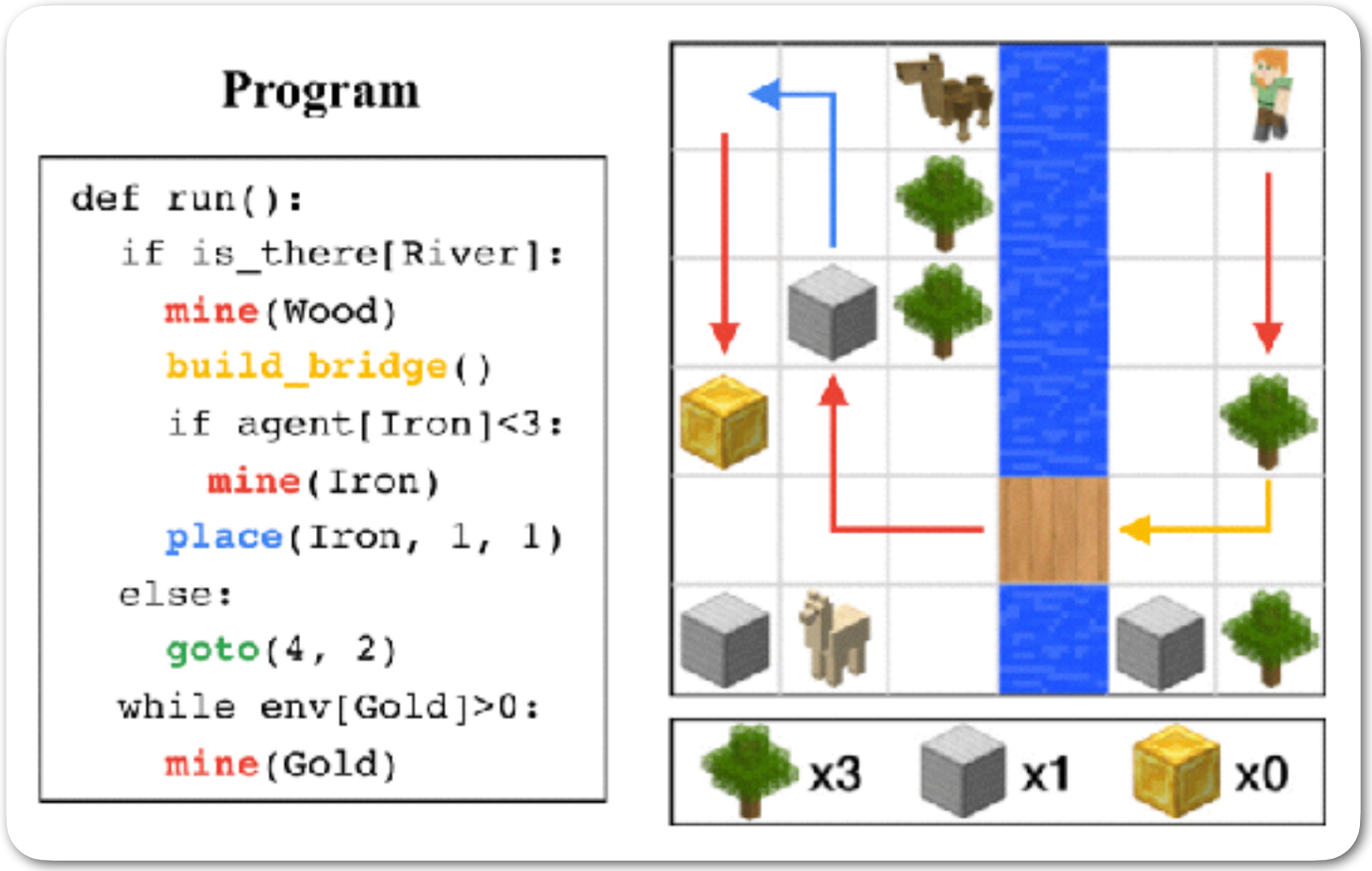
Program Guided Agent

ICLR 2020 (Spotlight)



Shao-Hua Sun

Te-Lin Wu

Joseph J. Lim

Follow an Instruction to Solve a Complex Task

Recipe: cooking fried rice

Stir-fry the onions until tender, and repeat this for garlic and carrots, if you have soy sauce, add some. Pour 2/3 cups the whisked eggs into the stir-fried and scramble.

Natural Language Instruction

Recipe: cooking fried rice

Stir-fry the onions until tender, and repeat this for garlic and carrots, if you have soy sauce, add some. Pour 2/3 cups the whisked eggs into the stir-fried and scramble.

Ambiguities in Language

- Scoping
- Coreferences
- Entities

Bandanau et al. in ICLR 2019
Misra et al. “Mapping Instructions to Actions in 3D Environments with Visual Goal Prediction” in EMNLP 2018
Anderson et al. “Vision-and-language navigation: Interpreting visually-grounded navigation instructions in real environments” in CVPR 2018
Misra et al. “Mapping Instructions and Visual Observations to Actions with Reinforcement Learning” in EMNLP 2017
Hermann et al. “Grounded Language Learning in a Simulated 3D World” in arXiv 2017

Program

Function: cooking fried rice

```
for item in [onions, garlic, carrots]:
    if is_there(“soy sauce”):
        add(“soy sauce”, “pot”)
    while not tender(item):
        stir_fry(item)
pour(whisked(“eggs”), “pot”, 0.66)
scramble(“eggs”)
```

Advantages of Programs

- Explicit scoping
- Resolved Coreferences
- Resolved Entities

Problem Formulation

Program

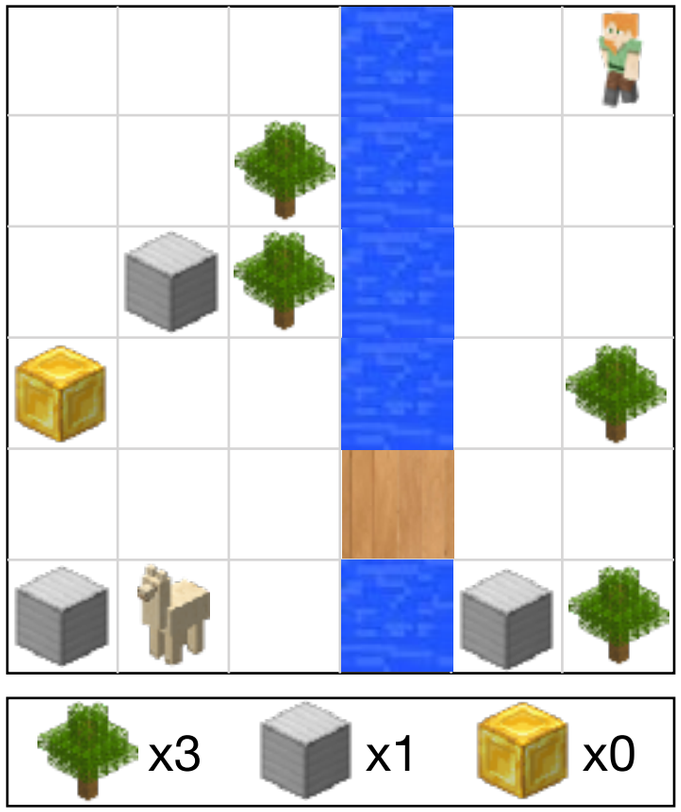
```
def run():
  if is_there[River]:
    mine(Wood)
    build_bridge()
    if agent[Iron]<3:
      mine(Iron)
    place(Iron, 1, 1)
  else:
    goto(4, 2)
  while env[Gold]>0:
    mine(Gold)
```

Problem Formulation

Program

```
def run():
  if is_there[River]:
    mine(Wood)
    build_bridge()
    if agent[Iron]<3:
      mine(Iron)
    place(Iron, 1, 1)
  else:
    goto(4, 2)
  while env[Gold]>0:
    mine(Gold)
```

State

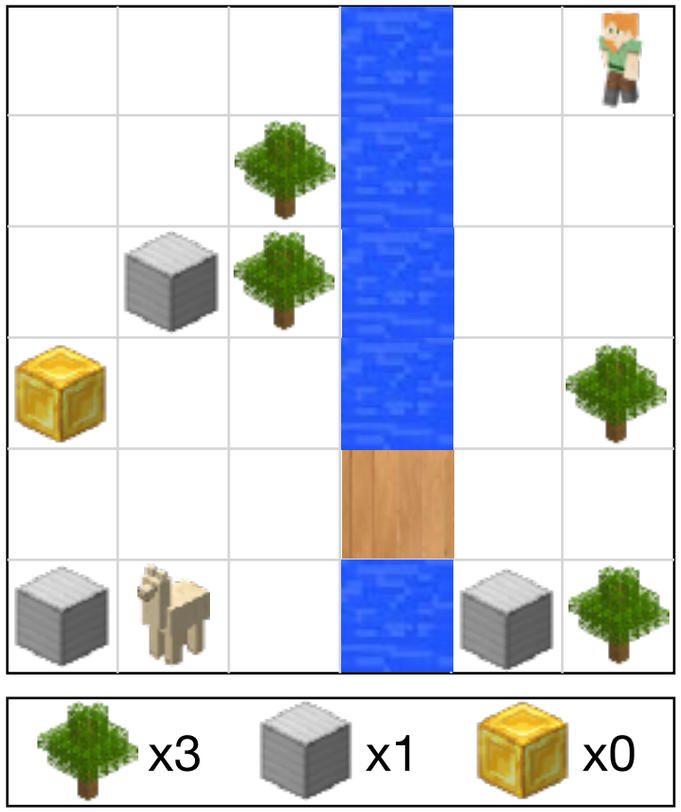


Problem Formulation

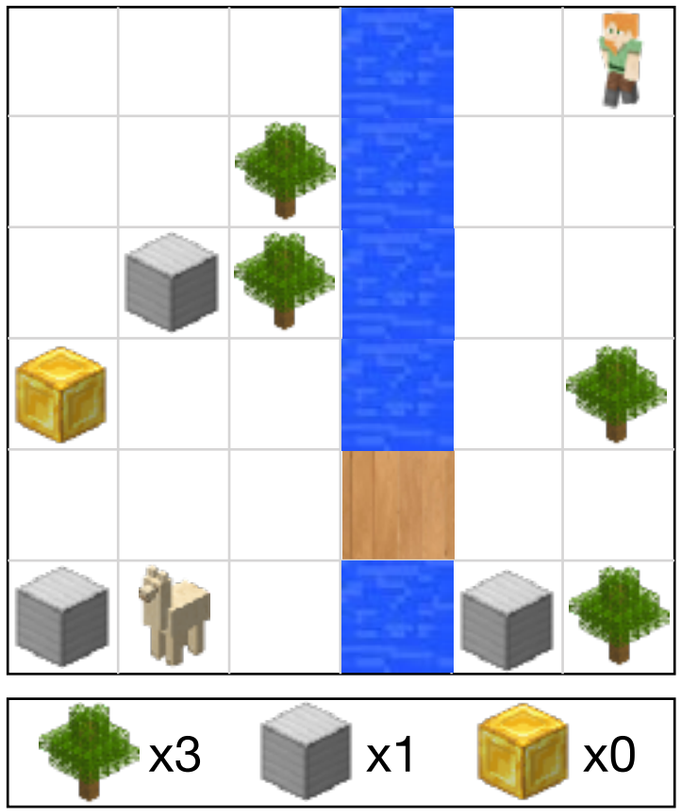
Program

```
def run():
  if is_there[River]:
    mine(Wood)
    build_bridge()
    if agent[Iron]<3:
      mine(Iron)
    place(Iron, 1, 1)
  else:
    goto(4, 2)
  while env[Gold]>0:
    mine(Gold)
```

