Dataflow Analysis of Computer Game Narratives

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What?

- Computer games have narratives
  - A story through events, choices
  - RPG, Adventure, FPS
- Should be consistent
  - Appropriate responses in all eventualities
- Greater scale => greater complexity
  - Large virtual world, multiple interacting events
  - Easy to make mistakes...

Narrative Flaws

- Game narratives often have flaws
  - Non-sequiturs
  - Unwinnable situations
    - “pointlessness”
  - Unanticipated game states
- Would be nice to analyze narratives
  - Detect flaws
  - Ensure good properties

Outline

- Narrative model
- Verification
- Dataflow analysis
- Experiments
- Future Work & Conclusions

Narrative Model

- Need a well-defined target
  - Graphics, input mechanism, etc. secondary
  - Adventure (Interactive Fiction) games
    - “Pure” narrative – limited eye candy
    - Covers essential narrative features
- Formal representation
  - Industry models ad hoc, incomplete
  - Existing IF languages messy

Narrative Model

- (P)NFG
  - Minimalist language for expressing an IF narrative
    - All essential narrative features
  - Simple but expressive grammar
    - Syntactic sugar added
  - Simple operational model
  - "Compiles" down to a well-defined Petri Net model
    - Flexible low-level verification/analysis

Narrative Model

- IF games:
  - Player directs a game avatar through a virtual world
  - World includes objects, locations (rooms)
  - Avatar responds to commands
    - Player input
    - Perform actions in the game world
  - Narrative progress through object, state interactions

Narrative Model

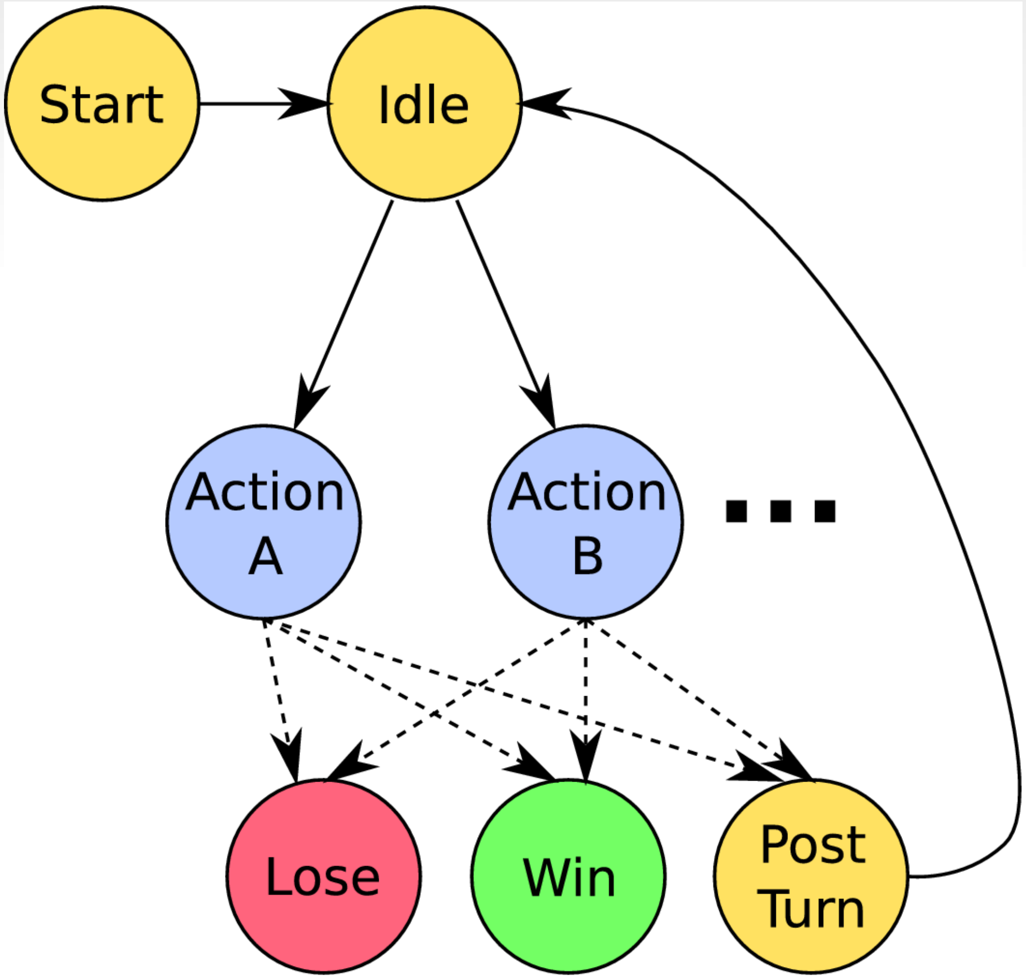
- Narrative components:
  - Objects
    - State variables
      - Booleans, counters
    - Location (rooms)
      - Tree-containment
  - Actions
    - Player-invoked (input event)
    - Test & modify state
      - state/location assignment, sequence, conditionals, output
      - no loops!

Narrative Model

- e.g., an object:
  - ```
    object pumpkin {
       state { lit }
    }
    ```
- And an action:
  - ```
    (you,light,pumpkin) {
       if (!pumpkin.lit) {
          +pumpkin.lit;
          "Is it Halloween already?";
       } else {
          "It's already lit!";
    }
    ```

Narrative Model

- Operational behaviour



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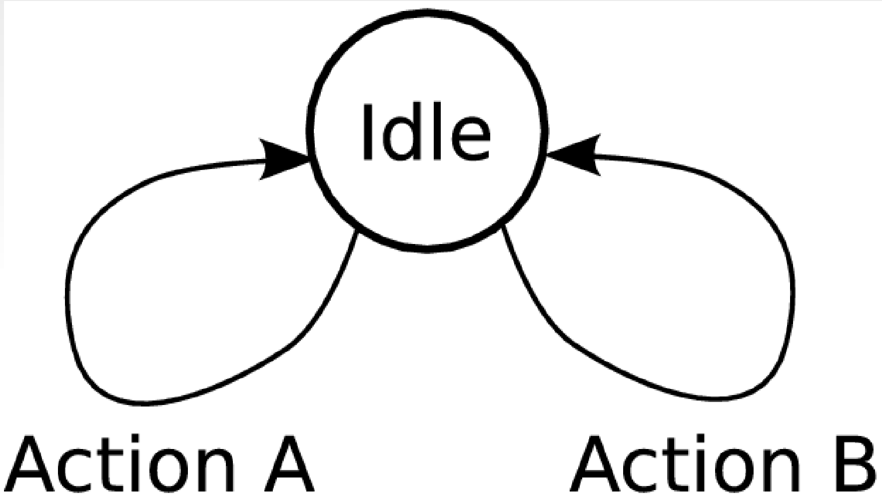
Verification

- Ensure good behaviour
- E.g., “winnability”
  - Basic state search problem
  - Is there a winning path from the current state?
  - List all winning paths.
- Backtracking search for winning states
  - Try all sequences of actions from initial state
- Reaching a winning game state gives game solution

Verification

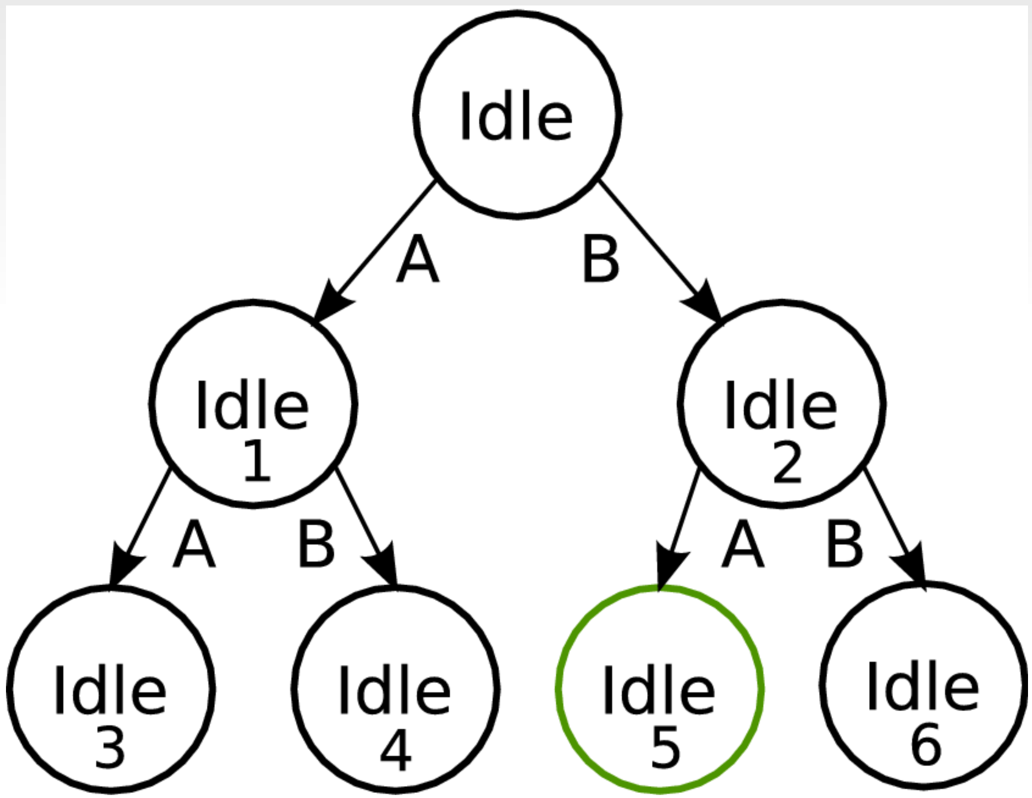
- Brute force:



for all possible actions

Verification

- A large state-space to search:



- Deep + large branching factor => not practical

Verification

- Basic searching optimizations
  - Bounded depth
  - Cycle detection
    - Catches empty/null moves as well
  - Error state detection
    - Recognize rejected action sequences
  - Search cache
- Can we do better with high level game information?

