# Discovering Options from Example Trajectories

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If we had a few expert traces,

trajectories of the problem being solved

We can find problem decompositions

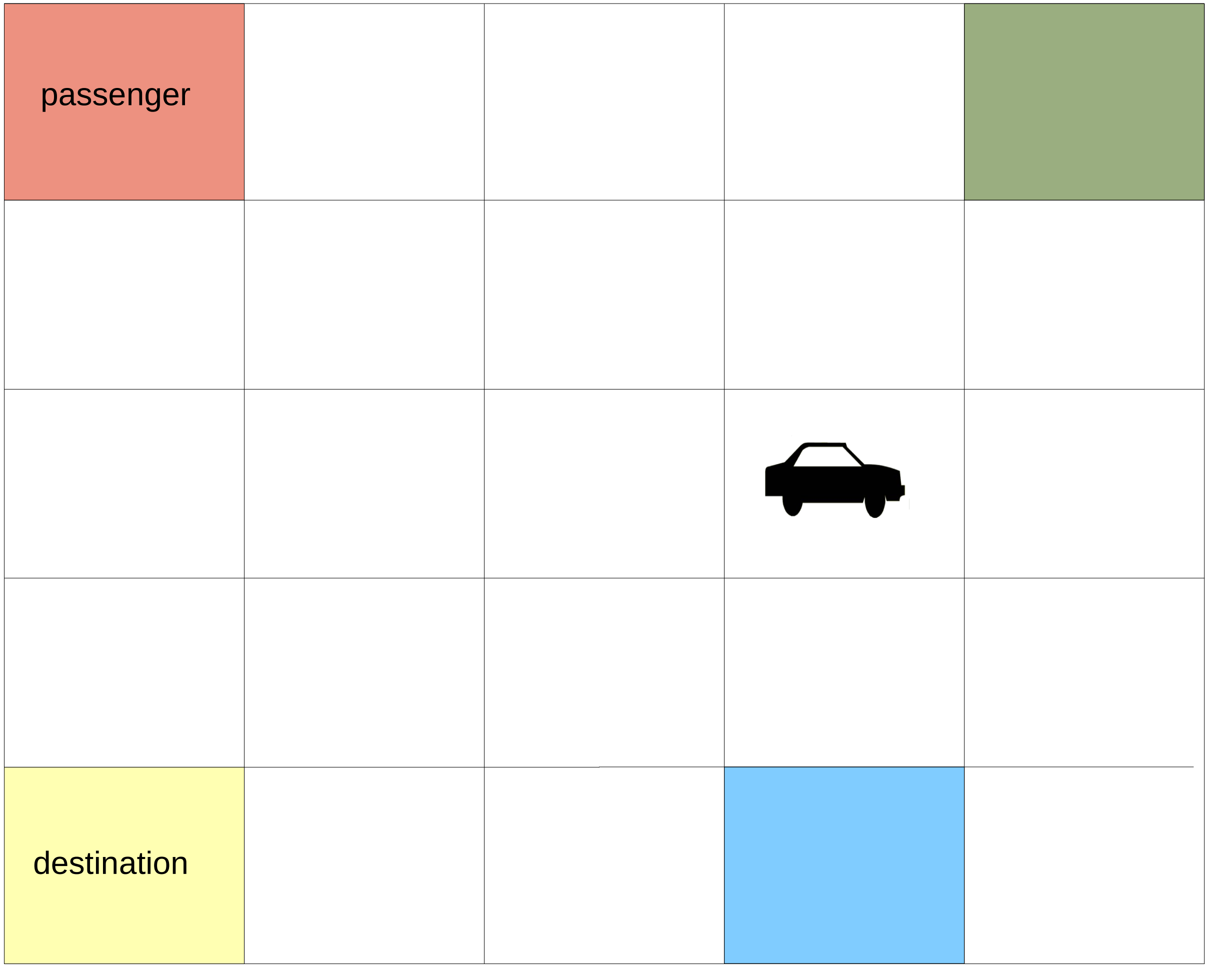
by examining those trajectores

And solve the problem faster

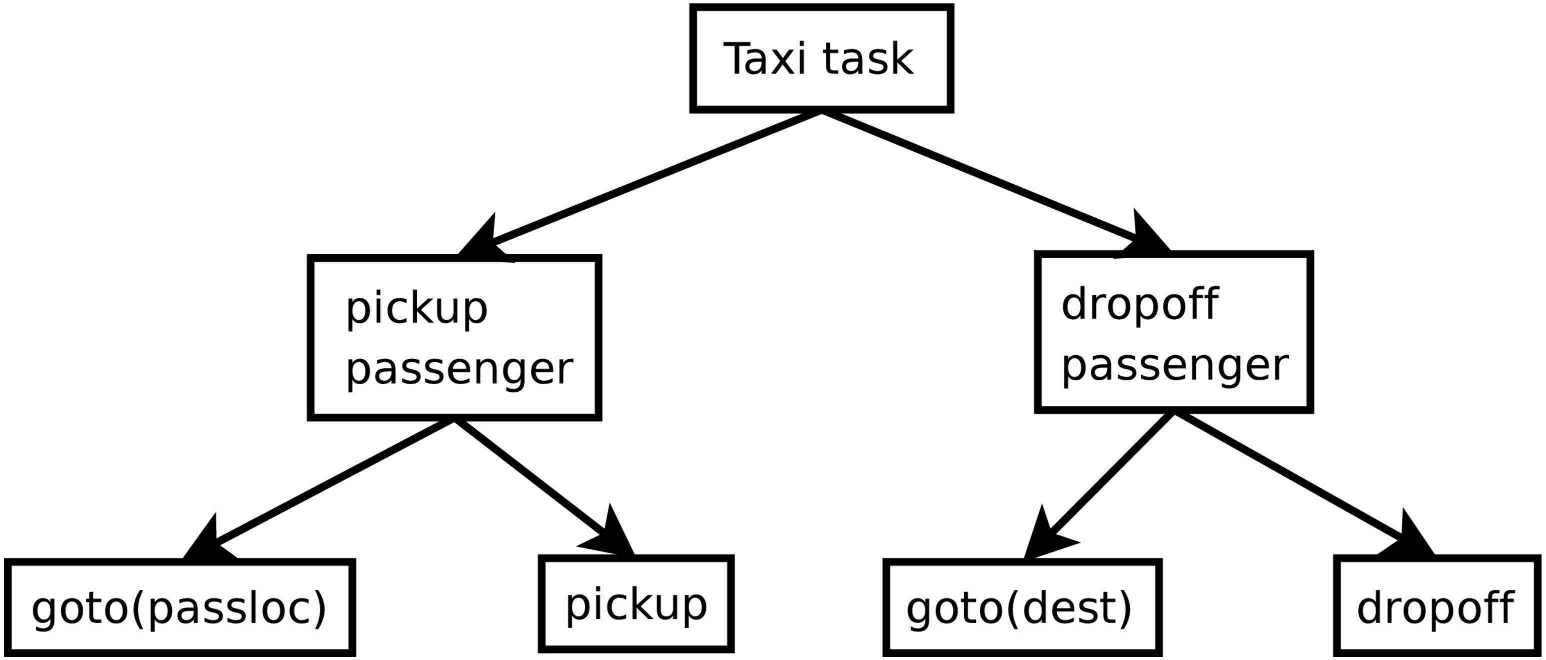
# Taxi Domain

**State features:**
X – taxi X
Y – taxi Y
P – passloc
D – destination

**Actions:**
N – North
S – South
E – East
W – West
P – Pickup
D – Dropoff



# Problem Decomposition



# Problem Decomposition

- Recognition

North, north, west, west, west, pickup, south, south, south, south, dropoff

goto(), pickup, goto(), dropoff

pickup-passenger, dropoff-passenger

# Problem Decomposition

- Transfer
  - Skills applicable to other tasks

    goto(), goto()

  - Decomposition applicable to other action sets

    pickup-passenger, dropoff-passenger

# Problem Decomposition

goto(■)

**State features:**
X – taxi X
Y – taxi Y

**Actions:**
N – North
S – South
E – East
W – West

pickup-passenger

**State features:**
X – taxi X
Y – taxi Y
P – passloc

**Actions:**
R – goto(■)
G – goto(■)
Y – goto(■)
B – goto(■)
P – Pickup

- Speedup
  - Breaks up the problem
  - Abstraction opportunities in subproblems
  - Reuse

# Focus of this work:

## Automating decomposition by finding and factoring out subtasks

Finding decomposition

- Action sequences contain signatures

  use to find good subtasks

- Heuristic for finding good subtask boundaries:

  “abstraction boundaries”

Using decomposition

- Direct incorporation of options

  solve transition and reward model

# Definitions

- SMDP: (S, A, P, R, γ)
  - feature based representation
  - known transition/reward model and action feature dependencies
- Subproblem: (M, F, A, ω)
- Option: (I, π, β)
- Trajectory: (s,a,s',d,r) sequence

| **State** | **Action** | **NextState** | **Duration** | **Reward** |
|---|---|---|---|---|
| X:0 Y:0 | East | X:1 Y:0 | 1 | -1 |
| X:1 Y:0 | East | X:2 Y:0 | 1 | -1 |
| X:2 Y:0 | Airport | X:9 Y:8 | 20 | -15 |
| … | | | | |

# Automated Decomposition

(What are good subproblems?)