State



Execution

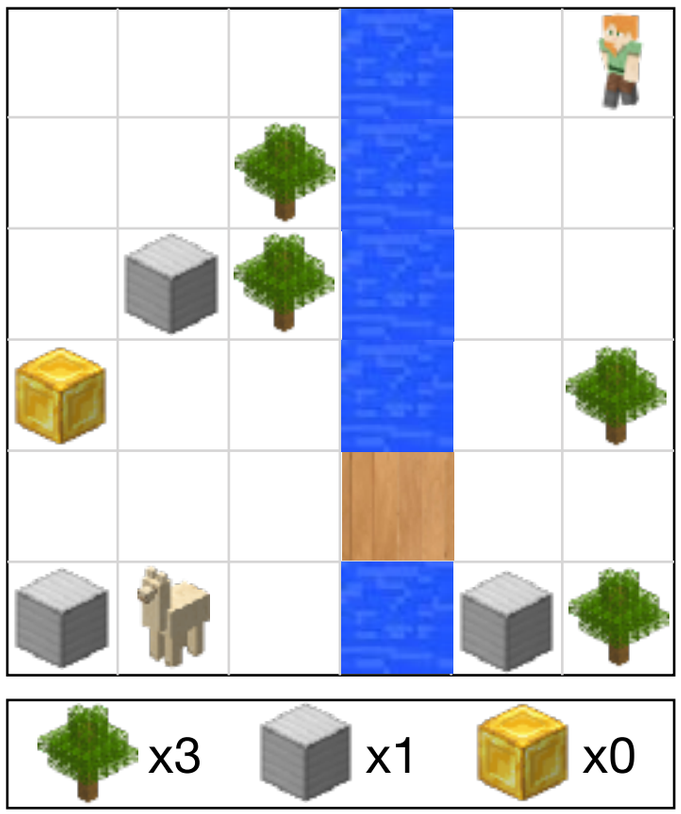


Problem Formulation

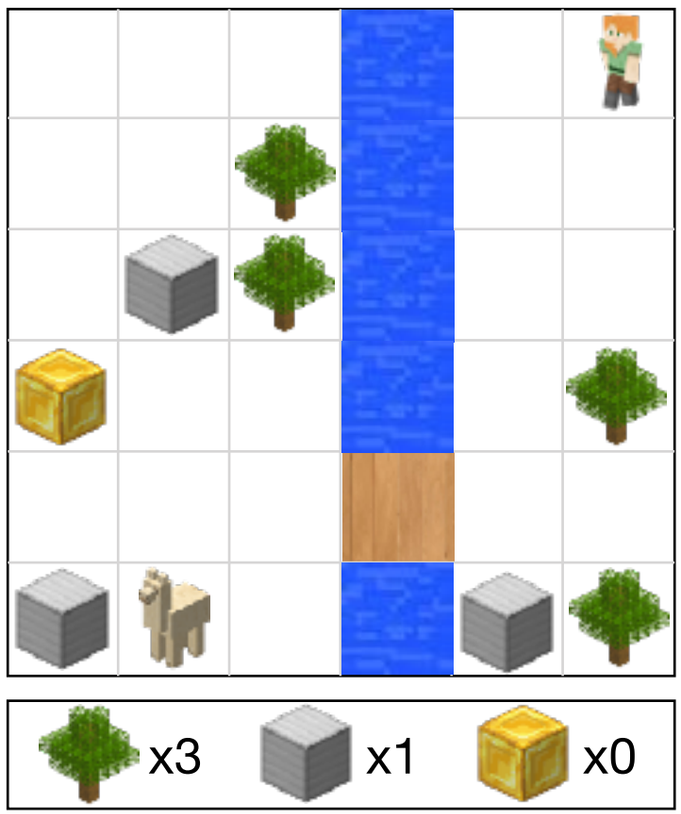
Program

```
def run():
  if is_there[River]:
    mine(Wood)
    build_bridge()
    if agent[Iron]<3:
      mine(Iron)
    place(Iron, 1, 1)
  else:
    goto(4, 2)
  while env[Gold]>0:
    mine(Gold)
```

State



Execution

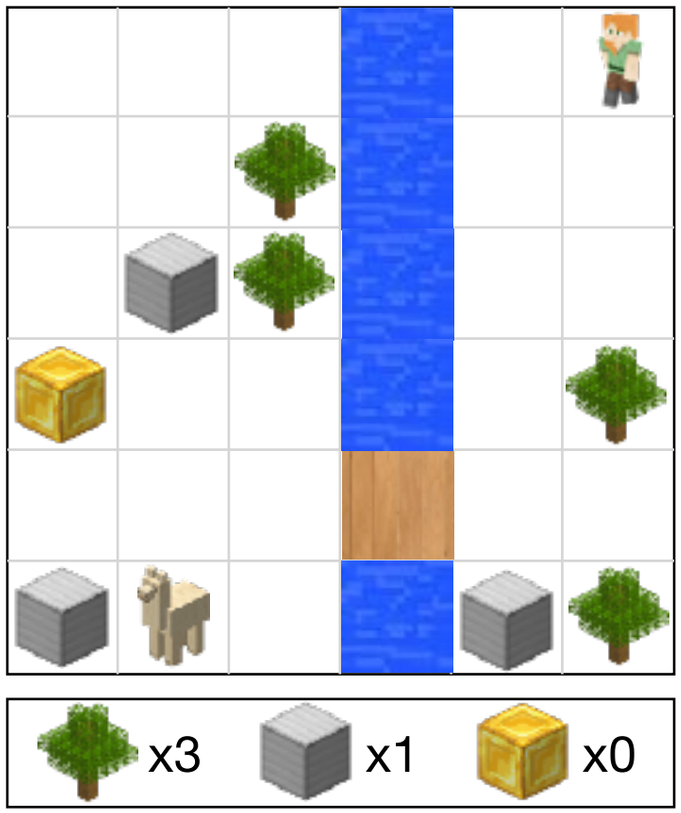


Problem Formulation

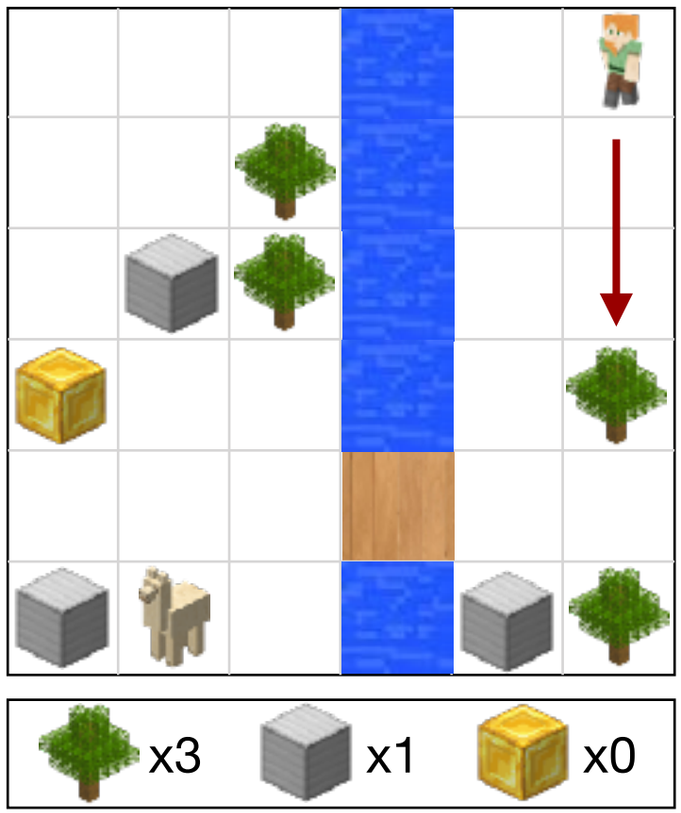
Program

```
def run():
  if is_there[River]:
    mine(Wood)
    build_bridge()
    if agent[Iron]<3:
      mine(Iron)
    place(Iron, 1, 1)
  else:
    goto(4, 2)
  while env[Gold]>0:
    mine(Gold)
```