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Dataflow Analysis

- Improve verification with HL game information
  - Dataflow on game narrative
- Heuristic observations
  - Actions are not entirely independent
    - “put on mittens” -> “put on ring”
    - “light candle” when the candle isn't around
  - Cause of excessive backtracking
  - And increased branching factor
    - A large number of action-pairs do not make sense

Dataflow Analysis

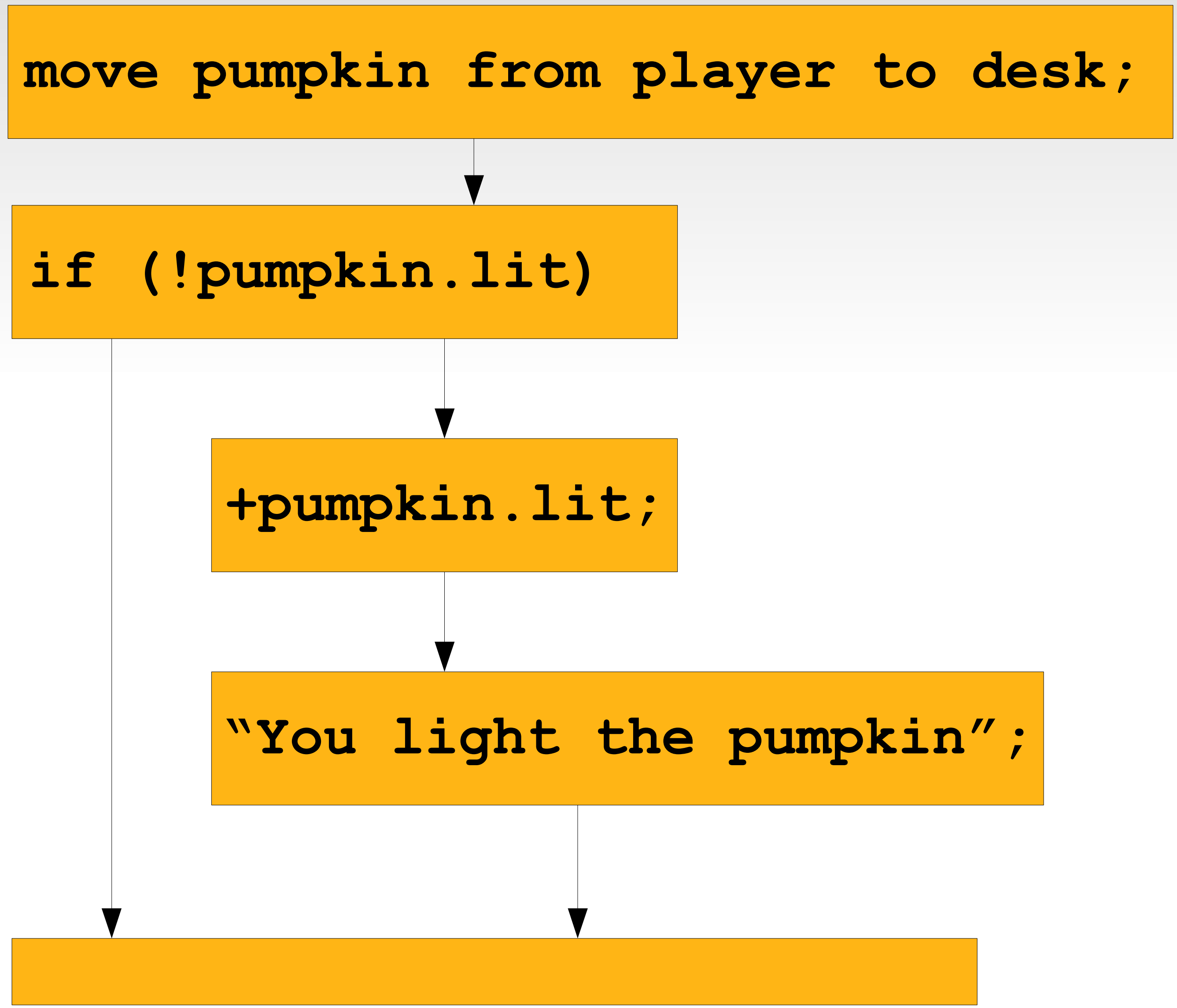
- AOT analysis of actions for better search decisions
- Two basic analyses of each game action
  - Post-conditions
  - Pre-conditions
  - Flow abstract game state through, see effects
- Help figure out which actions follow which
- Reduce branching factor in search

Post-Condition Analysis

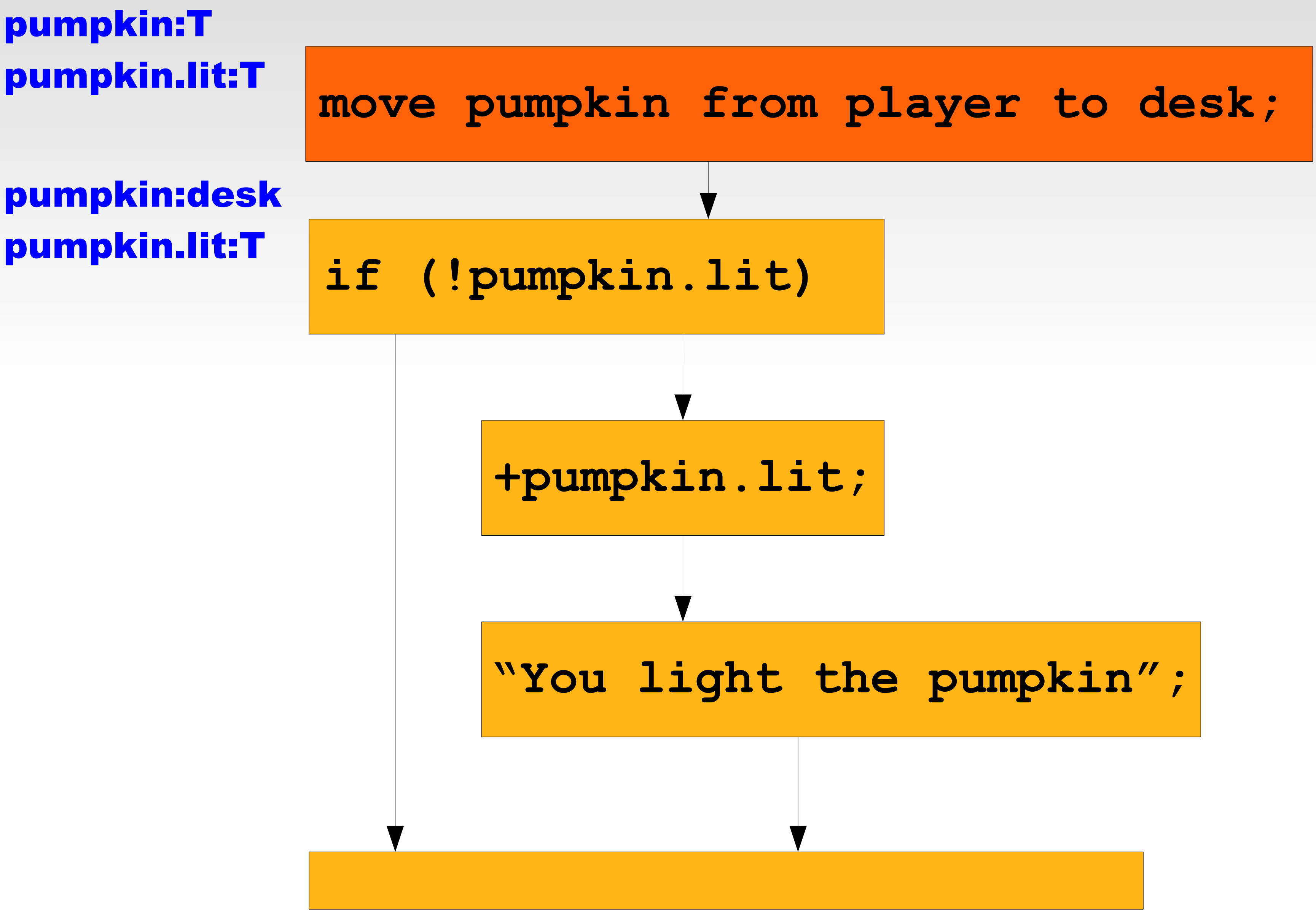
- What state does the action guarantee?
- Similar to constant propagation:
  - Boolean object states
    - object.state {bottom, true, false, top}
  - Enumerated locations
    - object.location {bottom, loc1, loc2, ..., top}