- Size: large enough to capture a significant portion of the problem but not the whole thing
- Frequency: reuse opportunities
- Abstraction: offers significant speedups

# Automated Decomposition

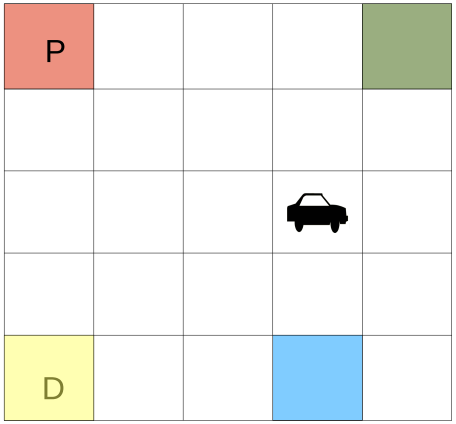
- Observation: Subproblems of significant size and frequency leave long, common action sequences in the trajectories that act as “signatures”
- Intuition: We can use these “signatures” to find good subproblems

- Observation: Different subproblems require different state features
- Intuition: Use “abstraction breaks” to find subtask boundaries.

# Discovery Algorithm

- Suffix tree to find common action sequences
- Extend to find goals
- Choose subtask based on most frequent goal
- Find and extract all instances of subtask
- Repeat

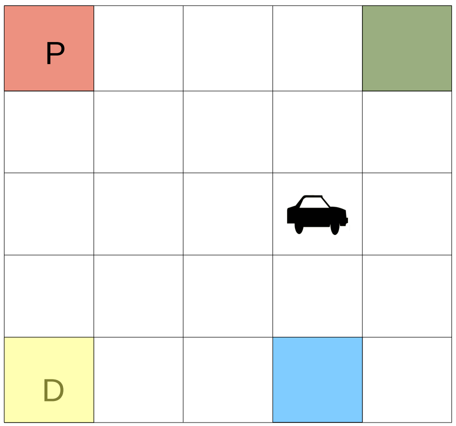
# Automated Decomposition




**Trajectories**

WWWNNPSSSSD
EESSPWWWNNNWND
NNEPSSSSD
NNWWWPSESSSEEED
WPNNNND
WPSSSEEESED
...

# Automated Decomposition




**Trajectories**

WWWNNPSSSSD

EESSPWWWNNNWND

NNEPSSSSD

NNWWWPSESSSEEED

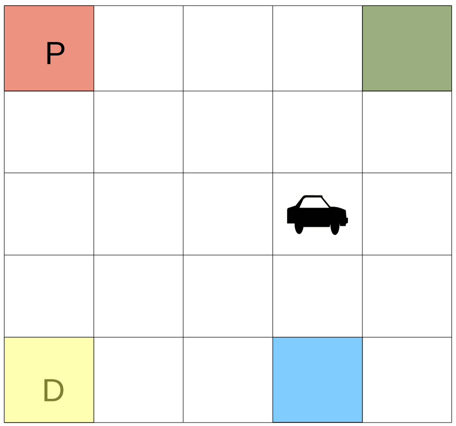
WPNNNND

WPSSSEEESED

...