State



Execution

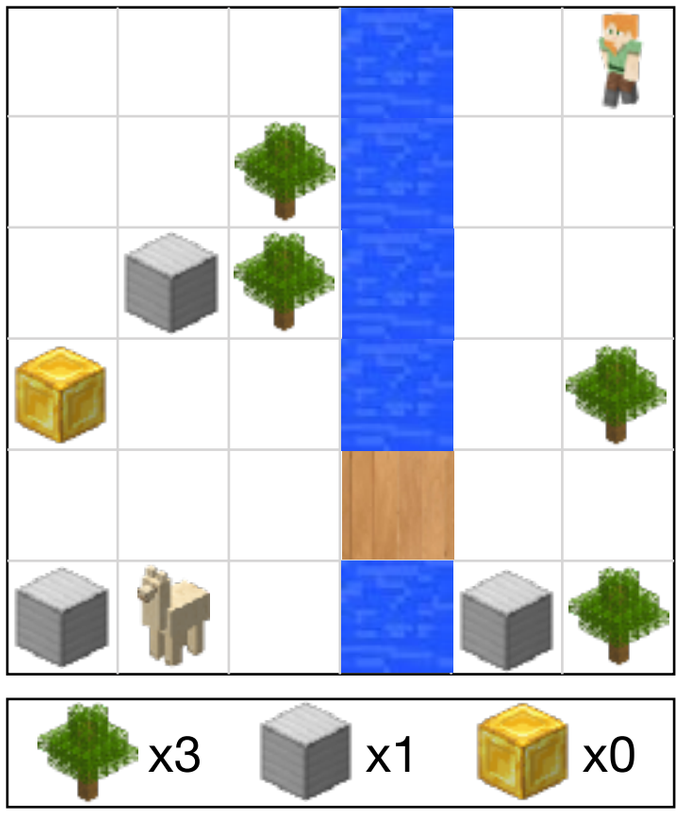


Problem Formulation

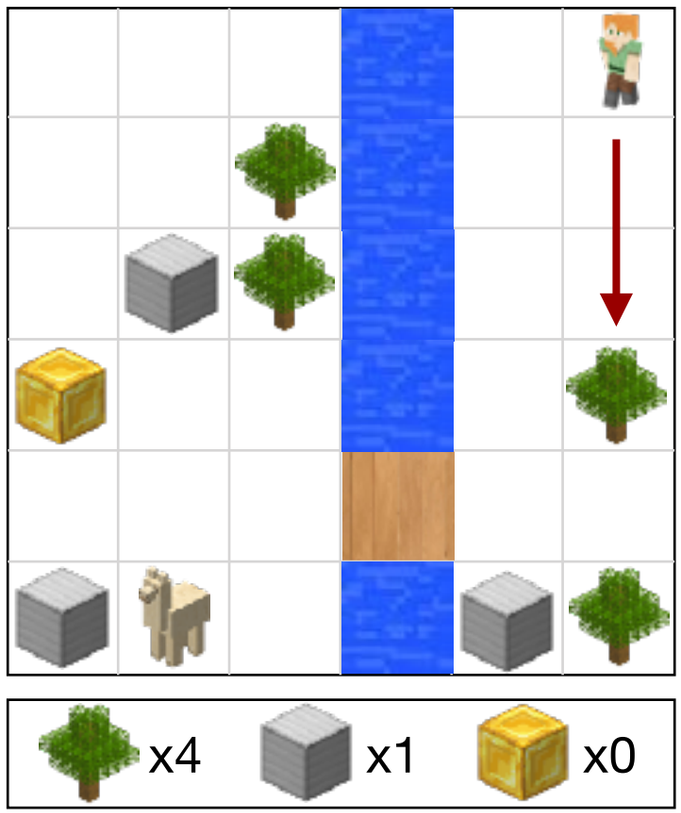
Program

```
def run():
  if is_there[River]:
    mine(Wood)
    build_bridge()
    if agent[Iron]<3:
      mine(Iron)
    place(Iron, 1, 1)
  else:
    goto(4, 2)
  while env[Gold]>0:
    mine(Gold)
```

State



Execution

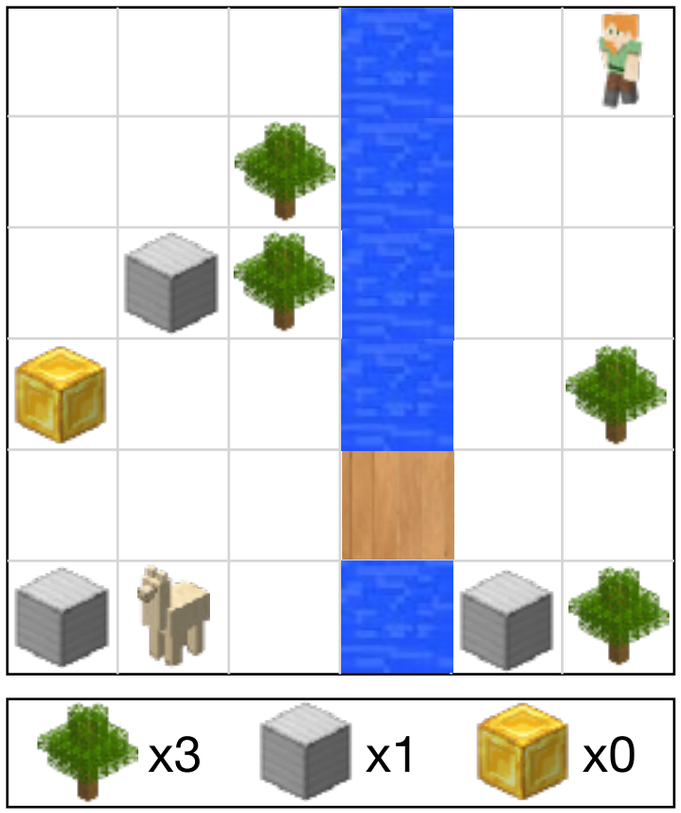


Problem Formulation

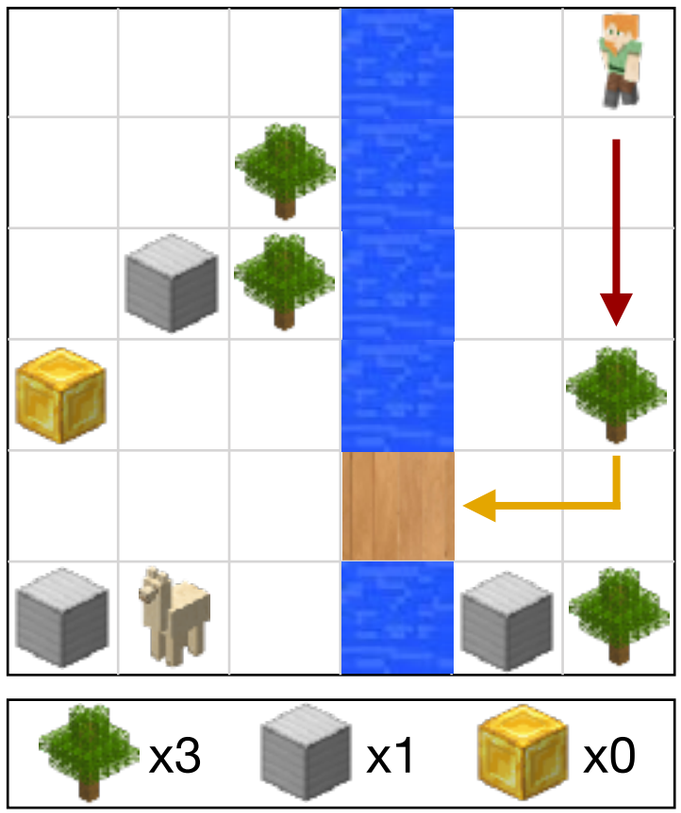
Program

```
def run():
  if is_there[River]:
    mine(Wood)
    build_bridge()
    if agent[Iron]<3:
      mine(Iron)
    place(Iron, 1, 1)
  else:
    goto(4, 2)
  while env[Gold]>0:
    mine(Gold)
```

State



Execution

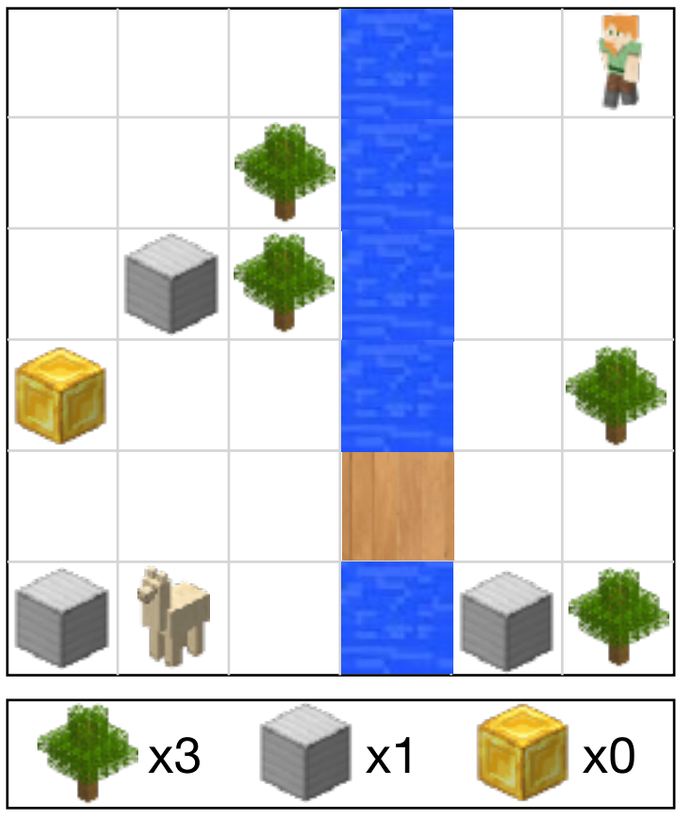


Problem Formulation

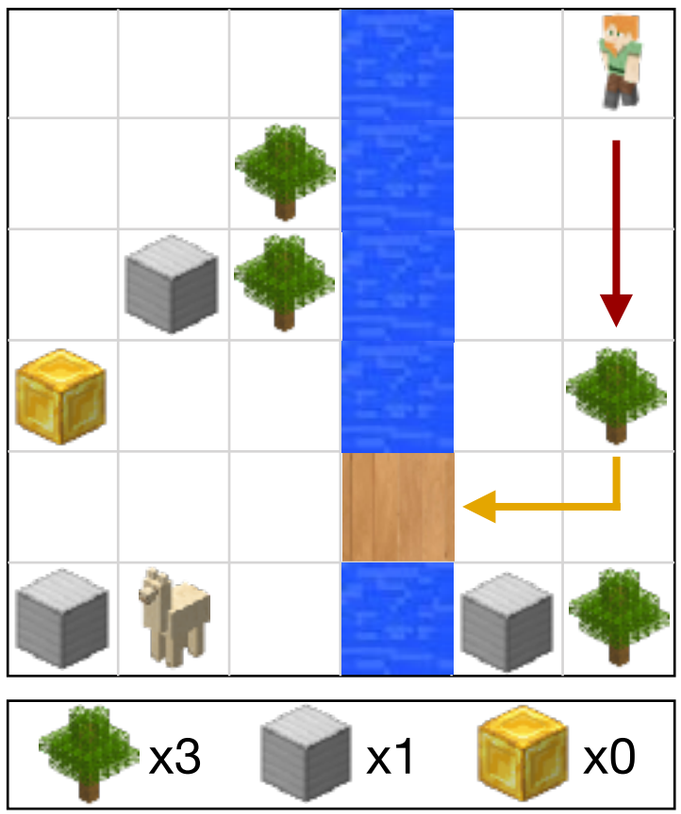
Program

```
def run():
  if is_there[River]:
    mine(Wood)
    build_bridge()
    if agent[Iron]<3:
      mine(Iron)
    place(Iron, 1, 1)
  else:
    goto(4, 2)
  while env[Gold]>0:
    mine(Gold)
```