Post-Condition Analysis

pumpkin:T
pumpkin.lit:T



Post-Condition Analysis



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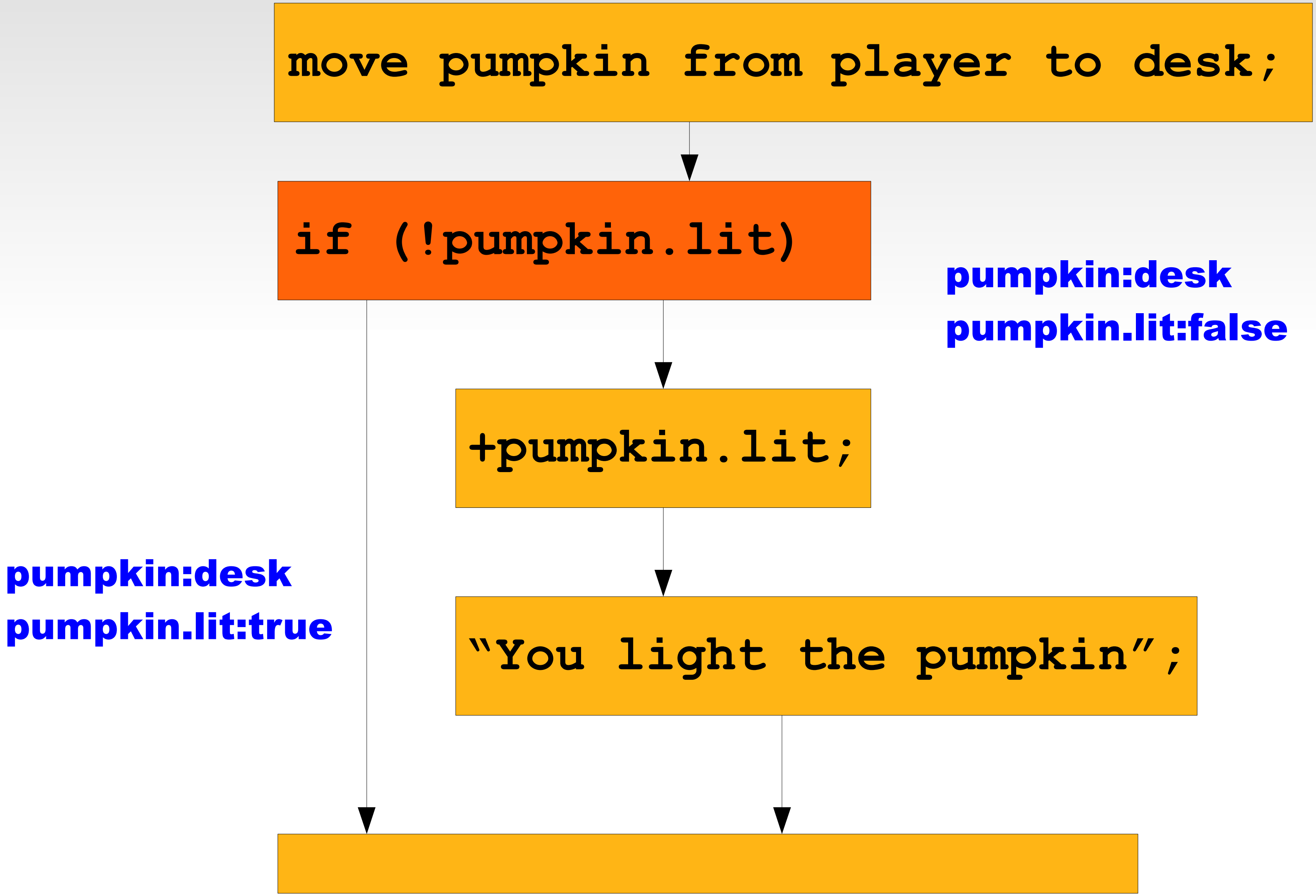

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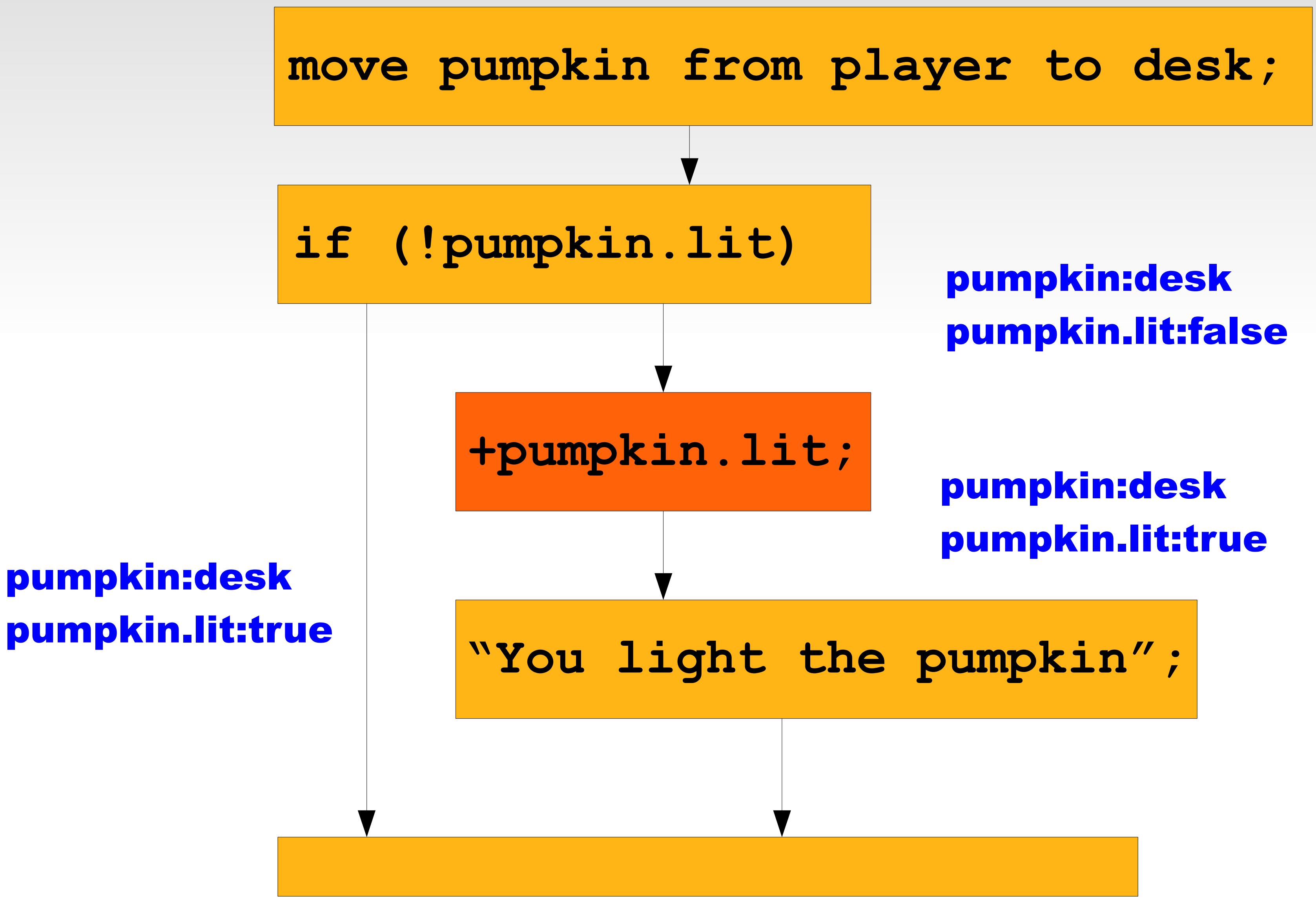

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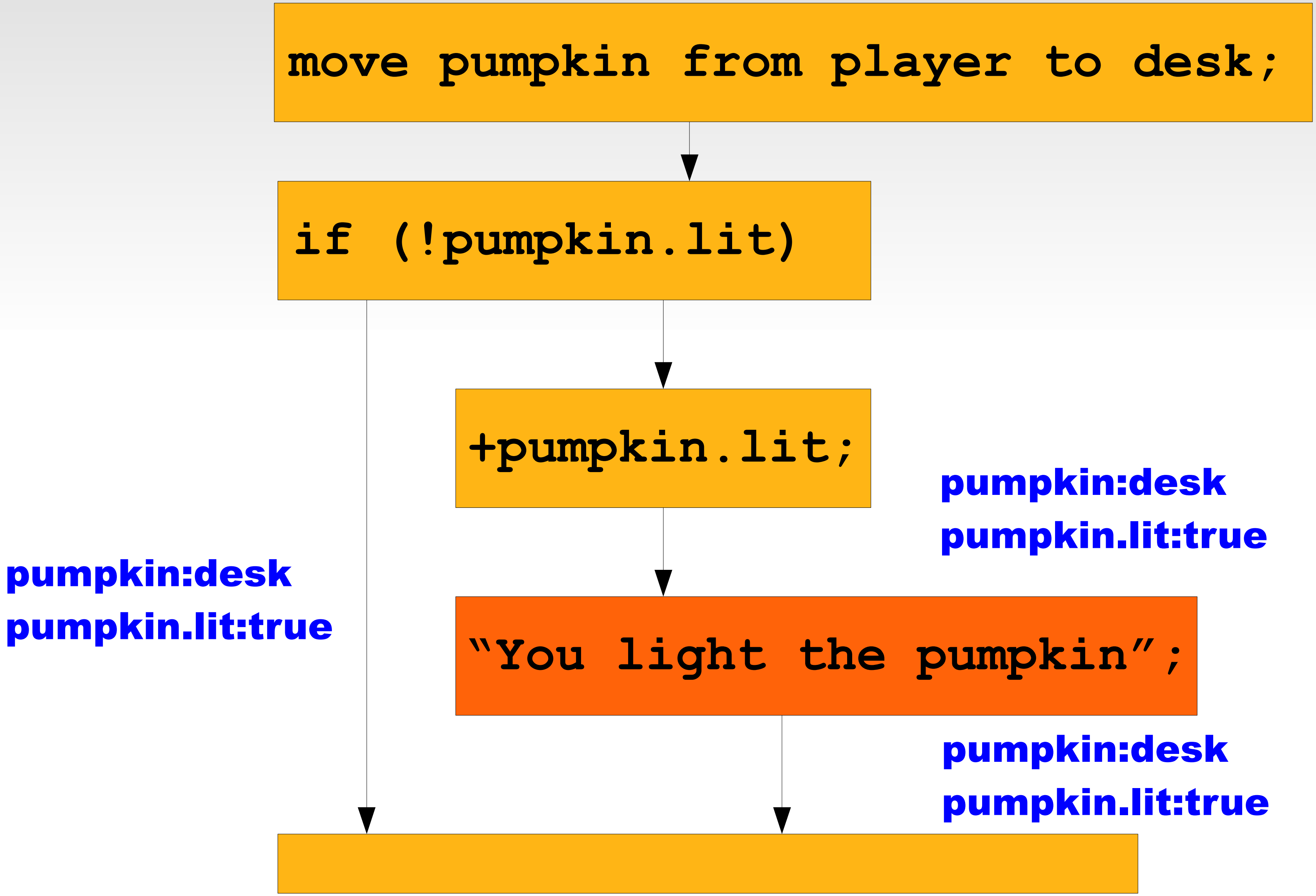

