A model of planning in human complex problem solving

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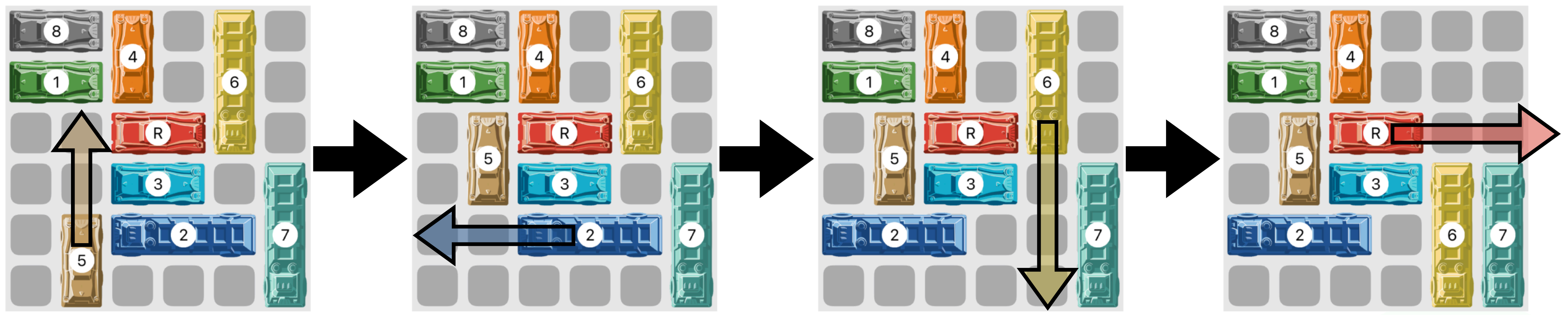
The task

Requirements:

- Complex yet tractable
  - Need to plan multiple steps ahead
  - Tractable state space
  - Optimal solutions available
- Minimal perceptual effects
  - Minimal pattern detection
- Minimal social component
  - Single player
  - No language
- Fun
  - Popular game

} Rush Hour



The implementation

```
Algorithm solve_puzzle(s)
  $a_{\text{init}} \leftarrow$ find_solving_move($s$)          ▷ Ultimate goal of the game
  $\pi \leftarrow [a_{\text{init}}]$
  while $\pi \neq \emptyset$ do
    $a \leftarrow \pi$.pop()                            ▷ Choose move at top of plan
    if is_valid_move($s, a$) then
      $s \leftarrow$ make_move($s, a$)                   ▷ Execution phase
    else
      $\pi \leftarrow$ extend_plan($s, \pi$)                ▷ Replanning
    end if
  end while
```

```
Algorithm extend_plan(s, π)
  $a \leftarrow \pi$[end]                          ▷ Select most recently planned move
  $C \leftarrow$ find_blocking_cars($s, a$)              ▷ AND node creation
  if $C = \emptyset$ then                       ▷ If move is valid, end planning phase
    return $\pi$
  end if
  $c \leftarrow$ choose_car($s, C$)                     ▷ AND node selection
  $\tilde{A} \leftarrow$ find_unblocking_moves($s, a, c$)     ▷ OR node creation
  $\tilde{a} \leftarrow$ choose_move($s, \tilde{A}$)                ▷ OR node selection
  $\pi$.push($\tilde{a}$)                             ▷ Plan extension
  return extend_plan($s, \pi$)                   ▷ Recurse
```

The representation

AND-OR tree

- Represents all the possible plans the model could propose
- "Unravel" from bottom up to find plans
- By itself, not sufficient to guarantee a solution
  - Replanning is almost always necessary

Model fitting

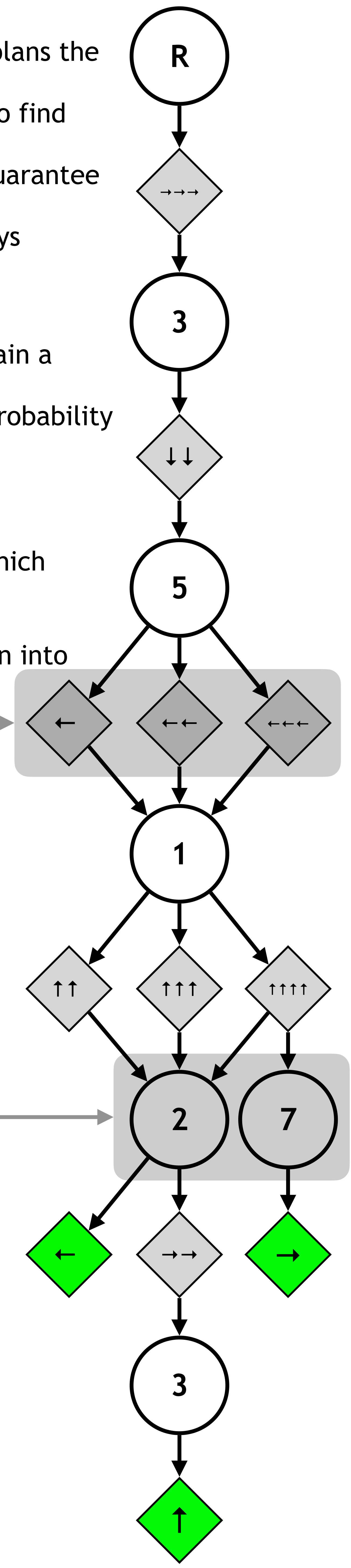
- Past moves inform which chain a subject is on
- Each chain has a different probability according to parameters
  - γ : stopping probability
  - λ : lapse rate
  - $\mathbf{h}$: heuristics to decide which AND/OR node to expand
- Based on last move in chain, probabilities over chains turn into probabilities over moves