State



Execution

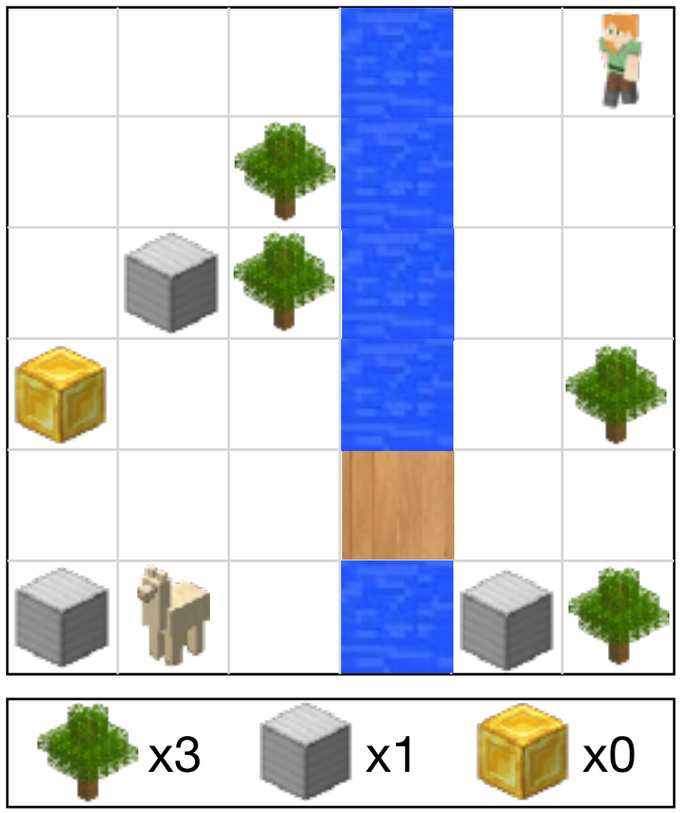


Problem Formulation

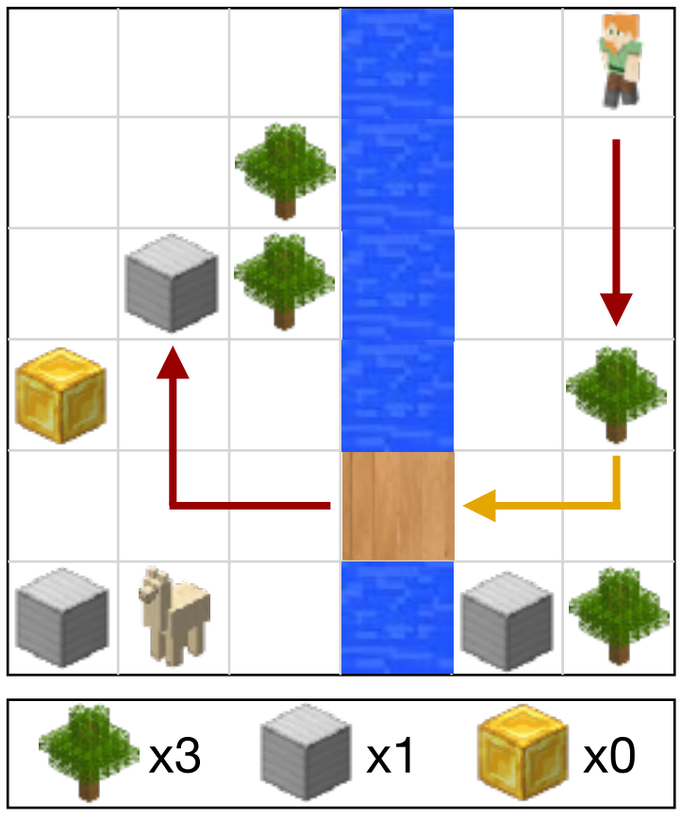
Program

```
def run():
  if is_there[River]:
    mine(Wood)
    build_bridge()
    if agent[Iron]<3:
      mine(Iron)
    place(Iron, 1, 1)
  else:
    goto(4, 2)
  while env[Gold]>0:
    mine(Gold)
```

State



Execution

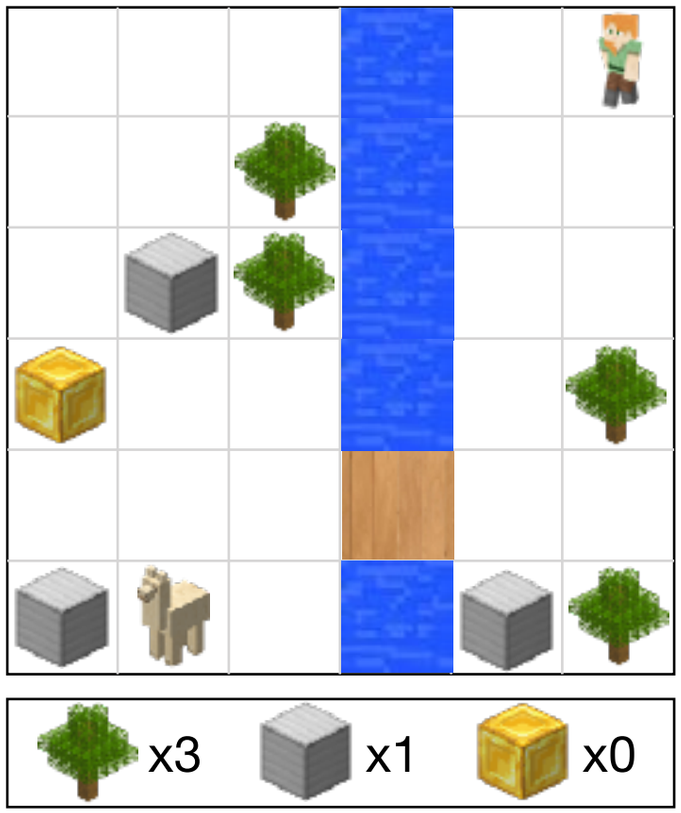


Problem Formulation

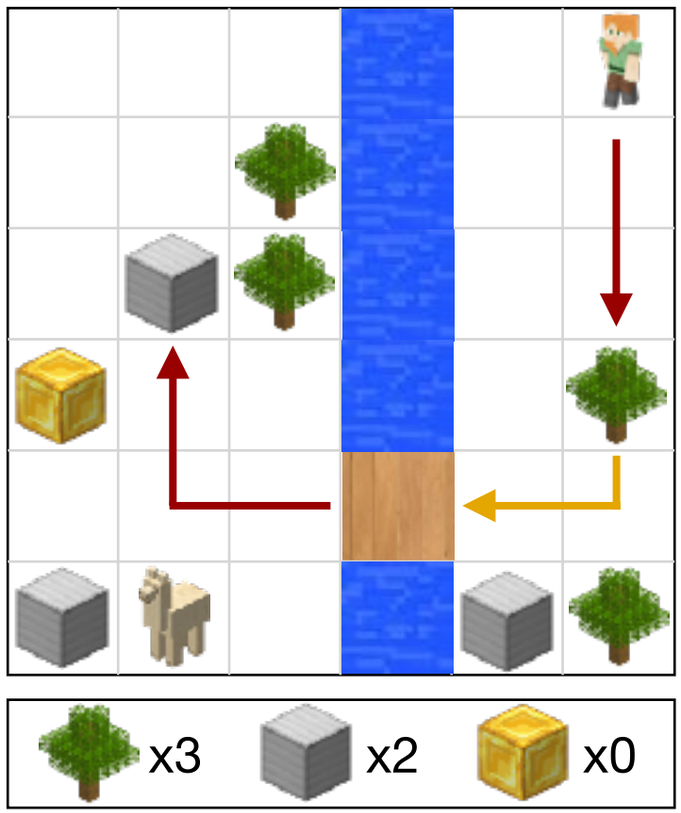
Program

```
def run():
  if is_there[River]:
    mine(Wood)
    build_bridge()
    if agent[Iron]<3:
      mine(Iron)
    place(Iron, 1, 1)
  else:
    goto(4, 2)
  while env[Gold]>0:
    mine(Gold)
```

State



Execution

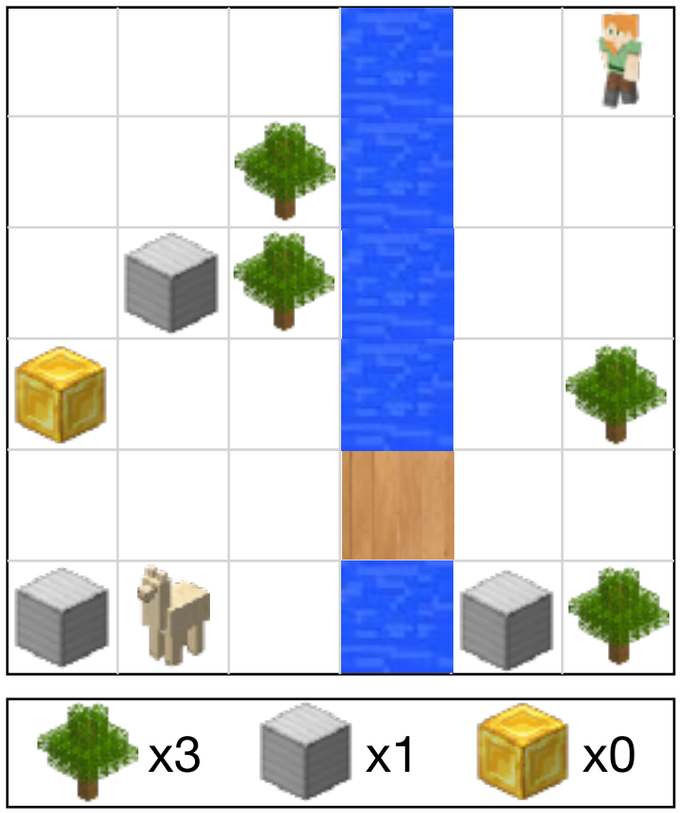


Problem Formulation

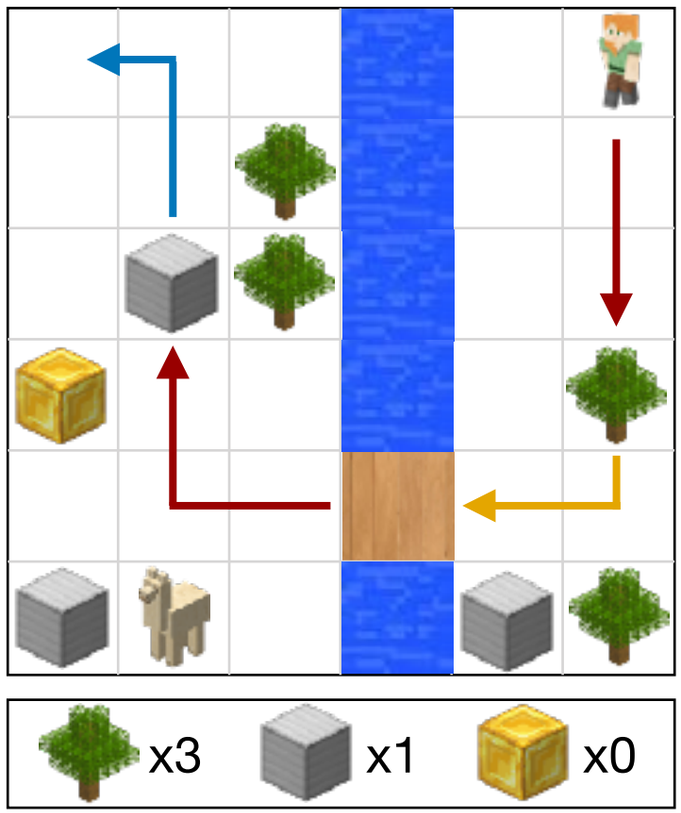
Program

```
def run():
  if is_there[River]:
    mine(Wood)
    build_bridge()
    if agent[Iron]<3:
      mine(Iron)
    place(Iron, 1, 1)
  else:
    goto(4, 2)
  while env[Gold]>0:
    mine(Gold)
```