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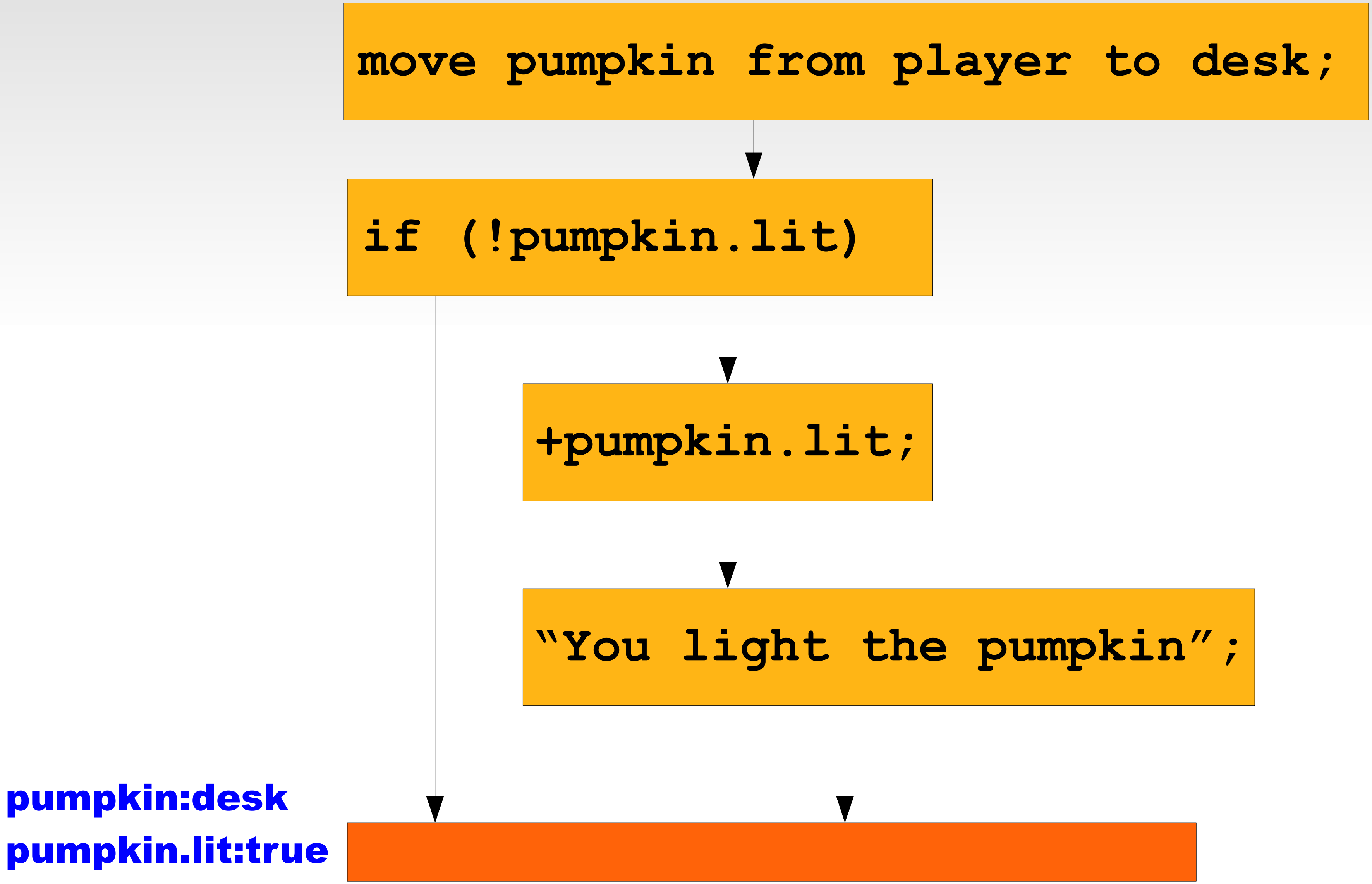
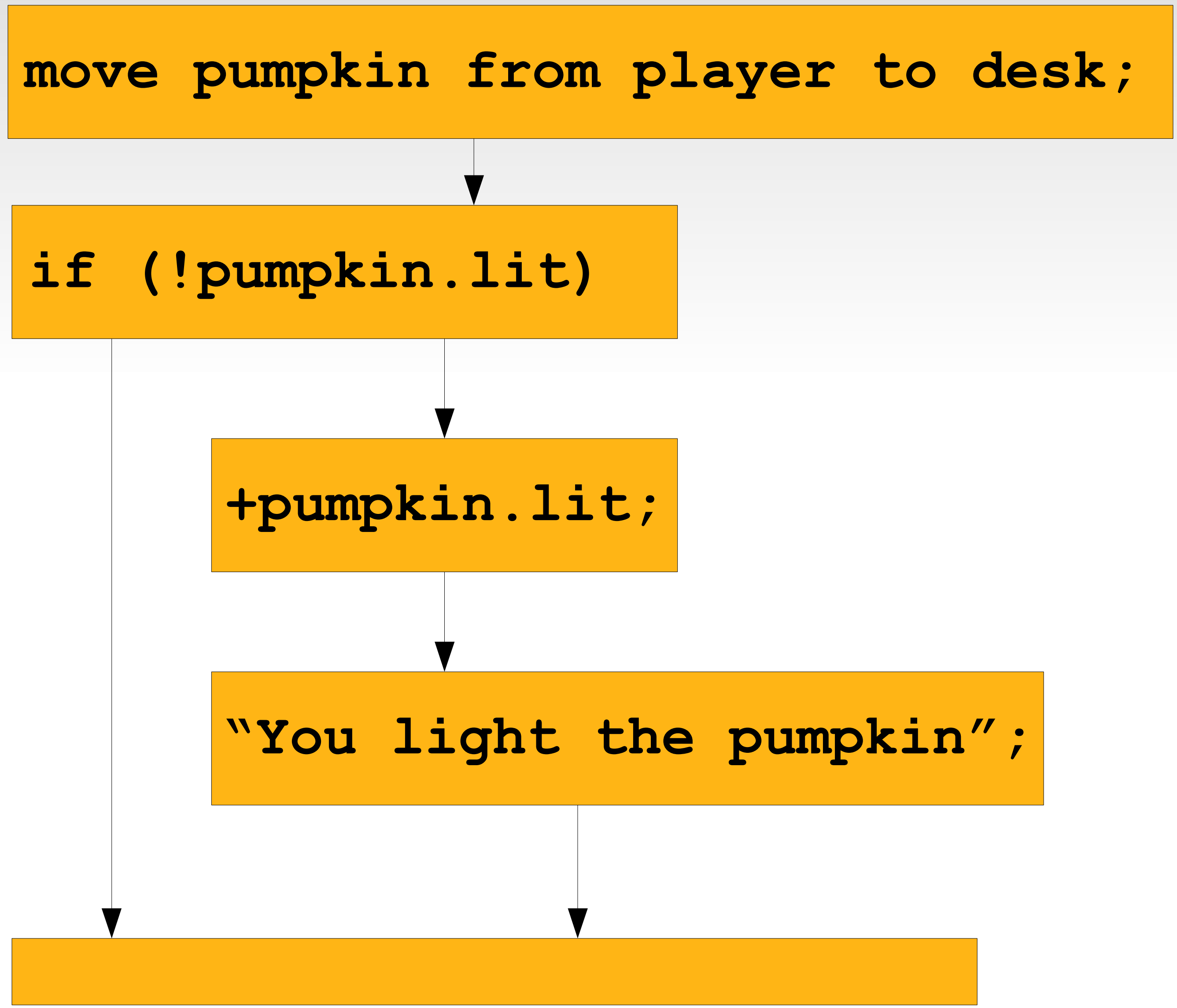


Pre-Condition Analysis

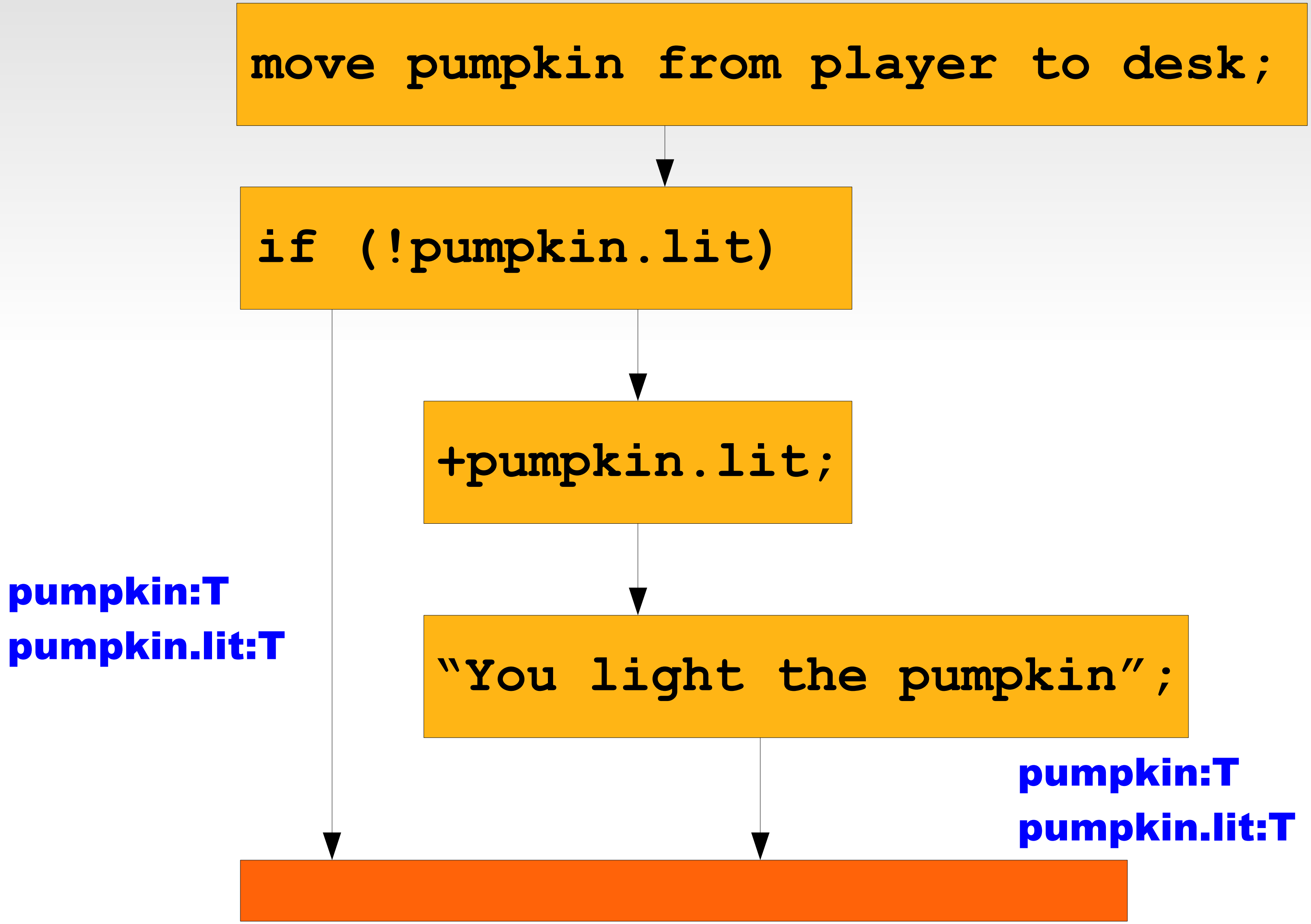
- Pre-condition analysis
  - Backward analogue of post-condition analysis
  - What conditions does an action require?
    - Require for correctness
    - Require in order to have a useful effect? (later)

