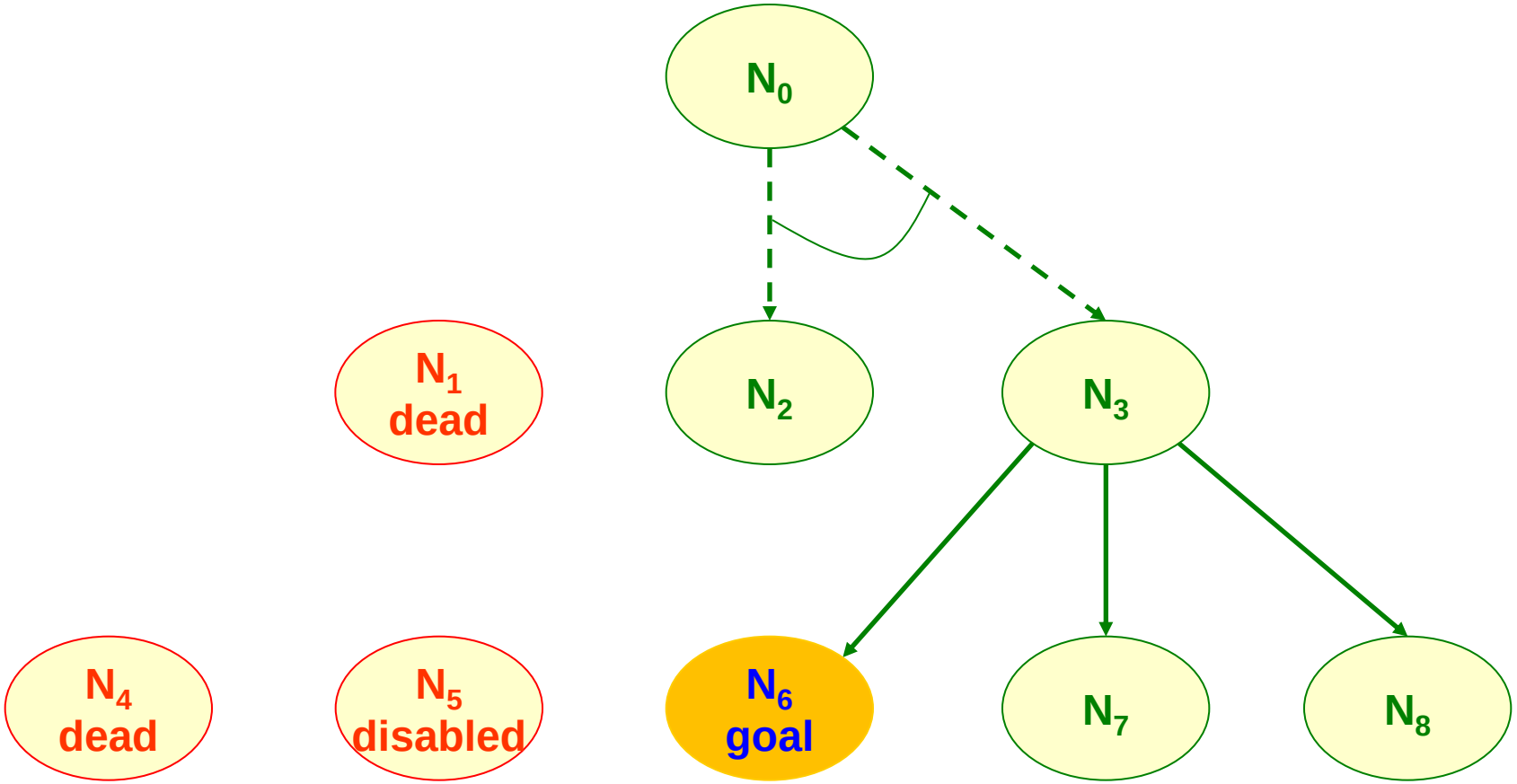

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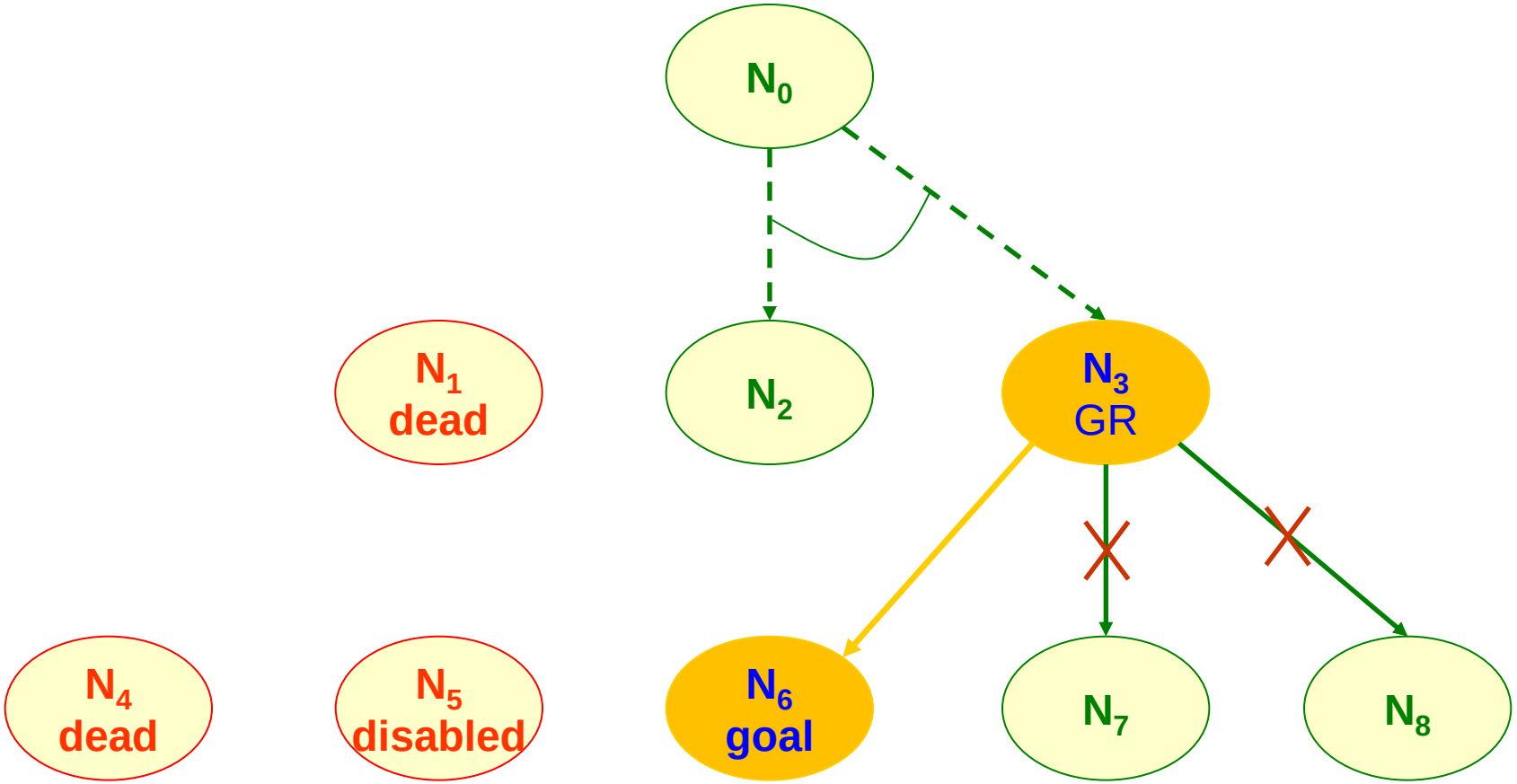