State



Execution

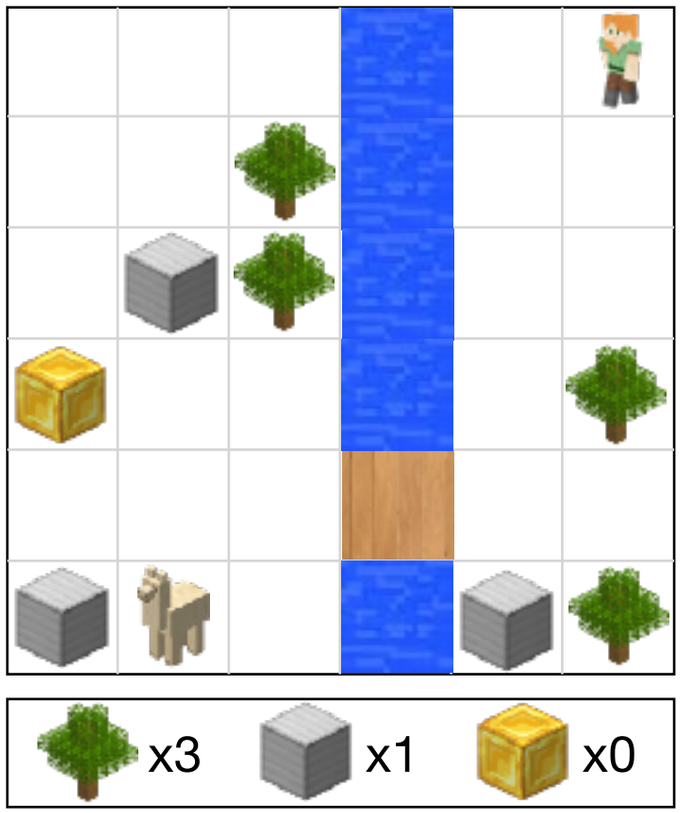


Problem Formulation

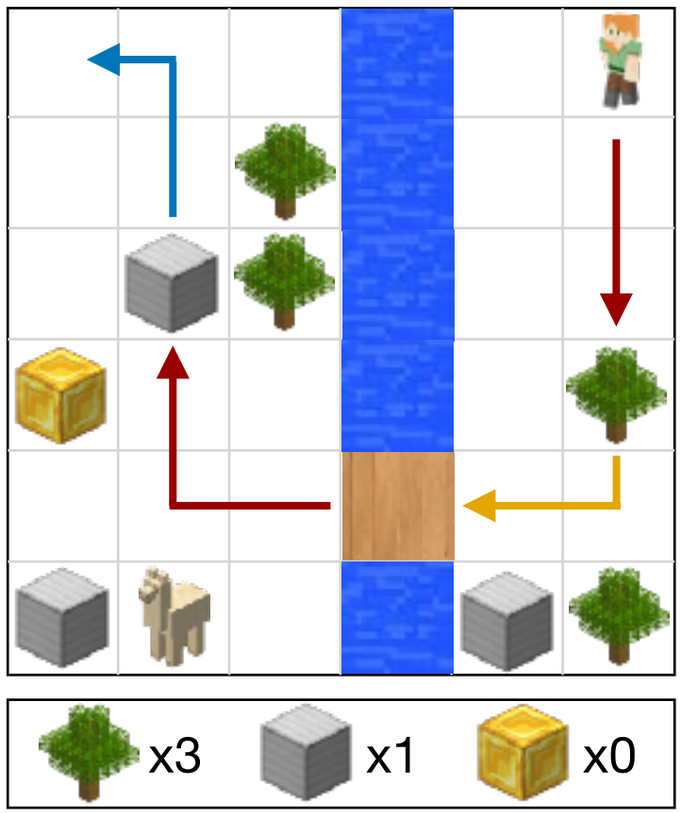
Program

```
def run():
  if is_there[River]:
    mine(Wood)
    build_bridge()
    if agent[Iron]<3:
      mine(Iron)
    place(Iron, 1, 1)
  else:
    goto(4, 2)
  while env[Gold]>0:
    mine(Gold)
```

State



Execution

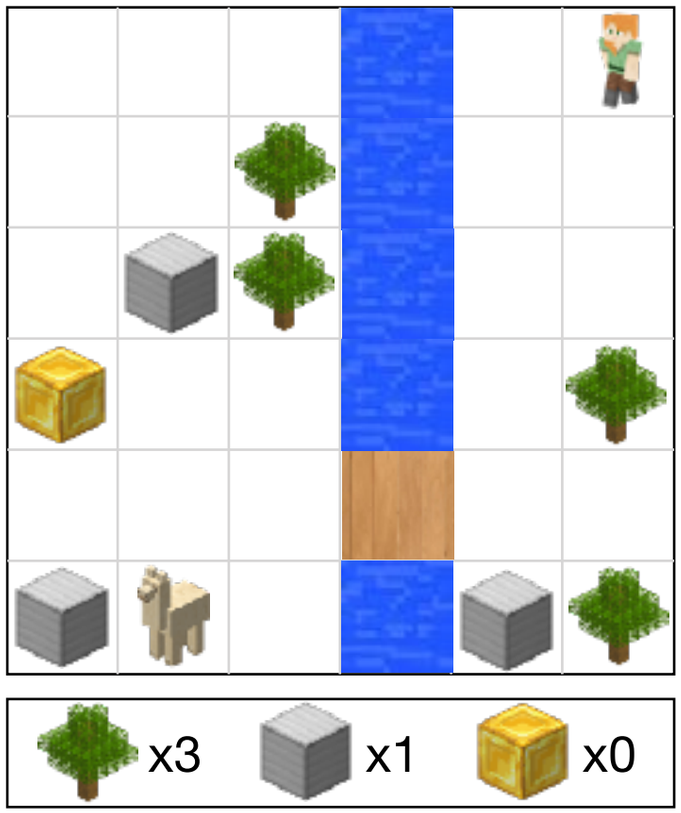


Problem Formulation

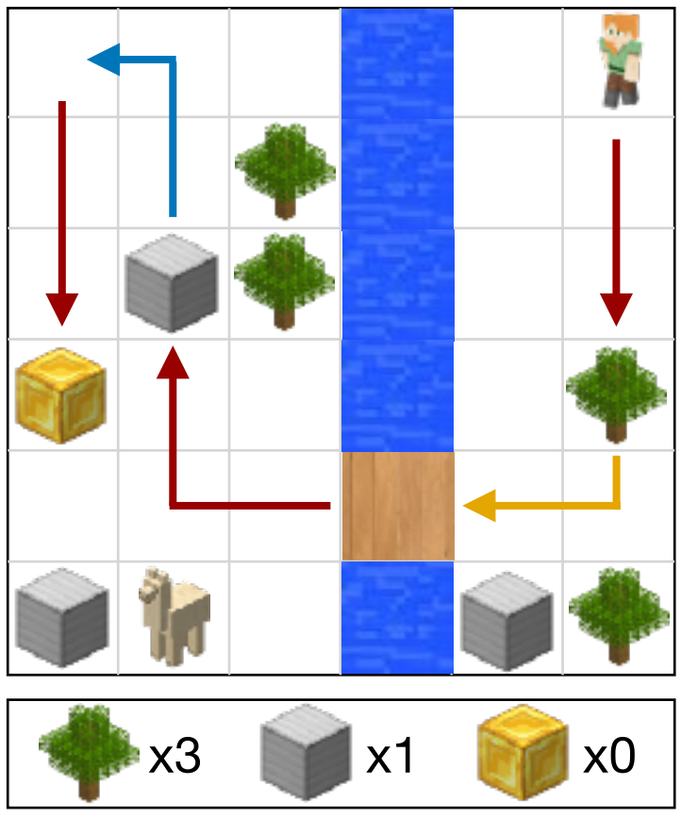
Program

```
def run():
  if is_there[River]:
    mine(Wood)
    build_bridge()
    if agent[Iron]<3:
      mine(Iron)
    place(Iron, 1, 1)
  else:
    goto(4, 2)
  while env[Gold]>0:
    mine(Gold)
```