Pre-Condition Analysis



pumpkin:T
pumpkin.lit:T

Pre-Condition Analysis



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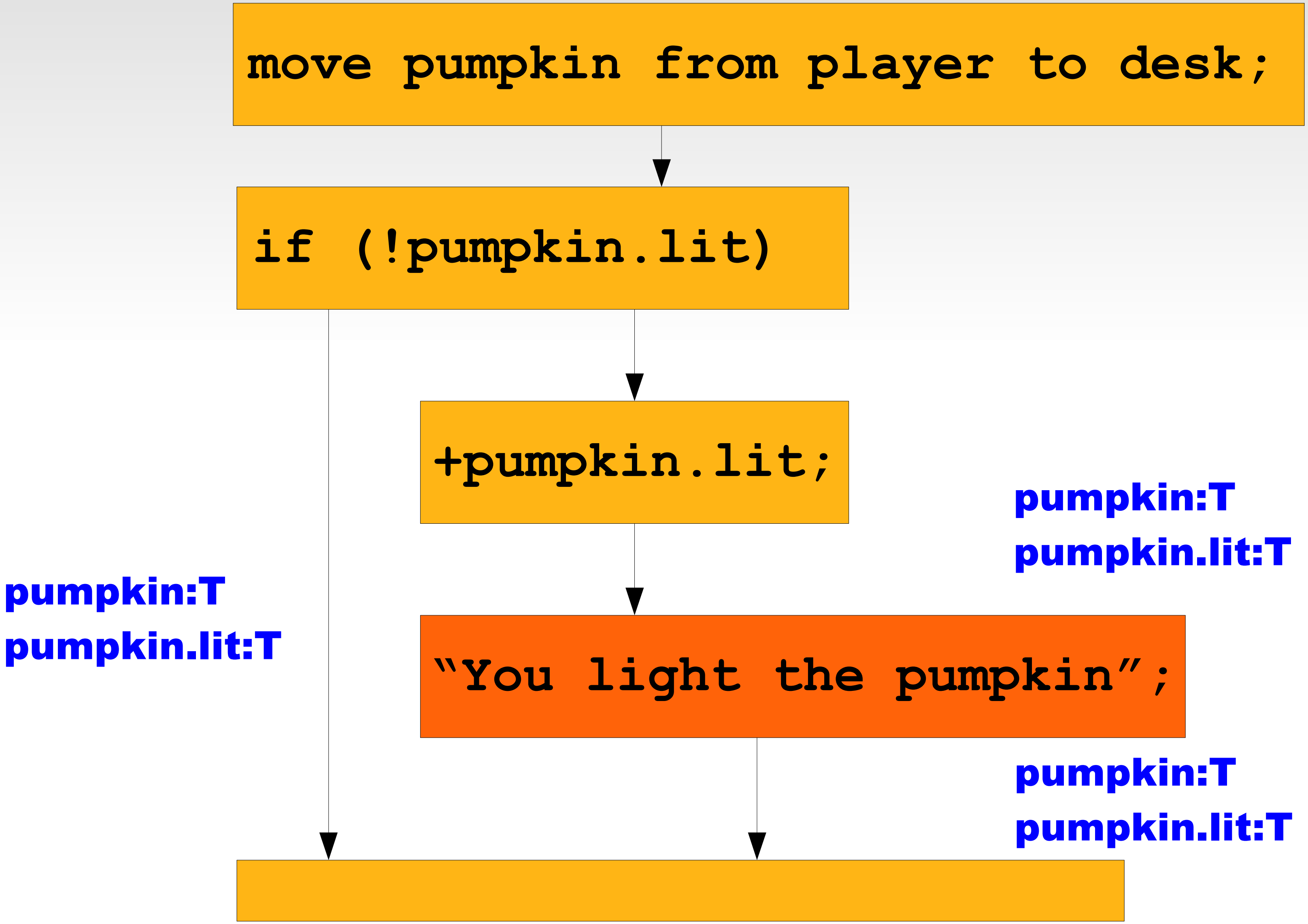

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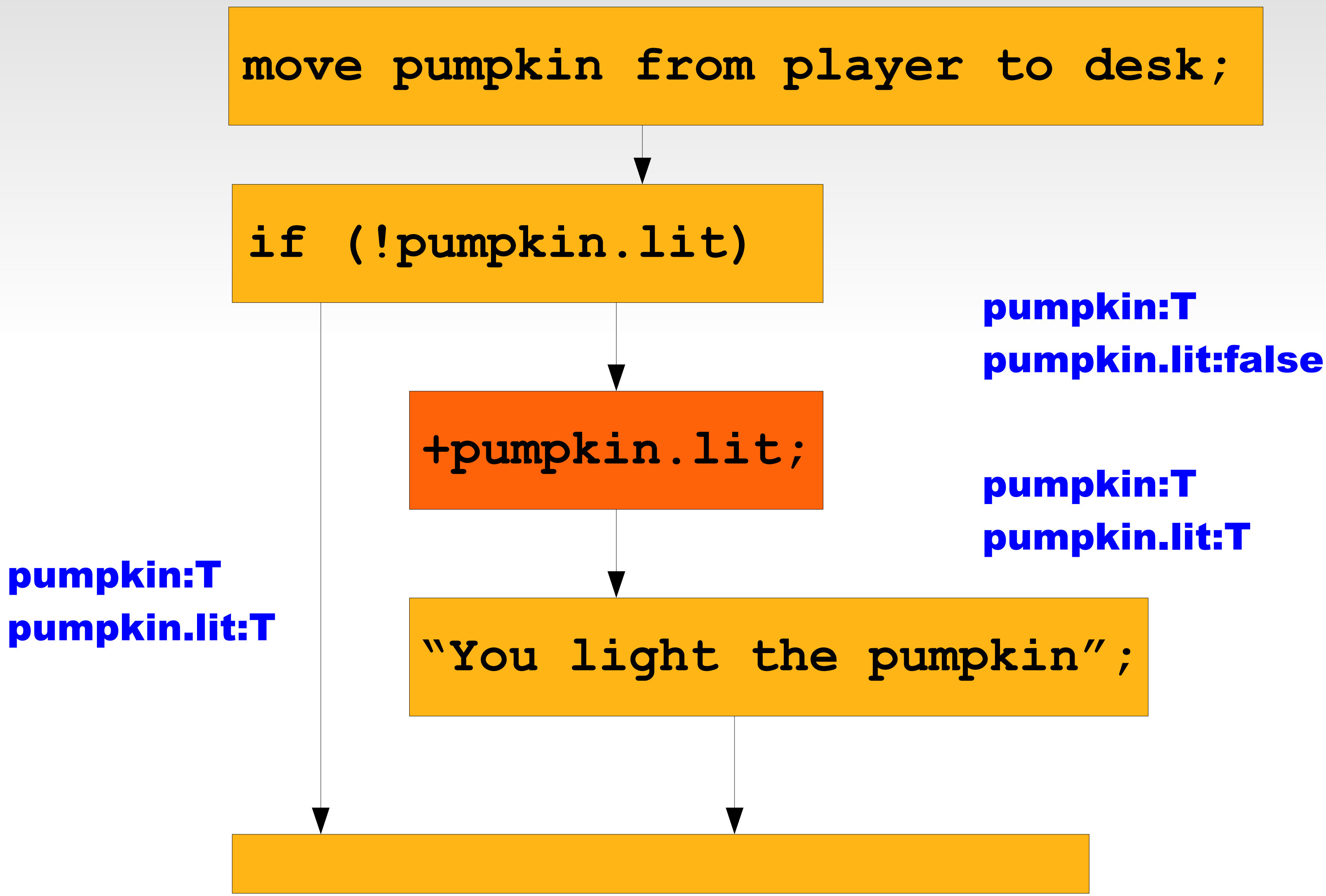