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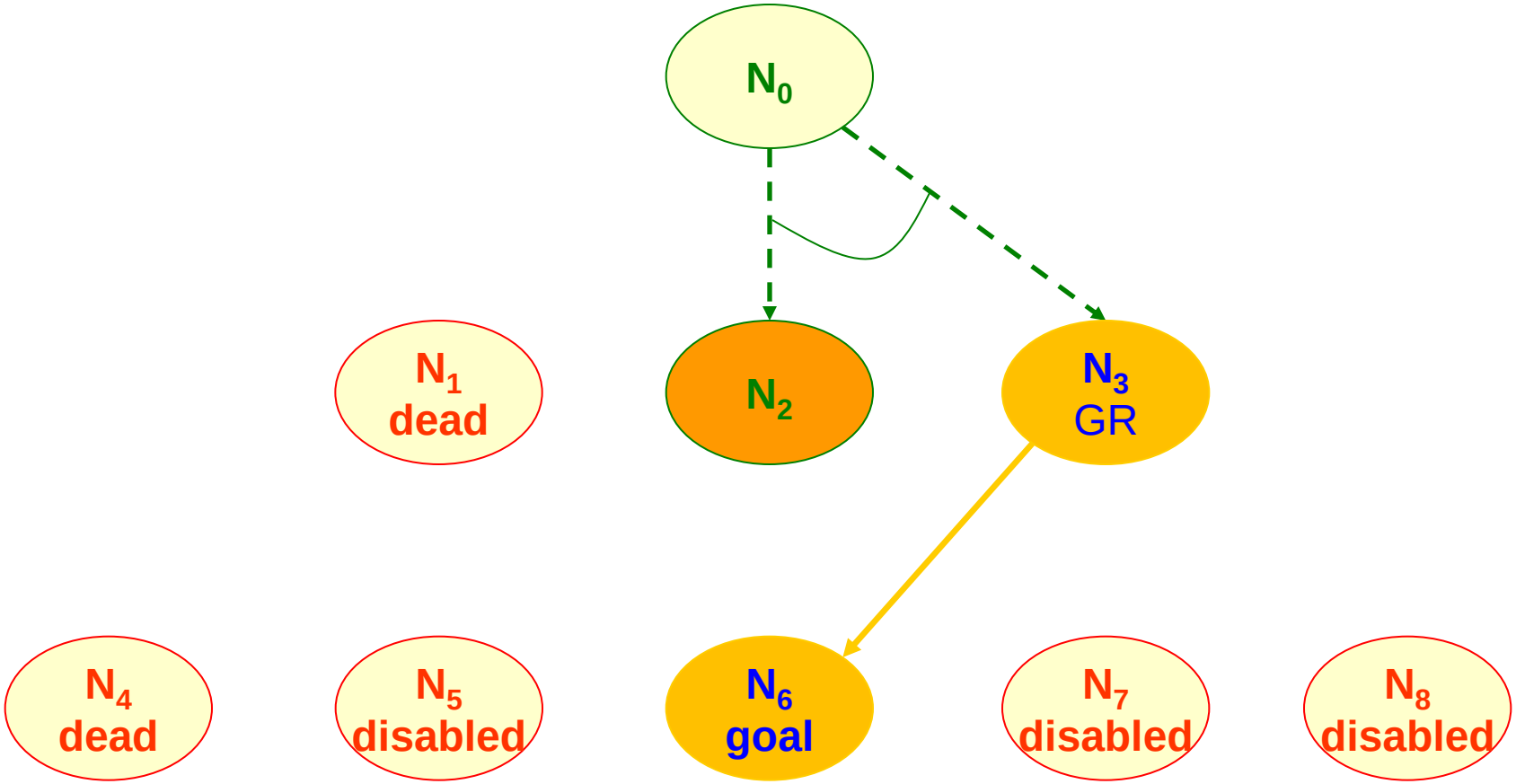