State



Execution

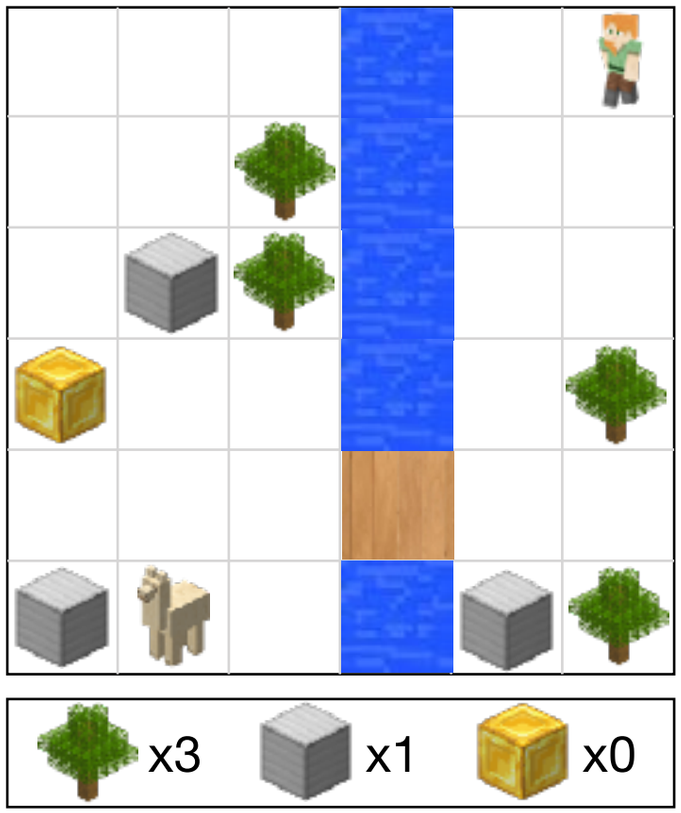


Problem Formulation

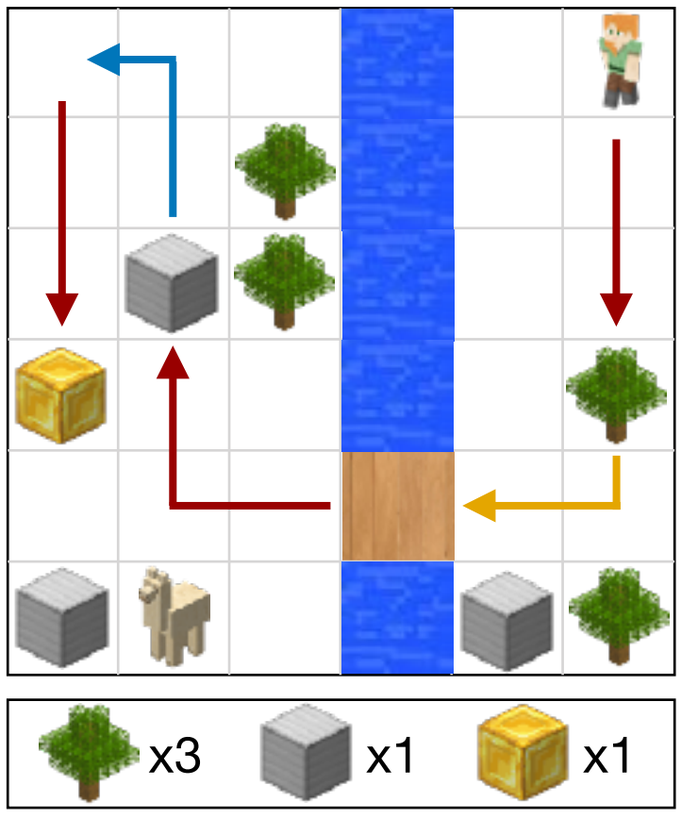
Program

```
def run():
  if is_there[River]:
    mine(Wood)
    build_bridge()
    if agent[Iron]<3:
      mine(Iron)
    place(Iron, 1, 1)
  else:
    goto(4, 2)
  while env[Gold]>0:
    mine(Gold)
```

State



Execution



Exemplar Instructions

Programs

```
def Task():
  if is_there[River]:
    mine(Wood)
    build_bridge()
    if agent[Iron] < 3:
      mine(Iron)
    place(Iron, 2, 3)
  else:
    goto(4, 2)
  while env[Gold] > 0 :
    mine(Gold)
```

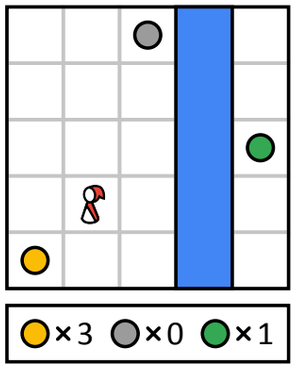
```
def Task():
  if is_there[River]:
    build_bridge()
  place(Gold, 3, 4)
  if agent[Gold] = = 1 3:
    while agent[Gold] <= 12:
      place(Gold, 8, 3)
    if agent[Iron] >= 8:
      place(Wood, 2, 4)
    elif env[Gold] <= 10:
      sell(Iron)
```

Natural Language Instructions

If a river is in the environment, mine a wood and then use it to build a bridge. And then if agent has less than there iron, place an iron at (2,3). Otherwise if no river, goto location (4,2). Finally, whenever there's still gold in the environment, mine a gold.

While agent has no more than 11 wood, place wood at (2,4) and iron at (1,1), then place iron at (8,5) and mine gold twice, then mine gold. After the preceding procedure, sell gold and sell iron 4 times.

End-to-end Learning Baseline



State

```
def run():
  while env[Gold] > 0:
    mine(Gold)
  if is_there[River]:
    build_bridge()
    place(Wood, 2, 3)
```

Program

If an agent has more than 1 iron, place an iron on (2,3), and then if there are less than 3 gold in the environment, mine gold; otherwise, goto (4,2). While gold in the environment is larger than 2, keep mining gold.