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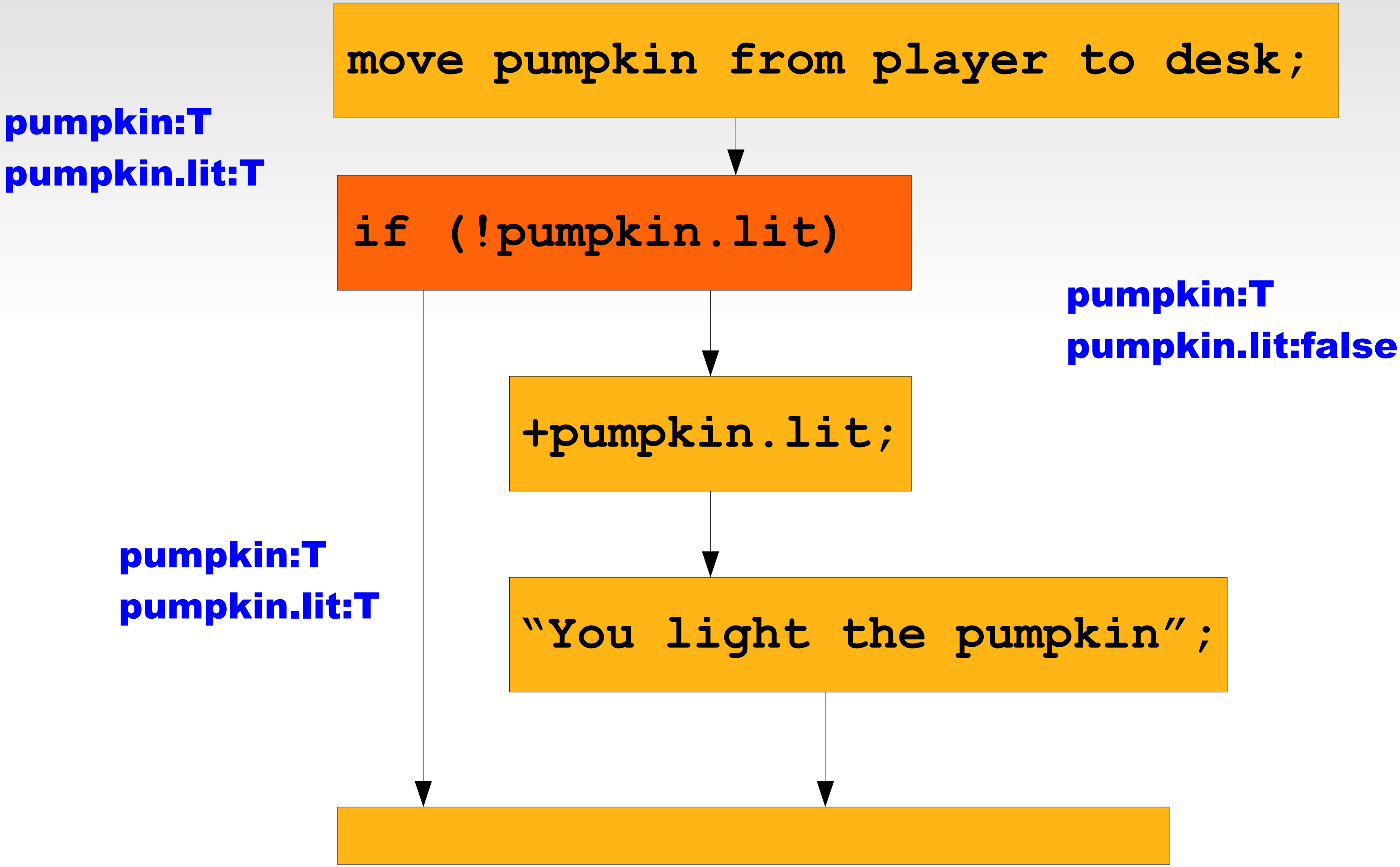


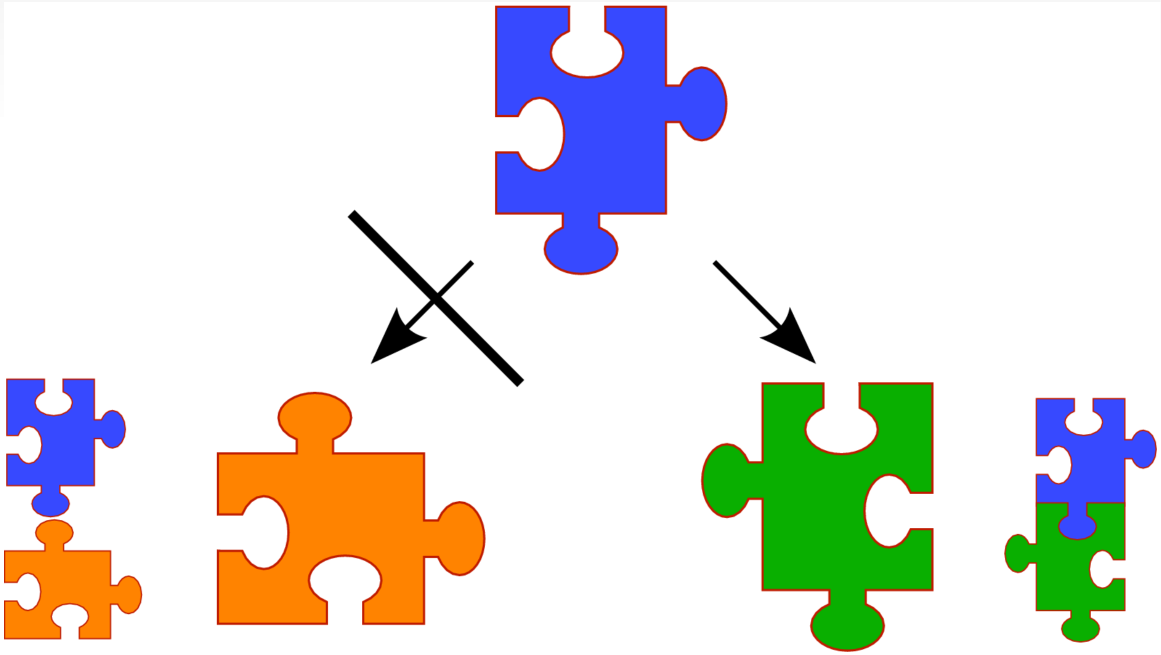
Pre-Condition Analysis

pumpkin:player
pumpkin.lit:T

pumpkin:T
pumpkin.lit:T

Dataflow Analysis

- Pre/post-conditions constrain which actions can follow which



Dataflow Analysis

- Can we make this more precise?
- Control flow often exists to give meaningful responses, even if there are errors
  - ```
    (you,wear,ring) {
        if (you contains mittens) {
            "you can't put on a ring while wearing mittens!"
        } else {
            move ring from desk to you;
        }
    }
    ```
- No constraints in "`wear mittens; wear ring`"
    ```

Accurate Match

- Accurate match analysis:
- Detect necessary internal predicate for any state change
  - Outermost conditional(s):
    ```
    if (you contains mittens)
    ```
- If one branch has no state changes
  - Pre-requisites for the action are preserved from the other branch
    - Gives conditions required for *meaningful* action sequencing

Winning Set

- Not all actions are required to win the game
  - Actions containing **`+game.win`**
  - Actions containing statements which enable reaching win
    - ...and so on, recursively
- "Enable" is based on state reachability
  - ```
    (you,do,something) {
        if (x) {
            if (y) {
                +game.win;
            }
        }
    }
    ```

Action (you,do,something) is part of the winning set.
    ```

Winning Set

- Not all actions are required to win the game
  - Actions containing **`+game.win`**
  - Actions containing statements which enable reaching win
    - ...and so on, recursively
- "Enable" is based on state reachability
  - ```
    (you,do,something) {
        if (x) {
            if (y) {
                +game.win;
            }
        }
    }
    ```

Winning enabled by actions which can make either **x** true or **y** true.
    ```

Winning Set

- Not all actions are required to win the game
  - Actions containing `+game.win`
  - Actions containing statements which enable reaching win
    - ...and so on, recursively
- "Enable" is based on state reachability
  - ```
    (you,do,somethingElse) {
        if (w) {
            if (z) {
                +x;
            }
        }
    }
    ```

x is enabled by action (you,do,somethingElse). Now we also need actions which can make either **w** true or **z** true...
    ```

Winning Set

- Not all actions are required to win the game
  - Actions containing **`+game.win`**
  - Actions containing statements which enable reaching win
    - ...and so on, recursively
- Result is a closed subset of actions
  - All actions required to win the game
    - No “useless” actions
  - Reduces branching factor

Useless Objects

- Winning set establishes “useless” actions
  - Actions that do not contribute to search goal
- Useless objects exist too
  - Window dressing, promote interesting gameplay
- But still have non-trivial state interactions
  - Conservatively kept in state space
  - Searching their states adds overhead

Useless Objects

- Useless objects
  - Useless state variable
    - Read/write only by useless actions
    - Read/write otherwise only to reassign itself
    - ```
      if (object.firstUse) {
          -object.firstUse;
          “Some text you only see once.”;
      }
      ```
  - Useless location
    - Similar constraints
      ```