**Find common action sequences using suffix tree**

# Automated Decomposition




X:0 Y:0

X:4 Y:0

**Trajectories**

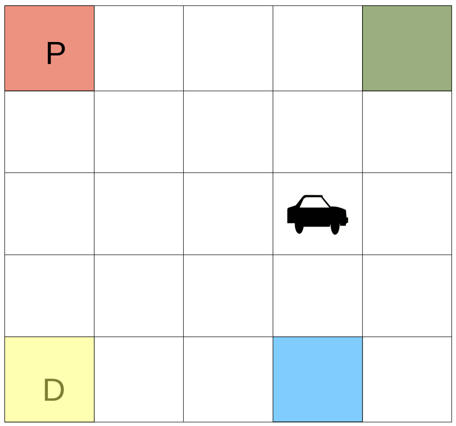
WWWNNPSSSSD
EESSPWWWNNNWND
NNEPSSSSD
NNWWWPSESSSEEED
WPNNNND
WPSSSEEESED
…

**we are navigating, only worrying about taxi location (X,Y). Now with the Pickup action we also need to worry about passenger location. Let's make this a boundary.**

**Extend to find goals.**

**We stop when the abstraction suddenly changes. Intuition is that this denotes a conceptual boundary. It also maximizes speedup opportunities.**

# Automated Decomposition




**Trajectories**

WWWNNPSSSSD
EESSPWWWNNNWND
NNEPSSSSD
NNWWWPSESSSEEED
WPNNNND
WPSSSEEESED
...

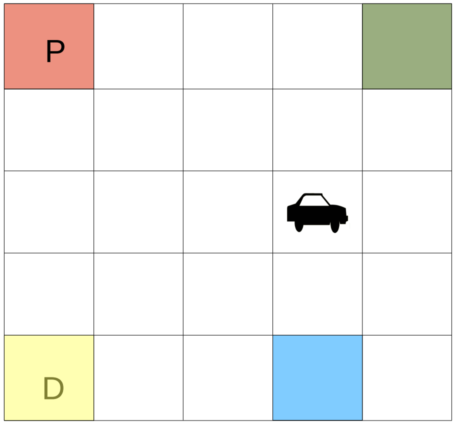
X:4 Y:0

**X:0 Y:0**

**Most common goal selected.**
**This creates subproblem:**

- **M: Taxi SMDP**
- **F: X, Y**
- **A: N,W**
- **ω: X:0 Y:0**

# Automated Decomposition




**Trajectories**

WWWNNPSSSSD
EESSPWWWNNNWND
NNEPSSSSD
NNWWWPSESSSEEED
WPNNNND
WPSSSEEESED
...

Extract subproblem:

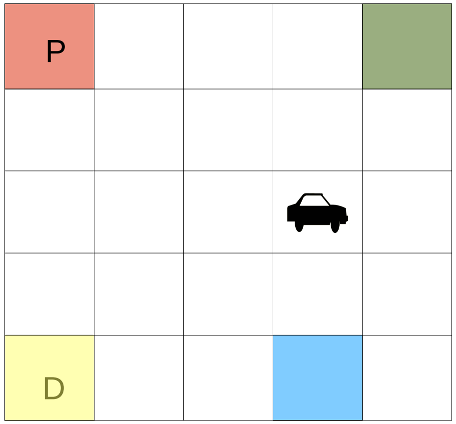
α – Goto (X:0 Y:0)

Note: we estimate the speed up for any proposed subproblem. We only perform extraction if we expect it to offer speedup

**New Trajectories**

αPSSSSD
EESSPαD
NNEPSSSSD
αPSESSSEEED
WPαD
αPSSSEEESED
...

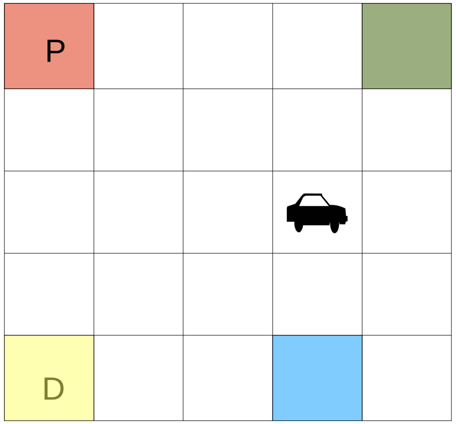
# Automated Decomposition




**Trajectories**
αPSSSSD
EESSPαD
NNEPSSSSD
αPSESSSEEED
WPαD
αPSSSEEESED
...

**Repeat finding additional subproblems until no subproblems are found. Subproblems are solved and inserted into the base problem. When no more subproblems can be found, we solve the augmented MDP.**

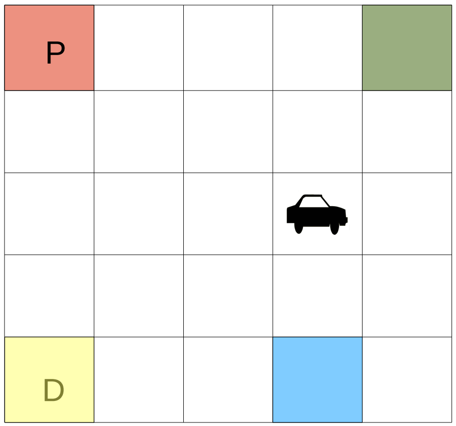
# Results





- Two Domains
  - Taxi World
  - Wargus (Simplified)