OR nodes

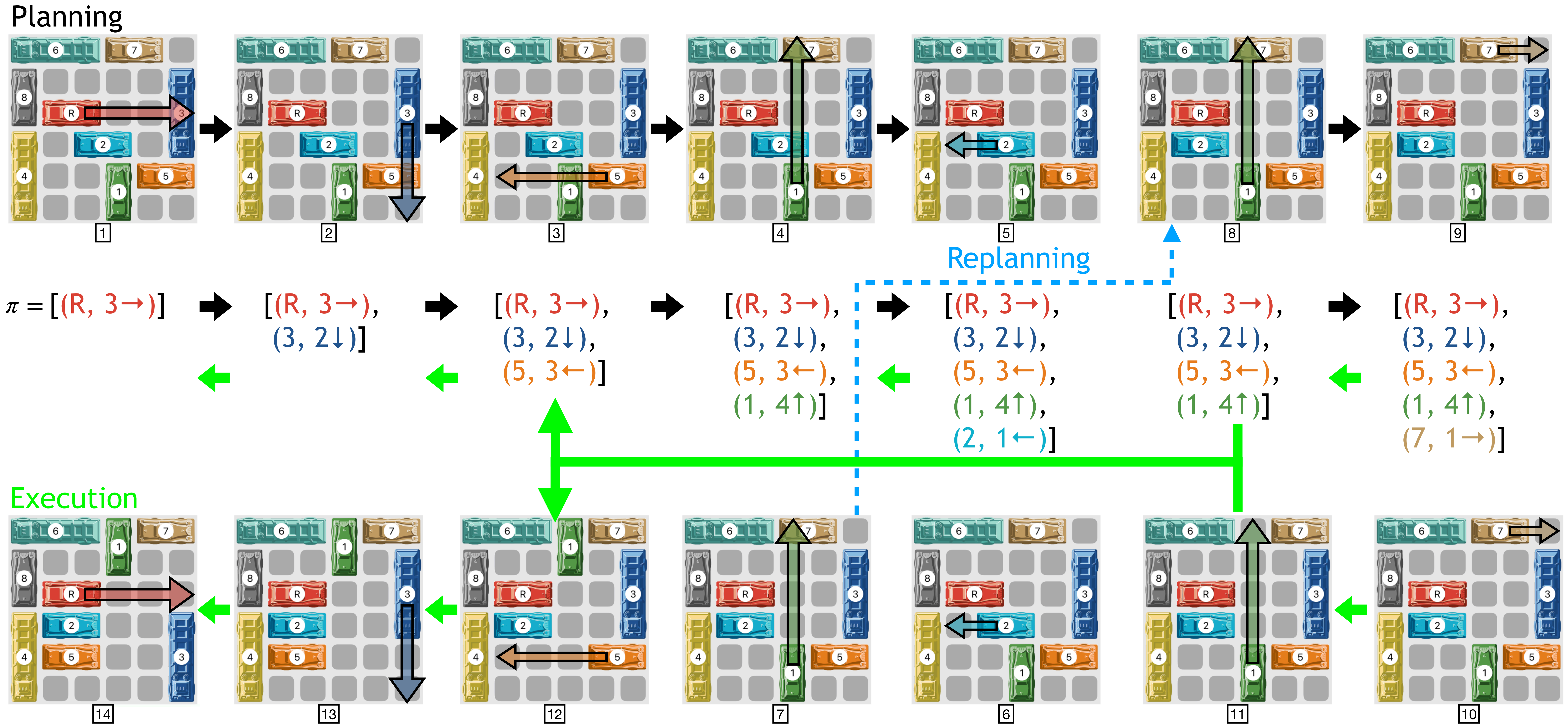
- Decisions
- Represent moves that unblock the parent car
- Either one unblocks the parent
- Subject plans along one of these

AND nodes

- Subgoals
- Represent cars that have to be unblocked
- All must be unblocked before parent move is possible
- One subgoal considered at a time
  - Exponential branching otherwise



The model



$\pi = [(R, 3\rightarrow)]$

$[(R, 3\rightarrow), (3, 2\downarrow)]$

$[(R, 3\rightarrow), (3, 2\downarrow), (5, 3\leftarrow)]$

$[(R, 3\rightarrow), (3, 2\downarrow), (5, 3\leftarrow), (1, 4\uparrow)]$

$[(R, 3\rightarrow), (3, 2\downarrow), (5, 3\leftarrow), (1, 4\uparrow), (2, 1\leftarrow)]$

$[(R, 3\rightarrow), (3, 2\downarrow), (5, 3\leftarrow), (1, 4\uparrow)]$

$[(R, 3\rightarrow), (3, 2\downarrow), (5, 3\leftarrow), (1, 4\uparrow), (7, 1\rightarrow)]$