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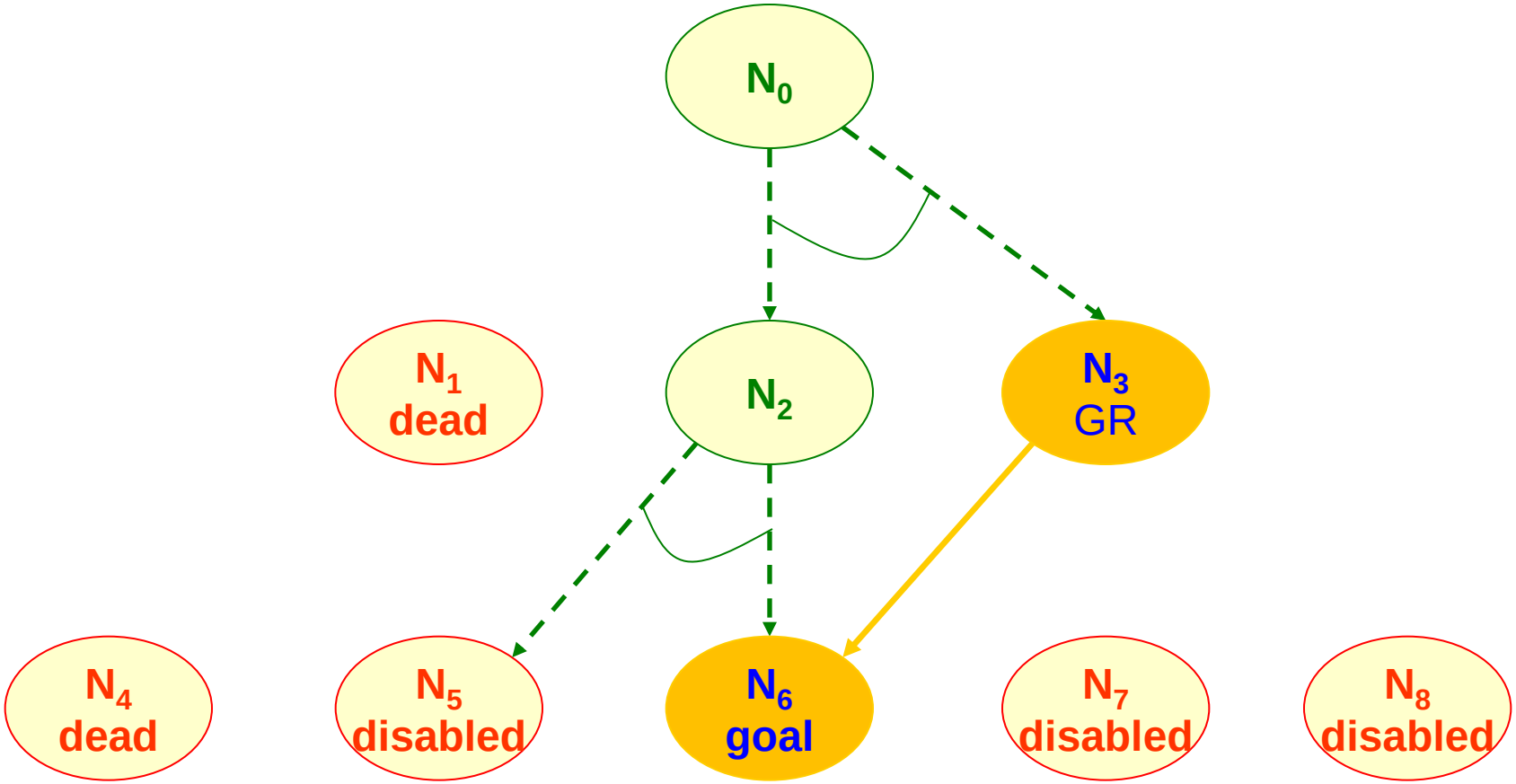