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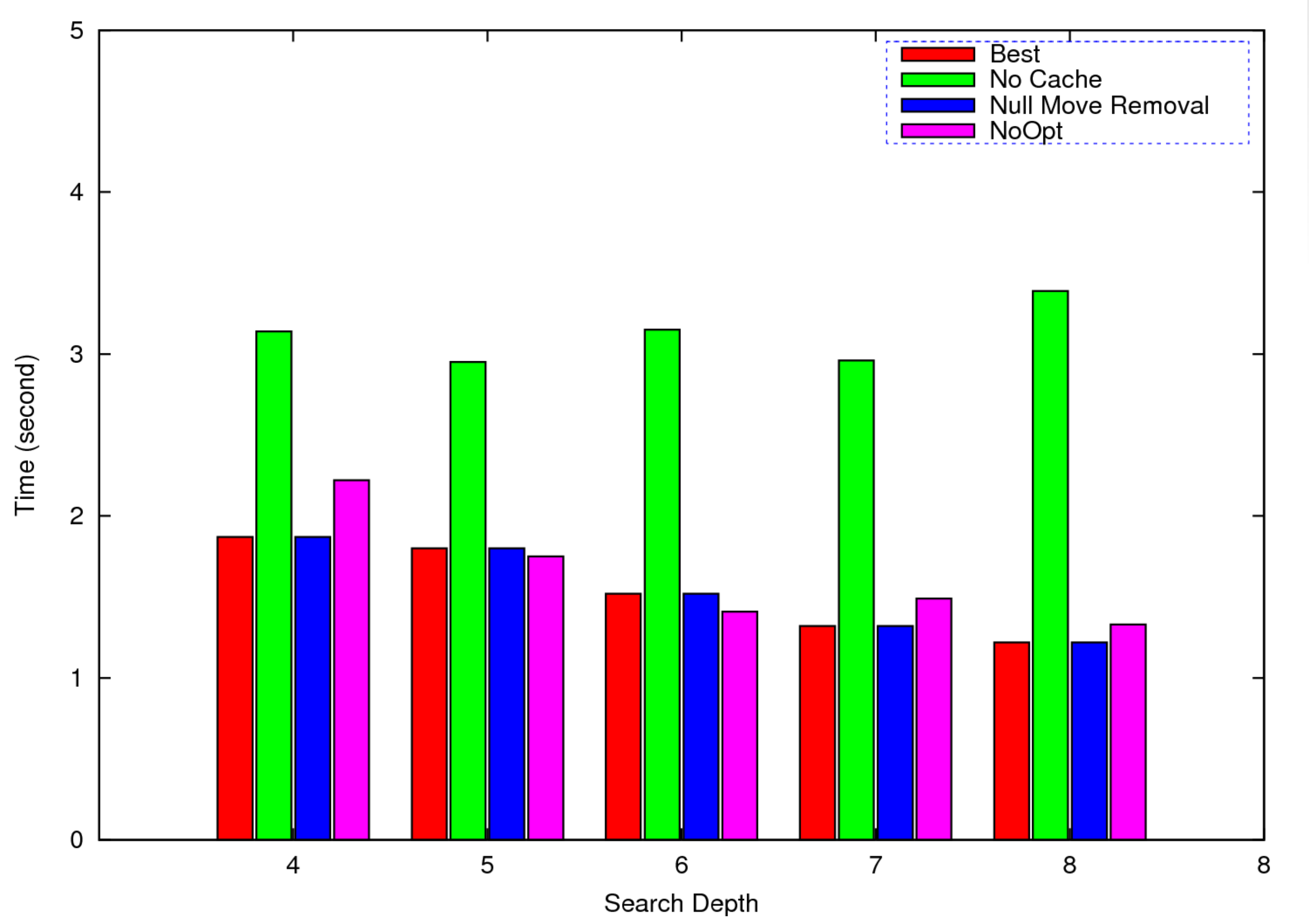
Experiments

- Variety of test narratives
  - Two chapters from Return to Zork
    - Prior work using LL analysis unable to solve
  - Non-trivial student narratives
    - Three Little Pigs
    - Complexity requirement
- Look for first winning path solution
  - various maximum search depths
- See effect of optimizations

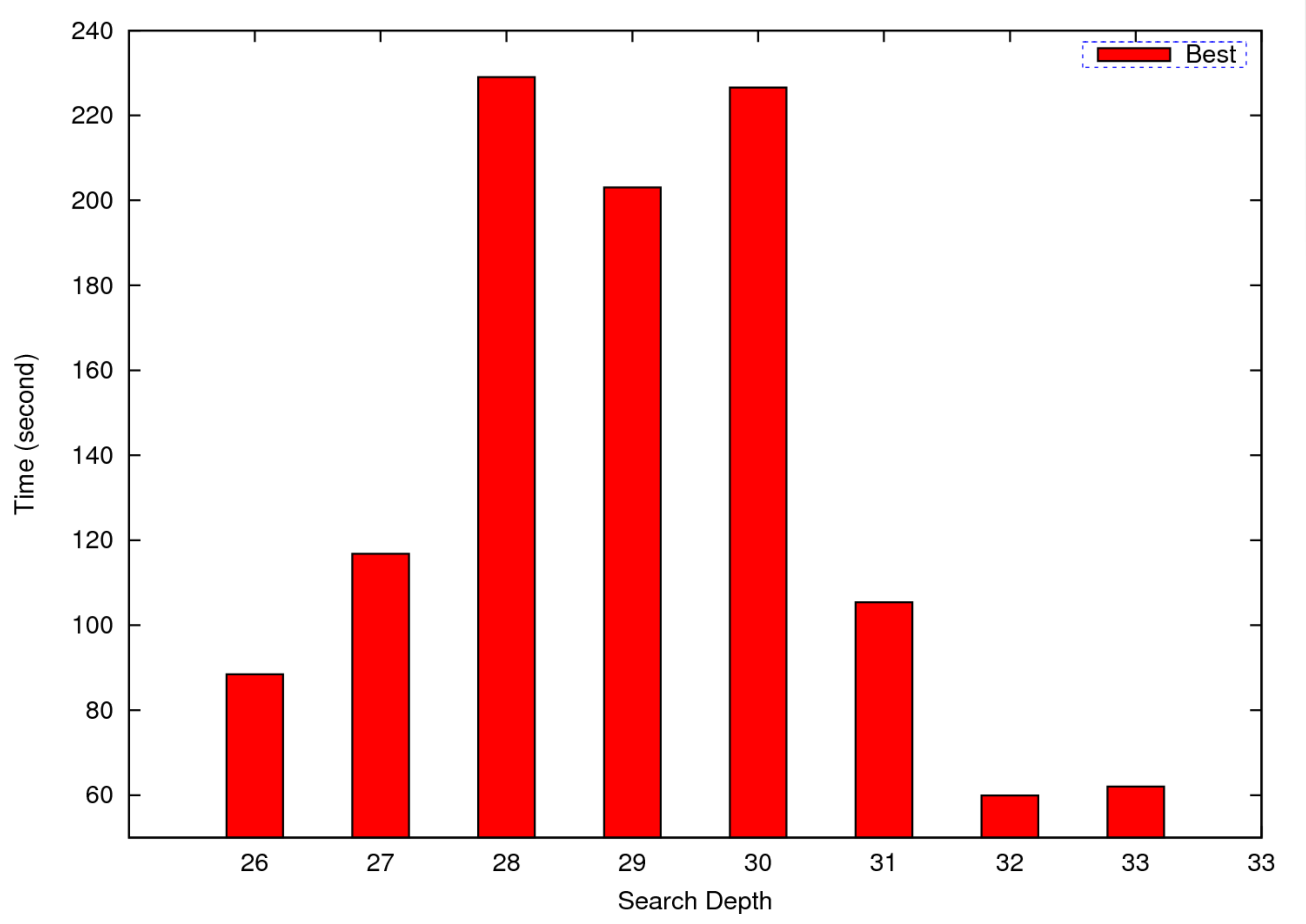
Experiments

- Small narrative (dpomer)



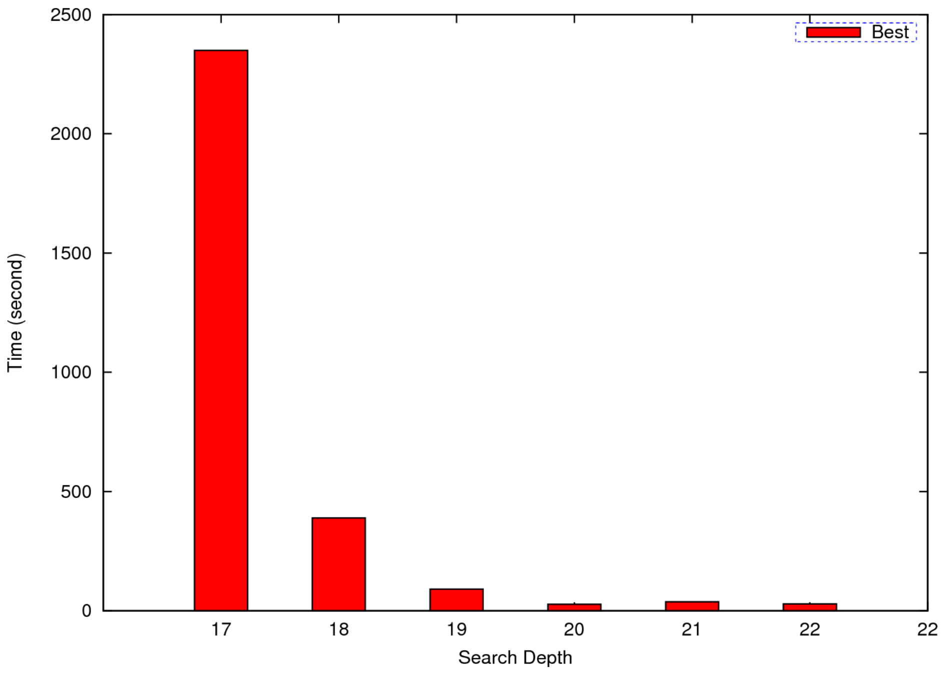
Experiments

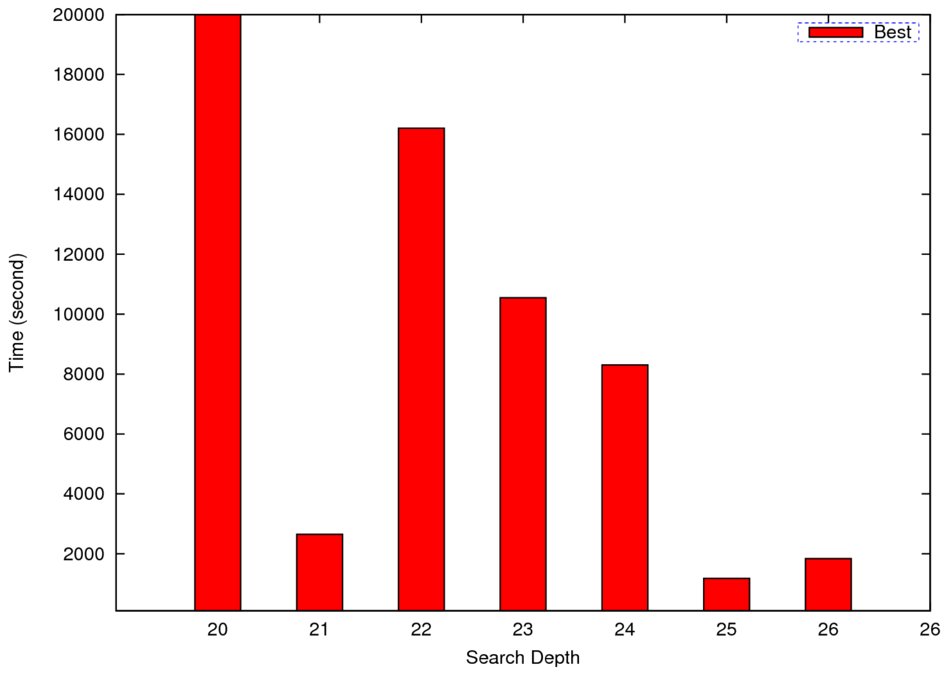
- Larger narrative (mcheva)