NL Instruction

OR

π

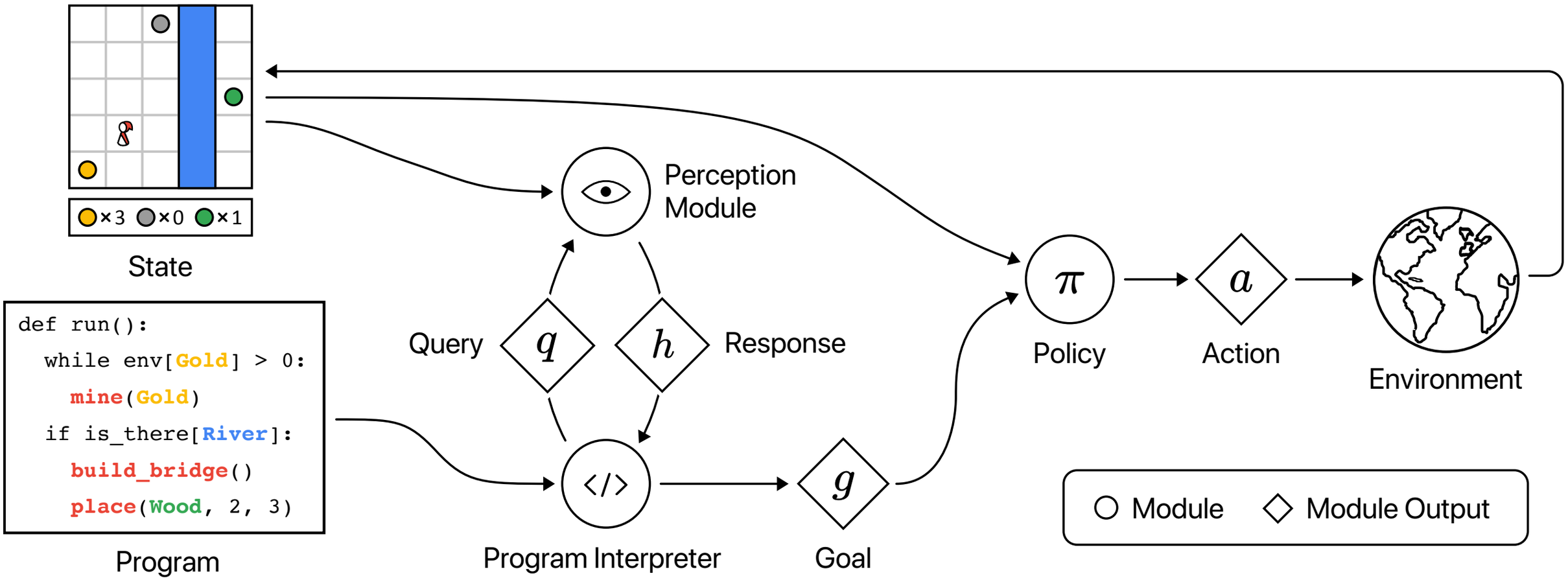
Policy

a

Action

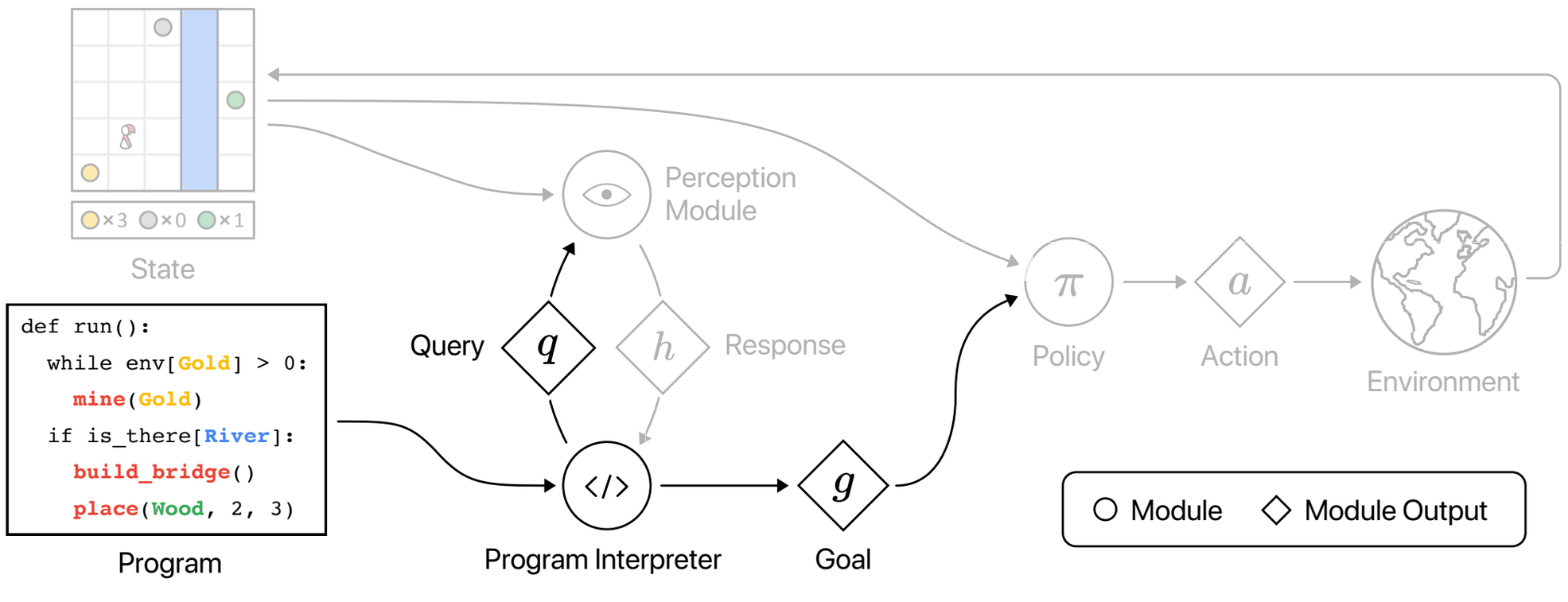
Environment

Program Guided Agent



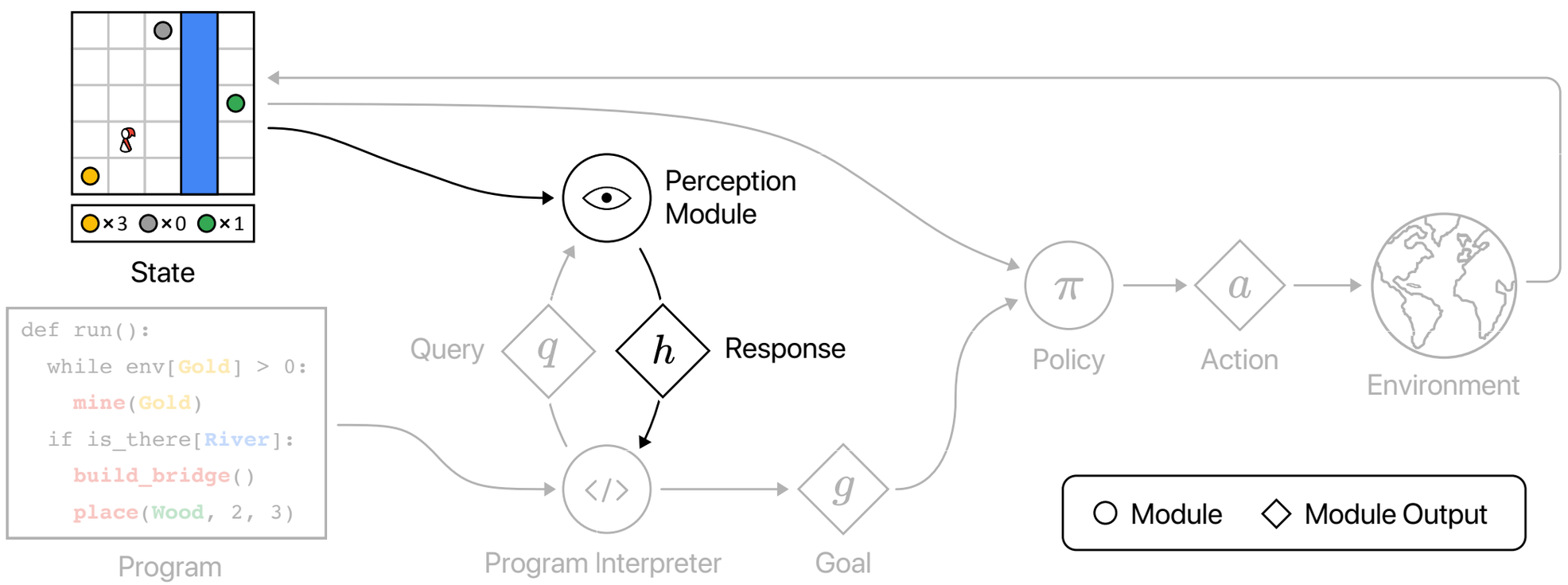
Program Interpreter

- Comprehend a given program to 3 categories:
  - **Subtasks (actions)**: what agent should perform
  - **Perception**: information from the environment
  - **Control flow**: decide to call different subtasks according to perceived information



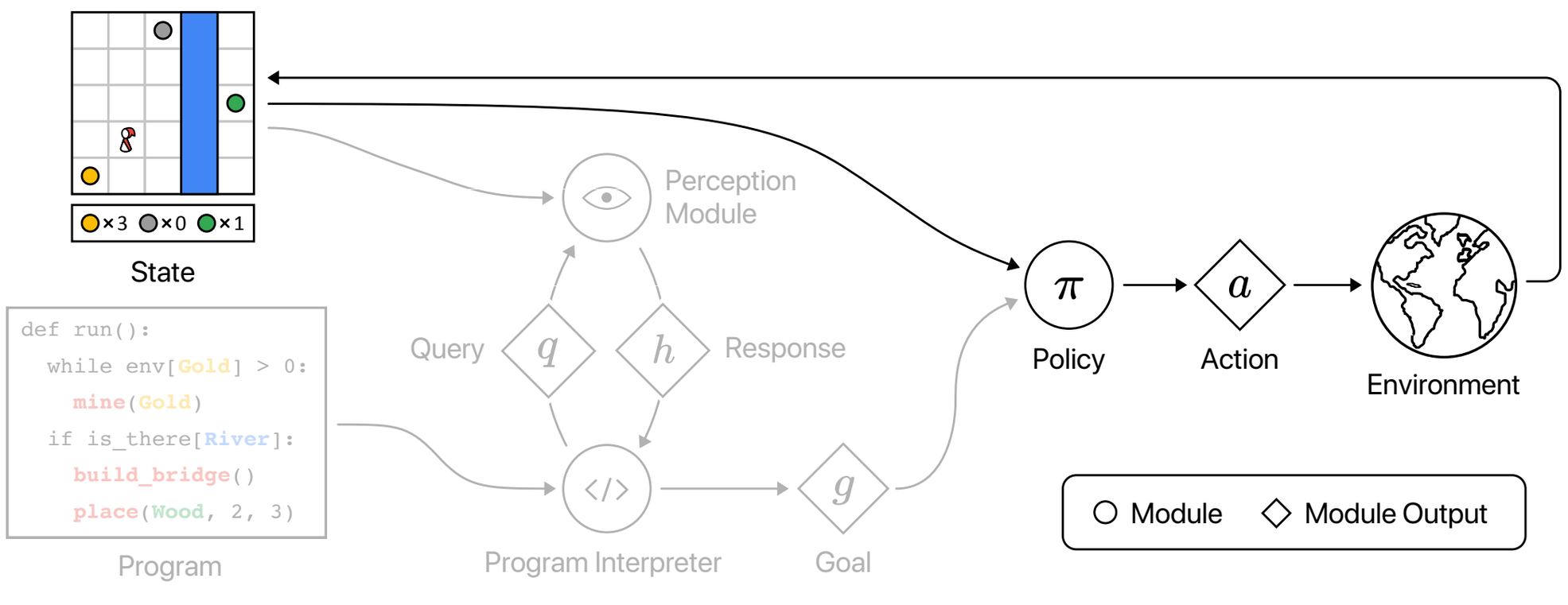
Perception Module

- Extract environmental information for choosing a path in a program
- Input
  - **Query**: a symbolically represented query (*e.g.* is_there[River])
  - **State s**: environment map and agent inventory status
- Output
  - Predicted **answer** to the query (*e.g.* True/False)



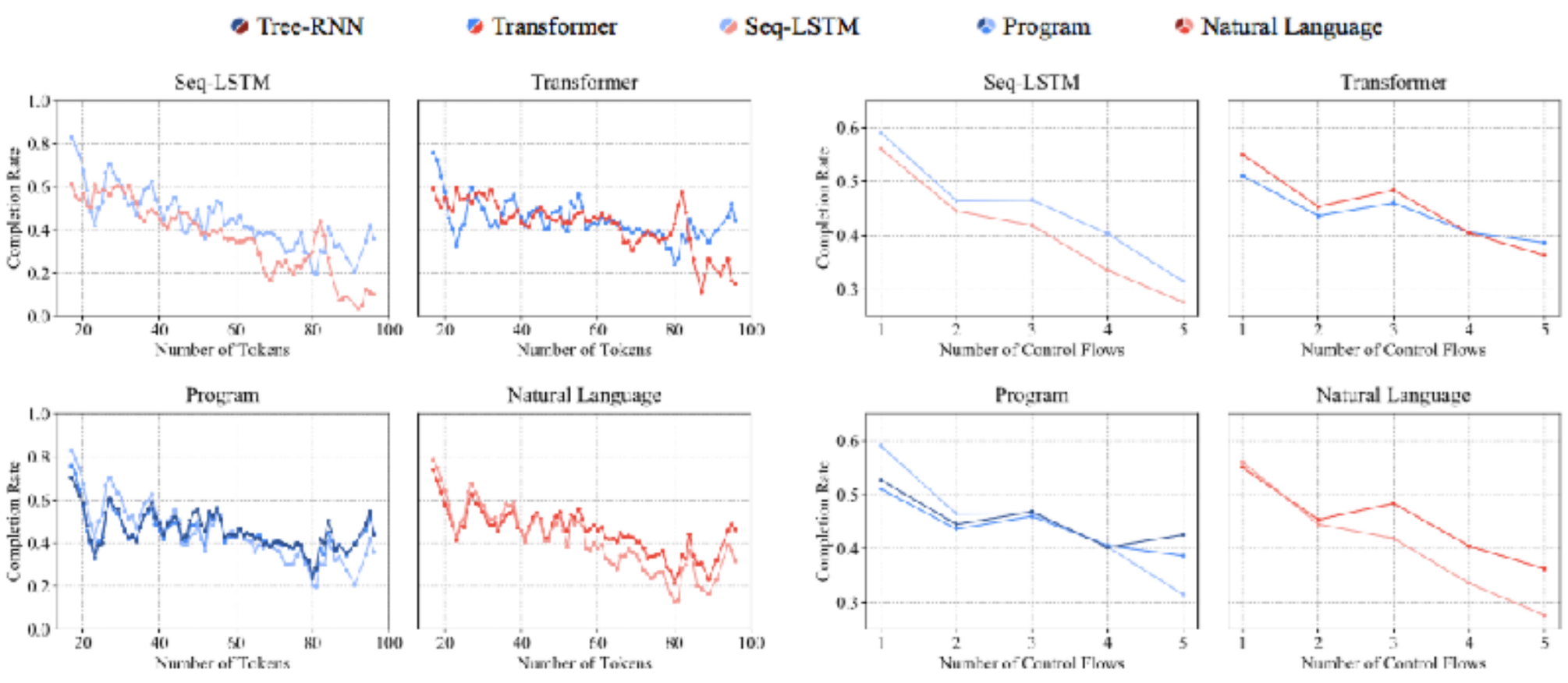
Policy

- Take low-level actions an the environment for fulfilling a subtask
- Input
  - Symbolically represented subtask (goal) **g**
  - State **s**
- Output
  - Predicted action distribution



Results

Instruction Method		Natural language descriptions		Programs				
		Seq-LSTM	Transformer	Seq-LSTM	Tree-RNN	Transformer	Ours (concat)	Ours
Dataset	test	54.9±1.8%	52.5±2.6%	56.7±1.9%	50.1±1.2%	49.4±1.6%	88.6±0.8%	94.0±0.5%
	test-complex	32.4±4.9%	38.2±2.6%	38.8±1.2%	42.2±2.4%	40.9±1.5%	85.2±0.8%	91.8±0.2%
Generalization gap		40.9%	27.2%	31.6%	15.8%	17.2%	3.8%	2.3%