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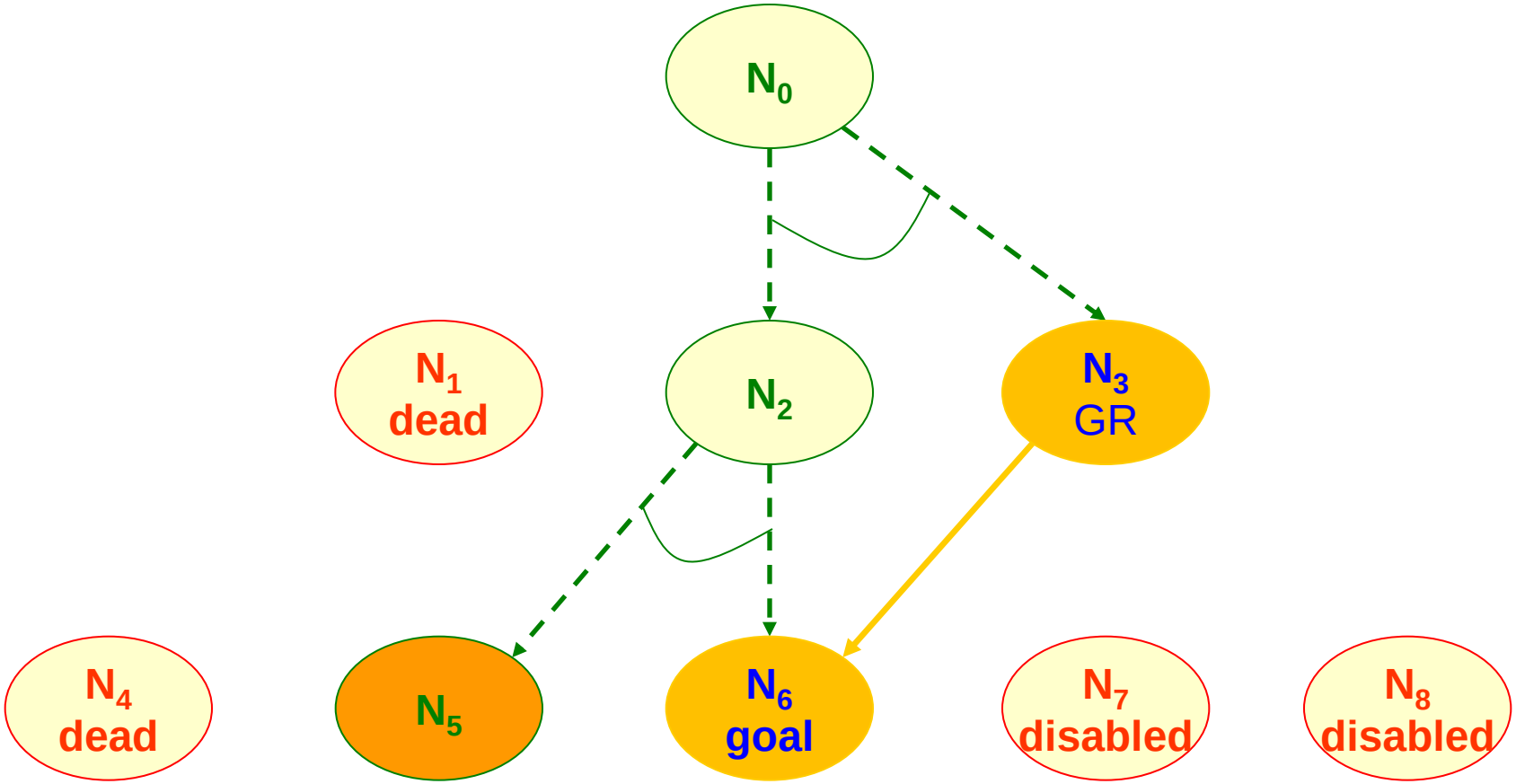