Experiments

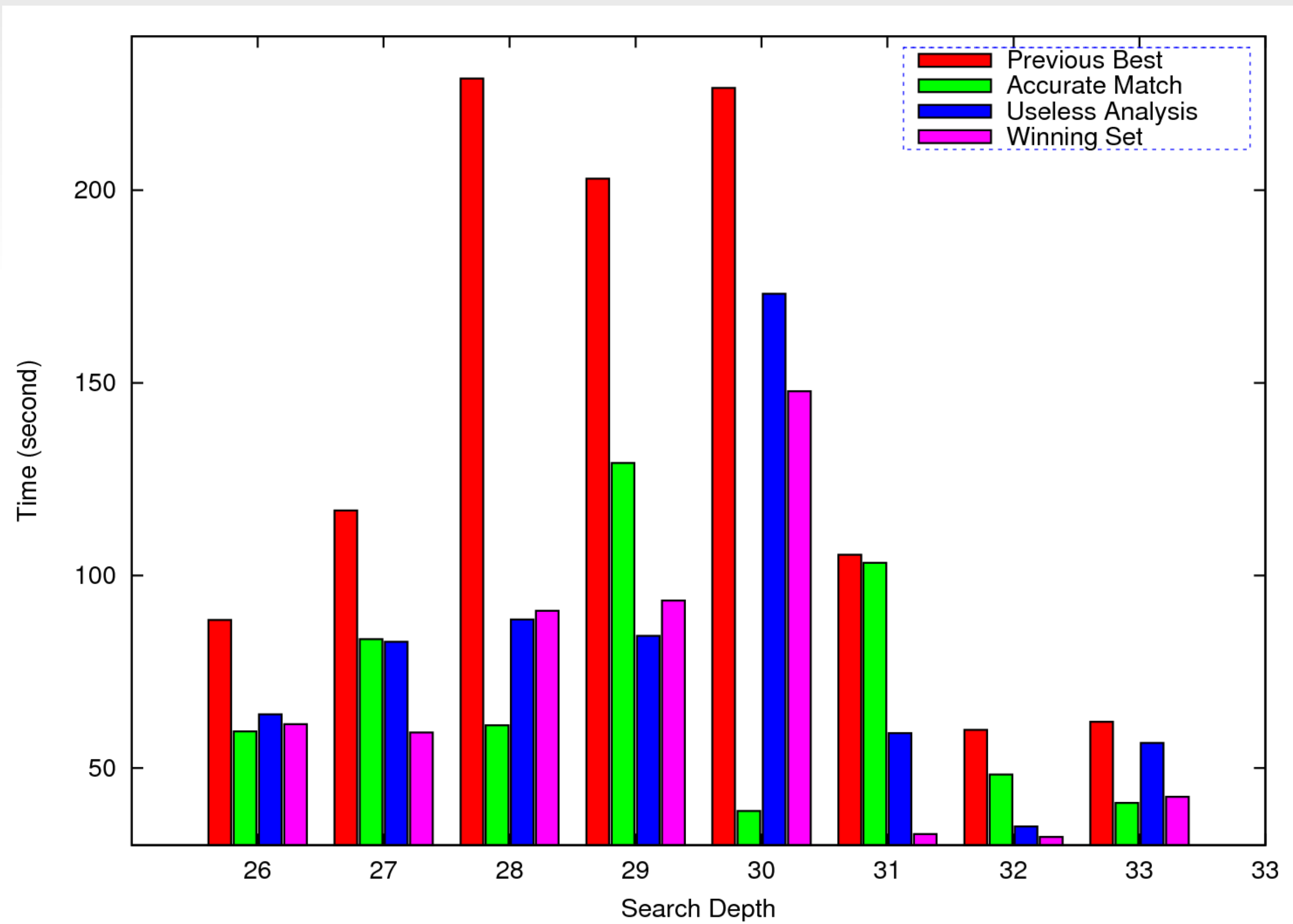
- sdesja8 and RTZtask02





Dataflow Experiments

- mcheva



Dataflow Experiments

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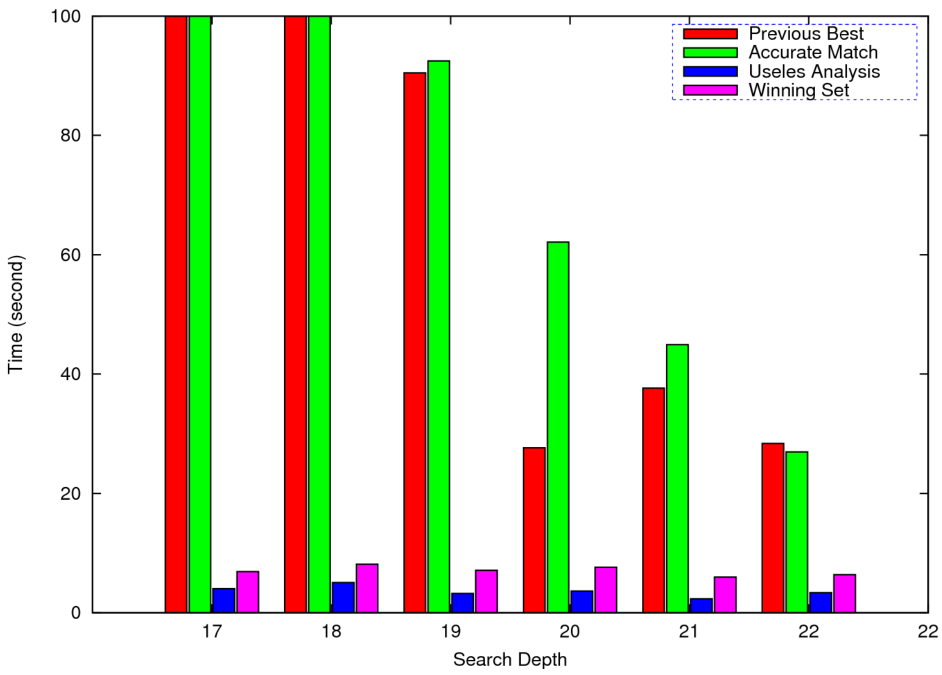

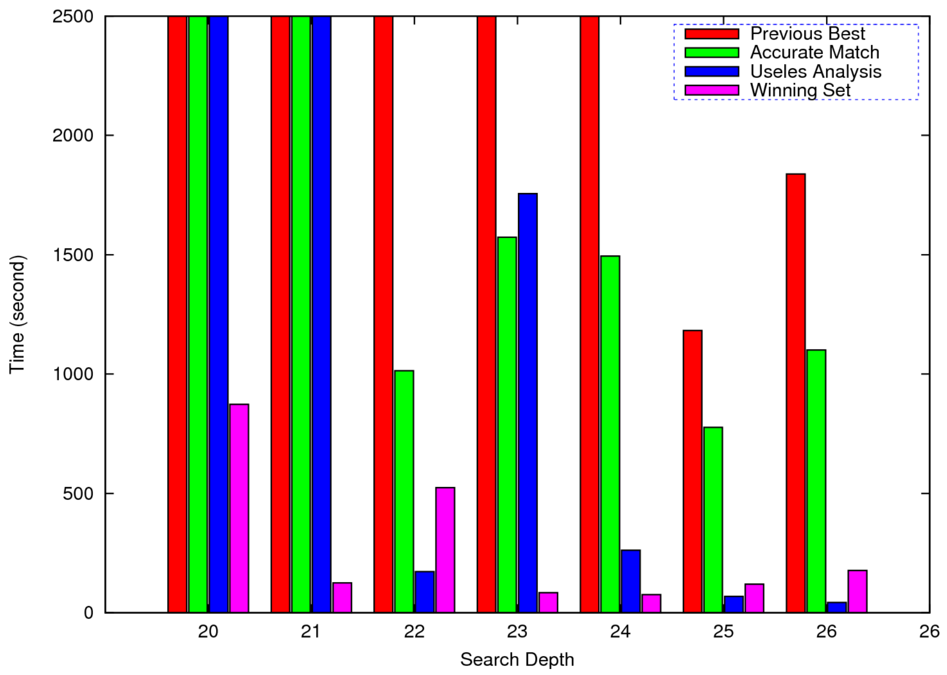

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Conclusions

- Previous work used low-level analysis
  - Hard to scale to larger narratives
  - Hours to days to analyze very small narratives
    - Even with state-of-the-art heuristic solvers
- Our approach has orders of magnitude improvement
- High-level info from dataflow analysis
  - Combined with efficient searching

Future Work

- Extend the experimentation
  - Model and analyze full commercial narratives
- Techniques to ease analysis
  - Syntax to better identify semantic structure
- Other dataflow analyses
  - context-sensitive
- Metrics
  - Quality, complexity, understanding

Thanks

Questions?