# Taxi World




State features:
X – taxi X
Y – taxi Y
P – Pickup
location
D – Destination

Actions:
N – North
S – South
E – East
W – West
P – Pickup
D – Dropoff

- Classic RL Problem
- Easily scalable, good for testing
- Deterministic and stochastic versions

# Wargus (Simplified RTS)


Features:

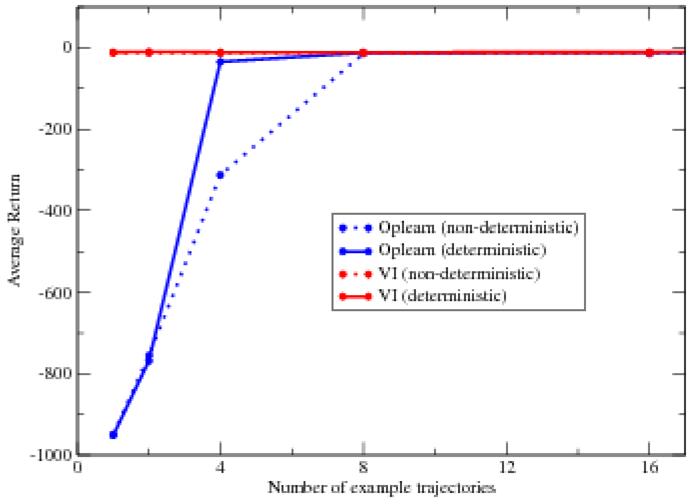
- Gold (hundreds)
- Wood (hundres)
- Grunts
- Farms
- LumberMill
- Barracks
- Blacksmith
- Time-of-day
- Location
- Status

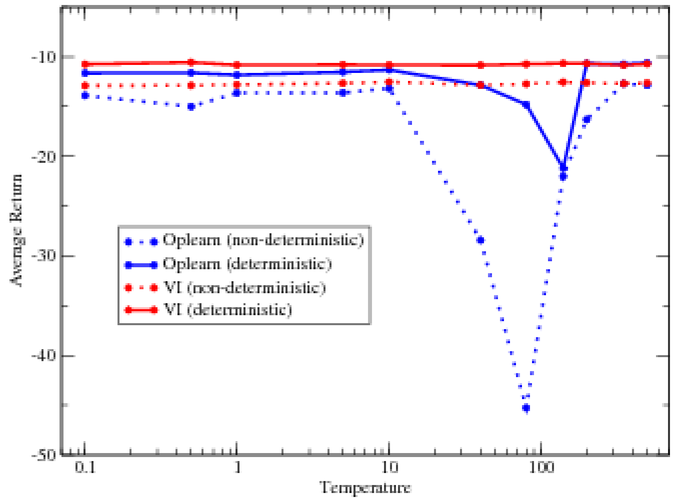
Actions:

- No-op
- GotoGoldmine
- GotoWoods
- GotoTownhall
- Chop
- Mine
- Deposit
- BuildFarm
- BuildBarracks
- BuildLumbermill
- BuildBlacksmith
- TrainGrunt

- Strategic planning problem
- Focuses on learning build order for grunt rush
- More features