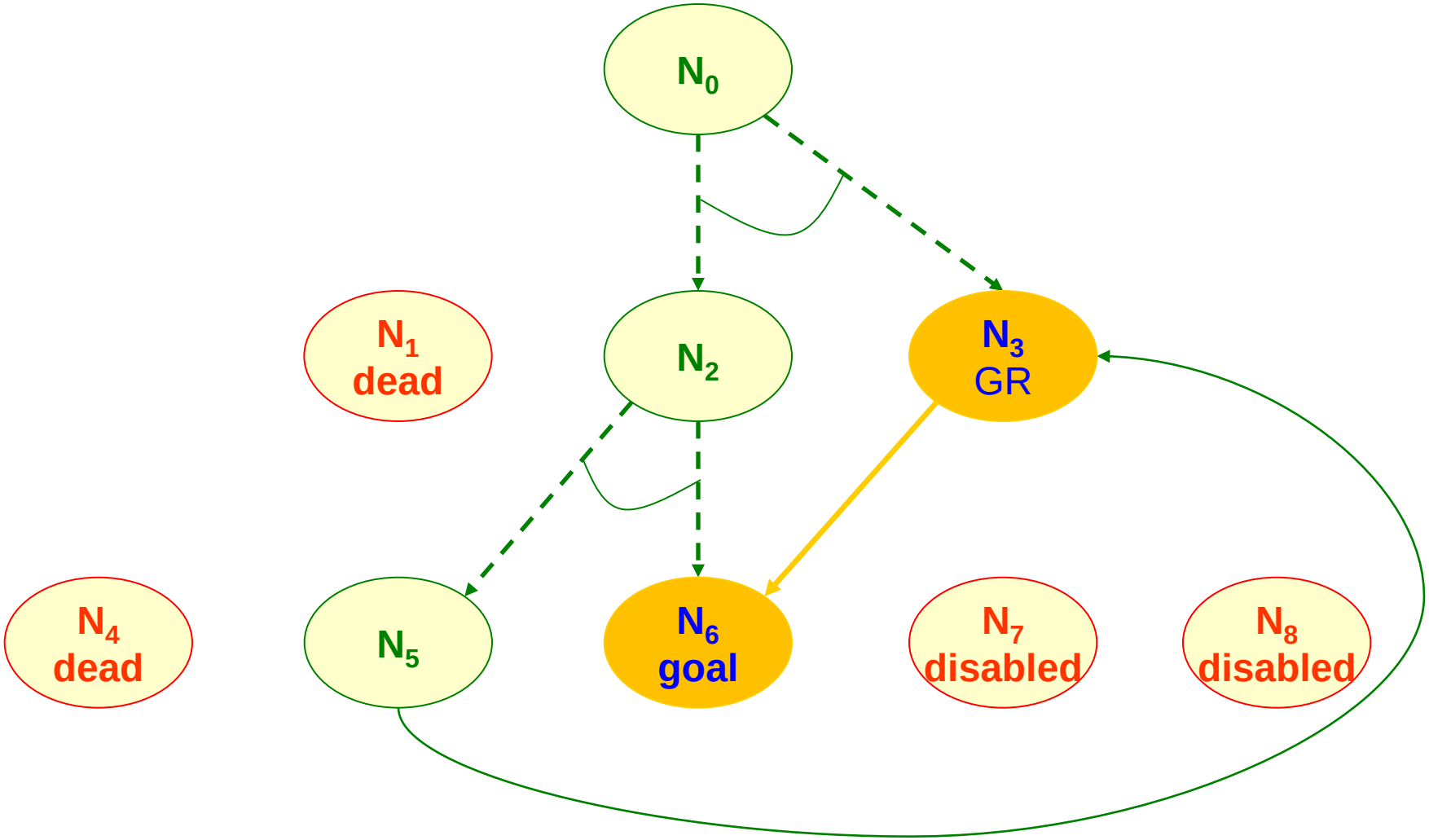
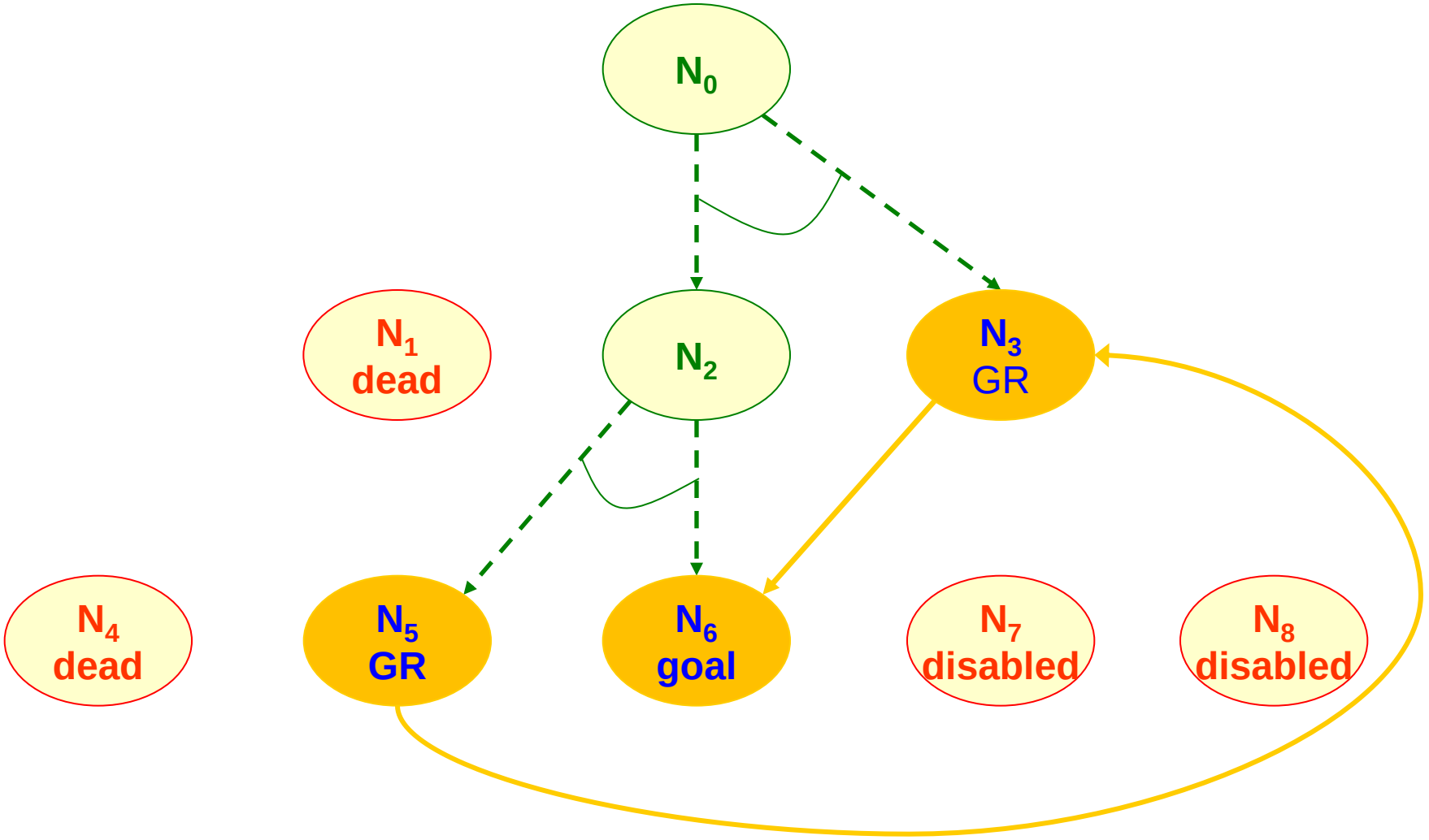