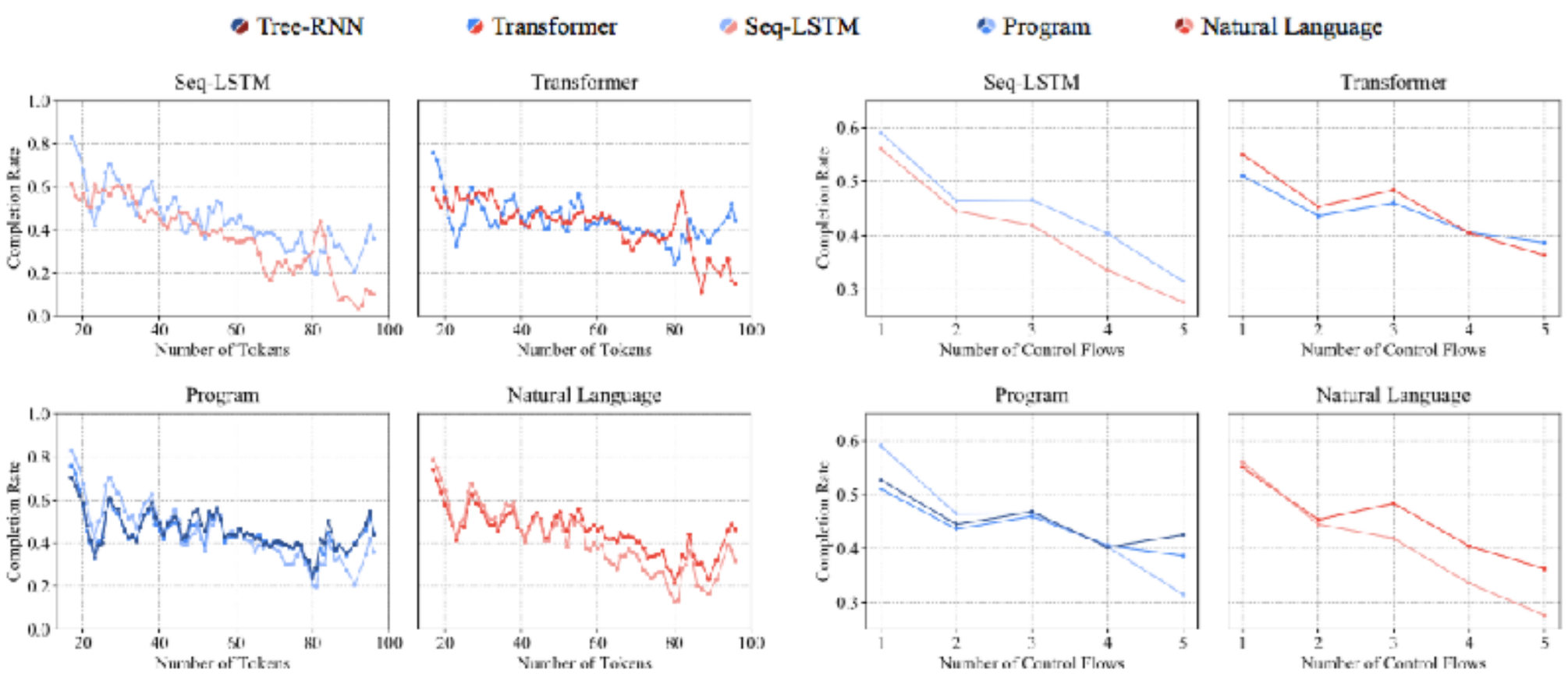


(a) Instruction Length

(b) Instruction Complexity

Result

Instruction Method		Natural language descriptions		Programs				
		Seq-LSTM	Transformer	Seq-LSTM	Tree-RNN	Transformer	Ours (concat)	Ours
Dataset	test	54.9±1.8%	52.5±2.6%	56.7±1.9%	50.1±1.2%	49.4±1.6%	88.6±0.8%	94.0±0.5%
	test-complex	32.4±4.9%	38.2±2.6%	38.8±1.2%	42.2±2.4%	40.9±1.5%	85.2±0.8%	91.8±0.2%
Generalization gap		40.9%	27.2%	31.6%	15.8%	17.2%	3.8%	2.3%



(a) Instruction Length

(b) Instruction Complexity

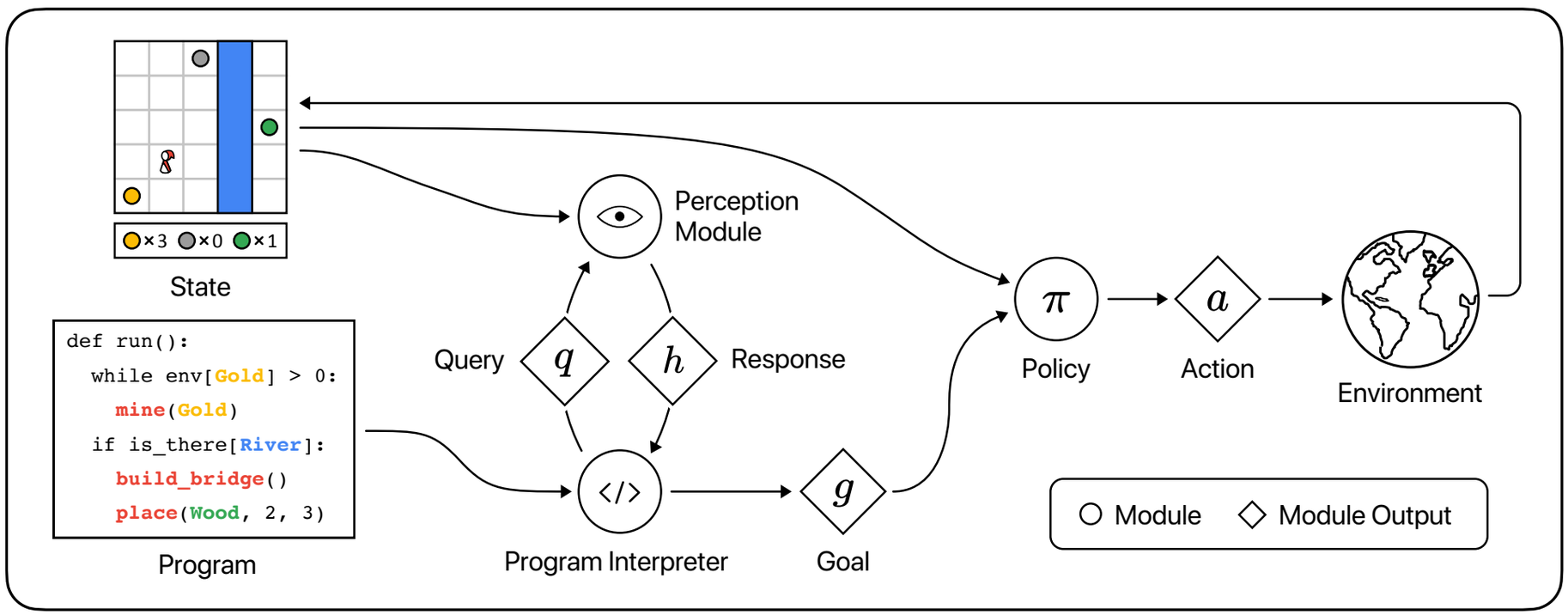
Conclusion

- Specific tasks using **programs**

Program

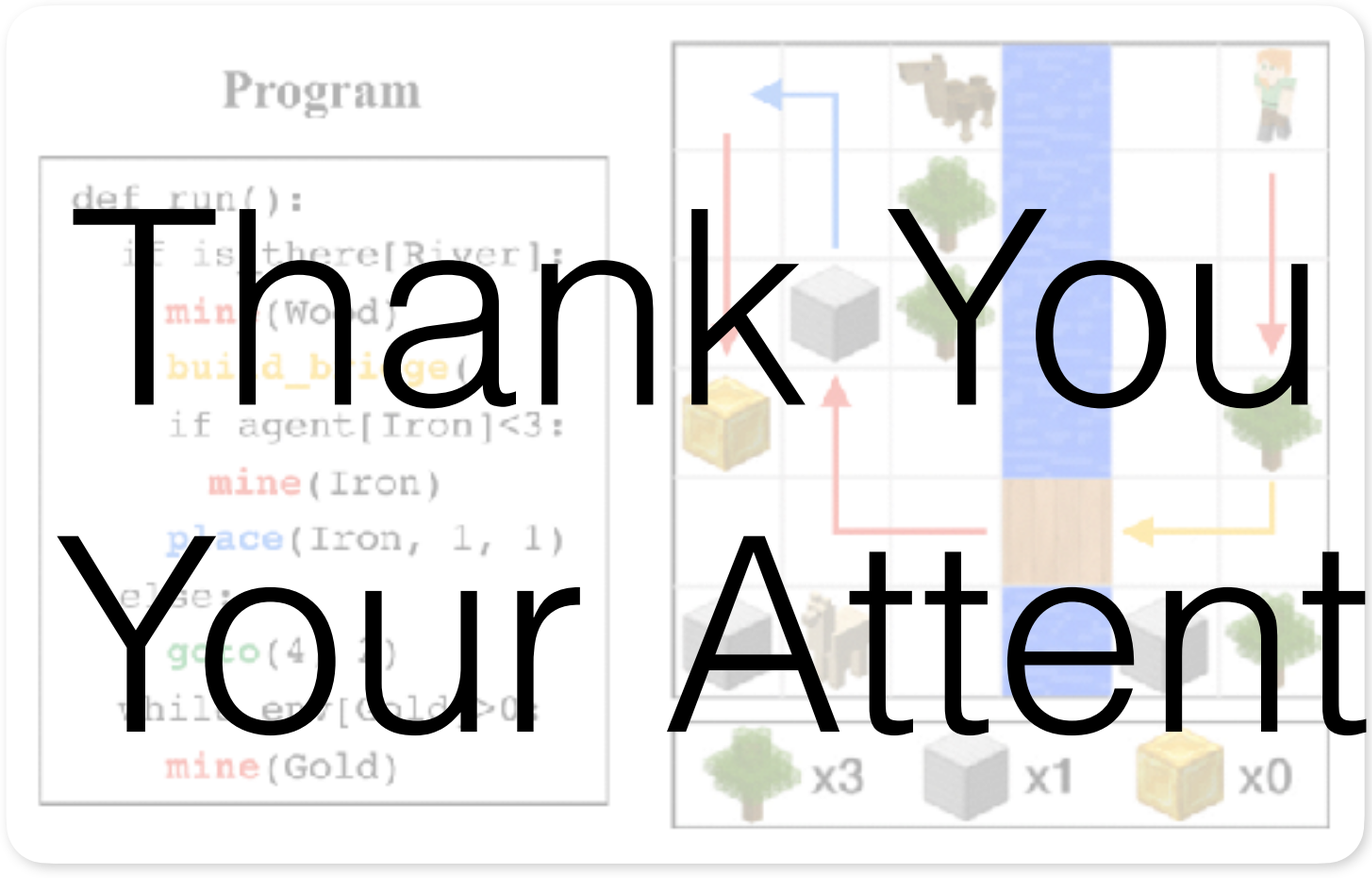
```
def Task():
  if is_there[River]:
    mine(Wood)
    build_bridge()
    if agent[Iron] < 3:
      mine(Iron)
    place(Iron, 2, 3)
  else:
    goto(4, 2)
  while env[Gold] > 0 :
    mine(Gold)
```

- Leverage the structure of programs with a modular framework



Program Guided Agent

ICLR 2020 (Spotlight)



Thank You for Your Attention

Shao-Hua Sun

Te-Lin Wu

Joseph J. Lim