# Robustness

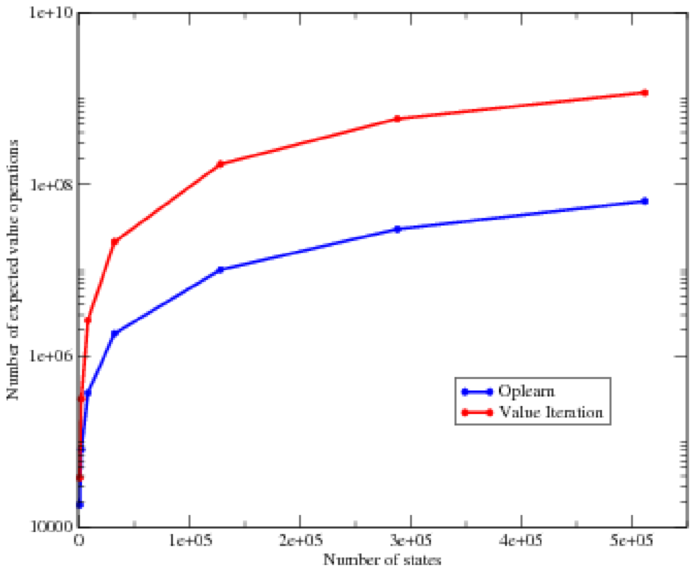


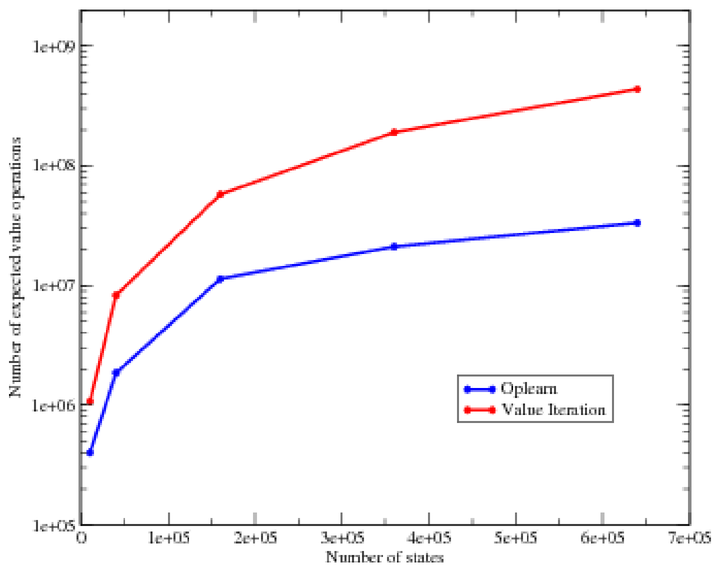

Number of expert trajectories

Quality of expert trajectories

# Speedup

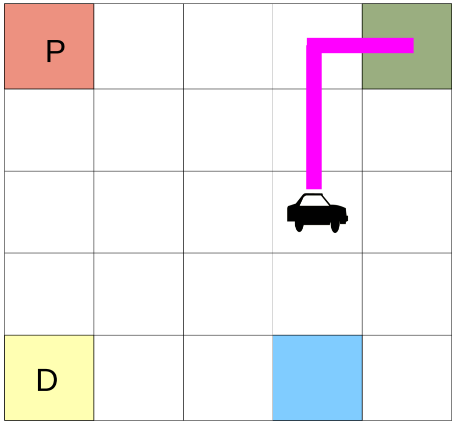


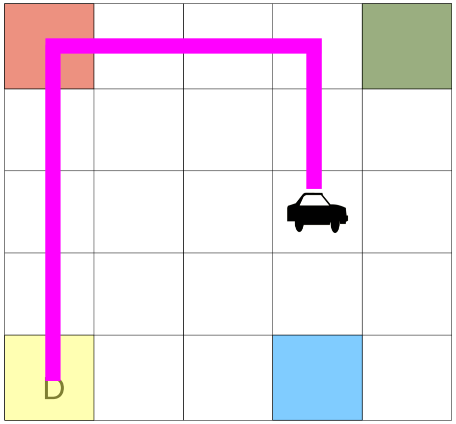

One passenger




Two passengers

# Discovered Options (Taxi)



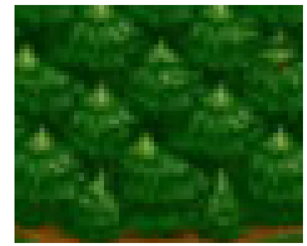




- Goto
- PickUp and Goto

# Discovered Options (Wargus)

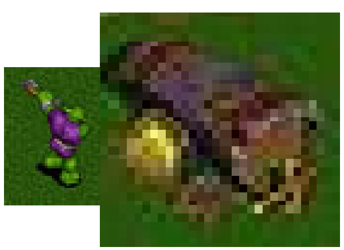
## Low level options

Mine gold
(goto-goldmine, mine, deposit, etc.)



Chop wood
(goto-woods, chop, deposit, etc.)

## High level options



Build a lumbermill
(chopwood, build-lumbermill, etc.)

Build a farm
(minegold, build-farm, etc.)

# Conclusion

- Use expert traces for problem decomposition
- Requires
  - Feature based state representation
  - Known transition/reward model and action feature dependencies
  - Some expert traces
- Buys you
  - Problem decomposition
  - Speedup