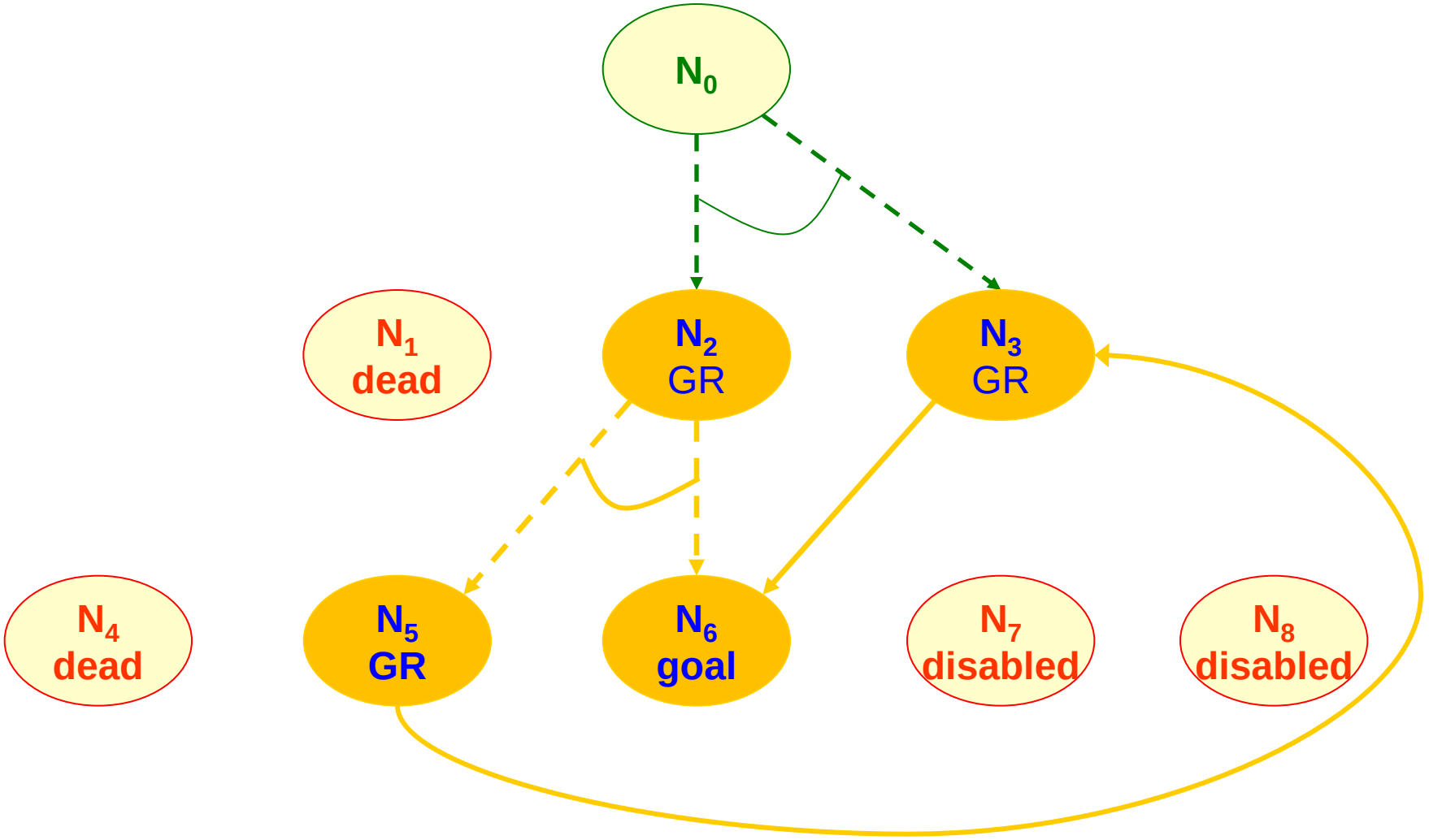
PrAO Algorithm



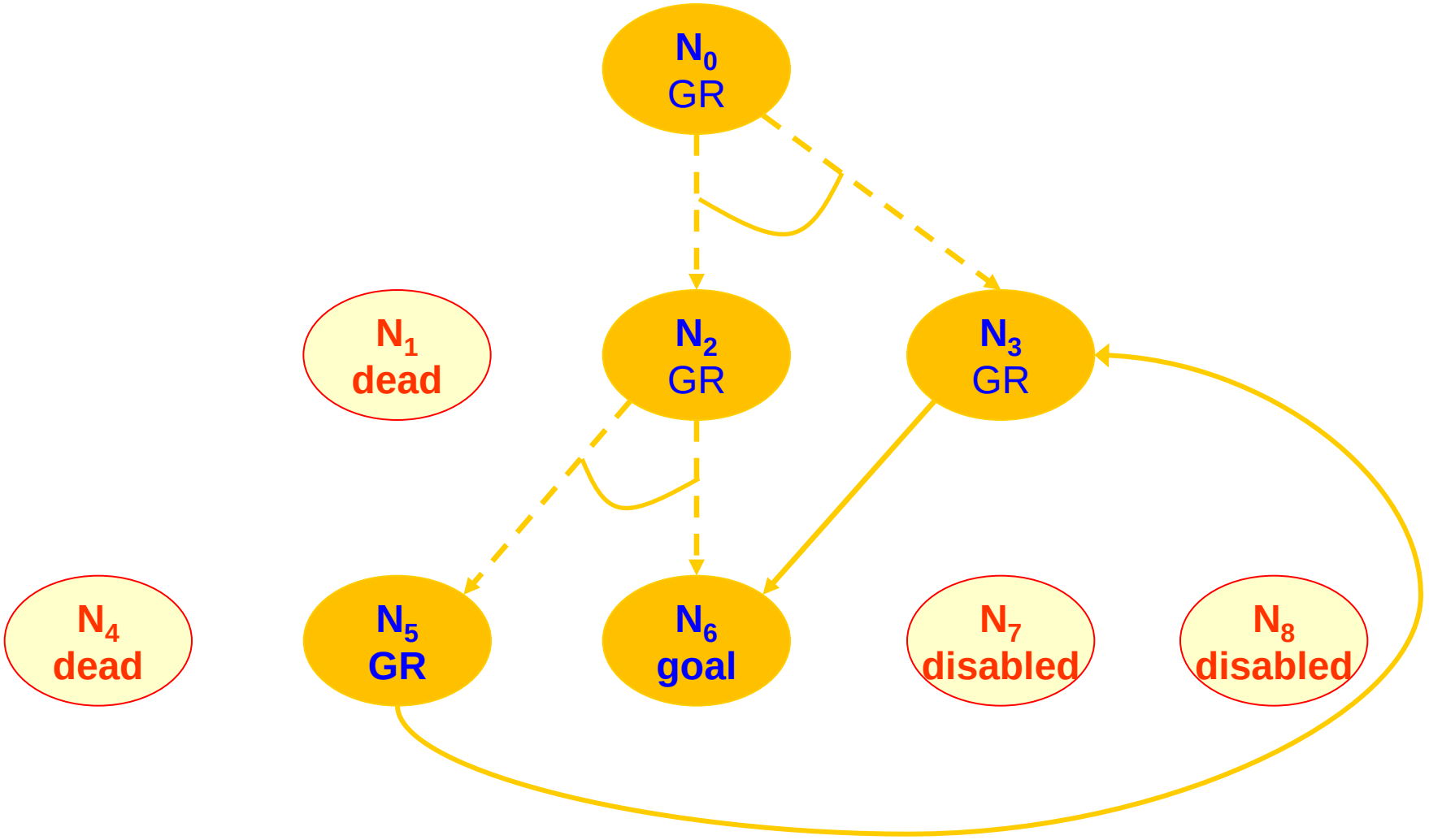
PrAO Algorithm



PrAO Algorithm



PrAO Algorithm



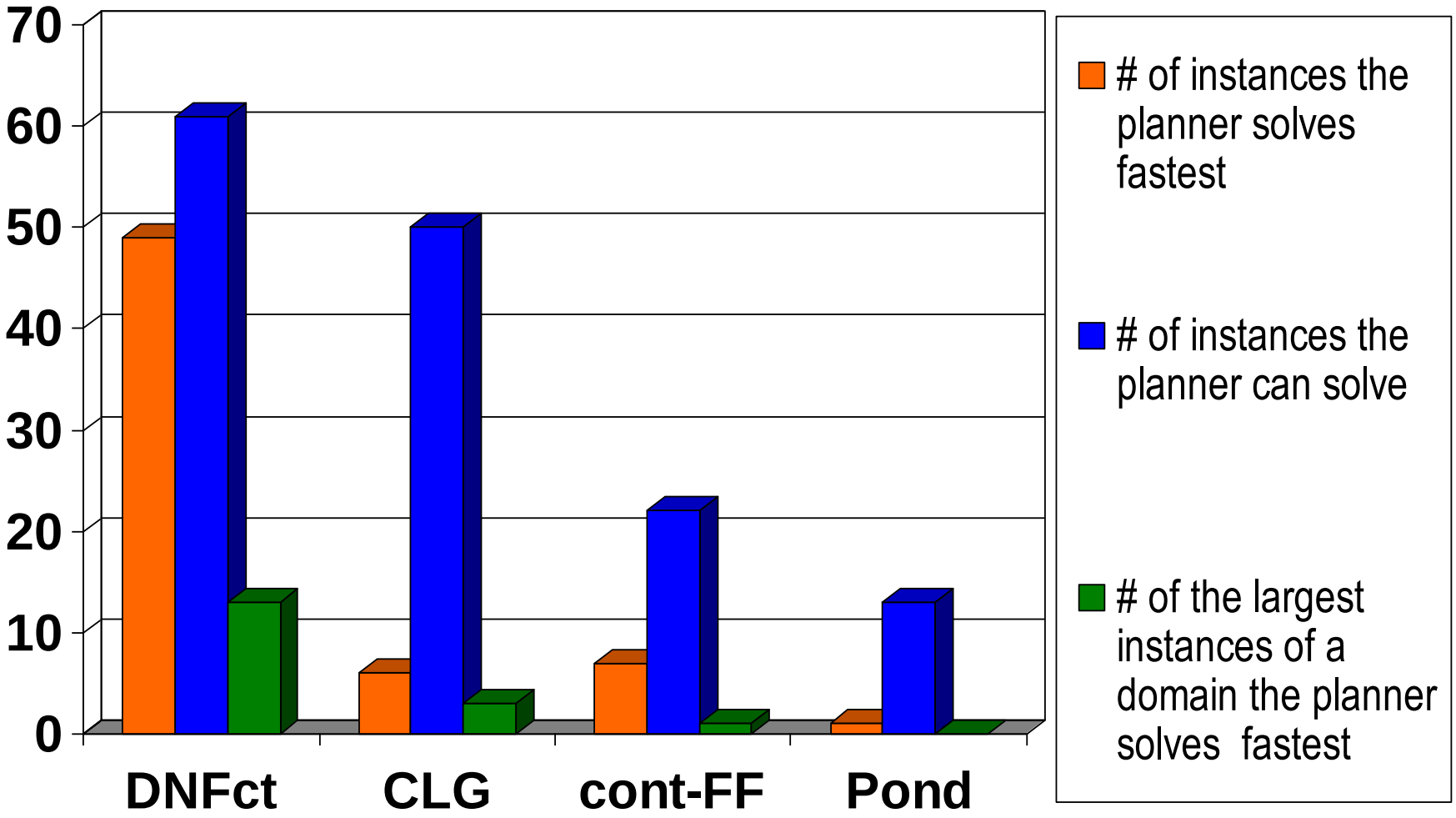
Outline

- ✓ Contingent planning
- ✓ Approach overview
- ✓DNF representation: review & extension
- ✓And/Or forward search: PrAO algorithm
- ➢ Experimental evaluation
  - •Experimental setup
  - ▪Performance comparison
- • Conclusion and future work

Experimental Setup

- Planners: compare DNF_{ct} with most state-of the-art:
  - CLG (Albore, Palacios, and Geffner IJCAI-2009)
  - Contingent-FF (Hoffmann and Brafman ICAPS-2005)
  - POND (Bryce, Kambhampati, and Smith JAIR-2006)
- Benchmarks:
  - From Pond, Contingent-FF, and CLG distribution.
  - Several obtained by our modification from conformant domains.
  - Total: 64 instances out of 17 domains.

Performance Comparison
on 64 Instances of 17 Domains



Outline

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Conclusion

- Extended DNF Representation to handle non-det & sensing actions in contingent planning:
  - Compact
  - Fast state computation
  - Complete
- Developed a new And/Or search algorithm PrAO with novel pruning techniques:
  - Avoid redundant expansion
  - Less expanded/generated nodes
  - Complete

Future Work

- DNF Representation
  - Not good when the size of DNF formulae representing belief states is too large.
- PrAO: And/Or forward search
  - In several problem instances, application of pruning techniques results in more generated/explored nodes.

Thank you!

Question?