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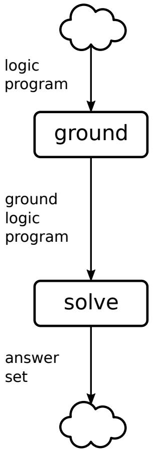
Winning Snake: Design Choices in Multi-Shot ASP

Dallas, USA, October 16th 2024

Overview

Motivation


logic
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ground
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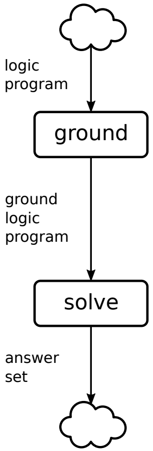
logic
program
solve
answer
set

Motivation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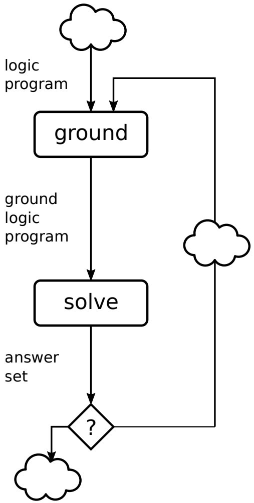
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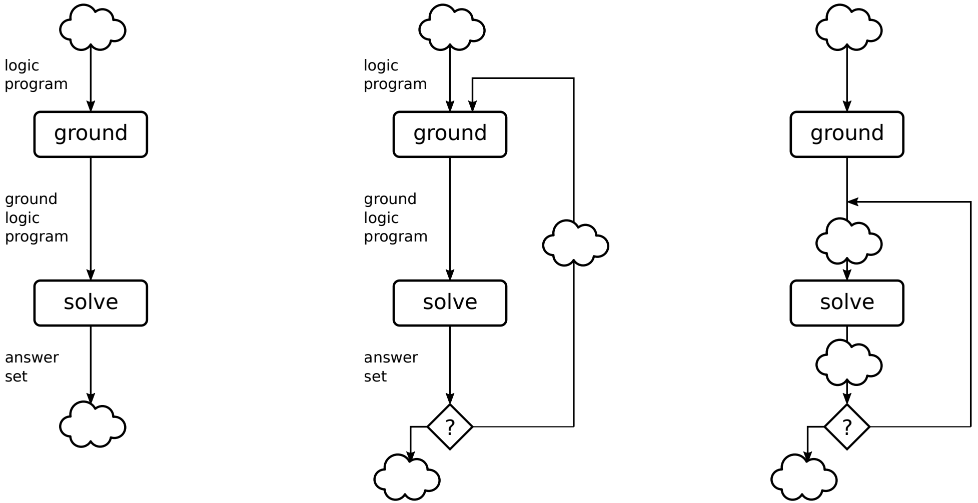
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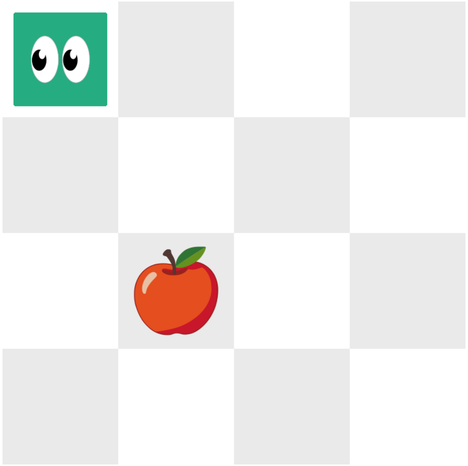
About Snakes



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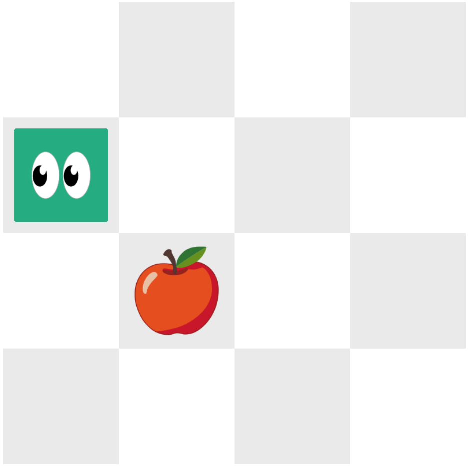

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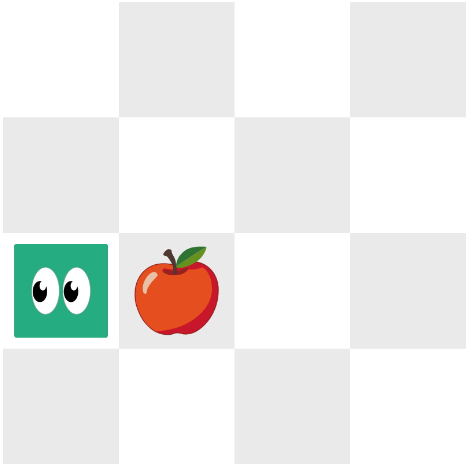

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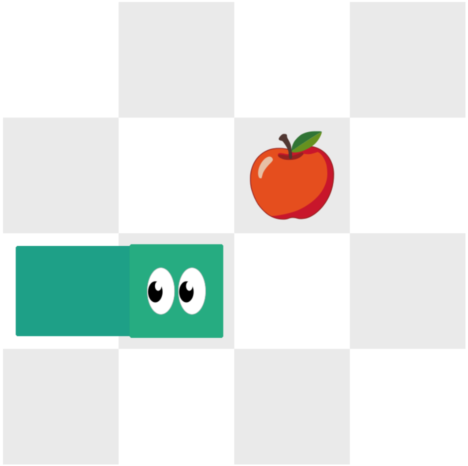

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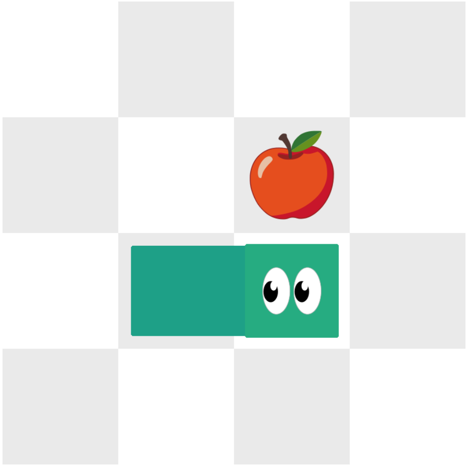

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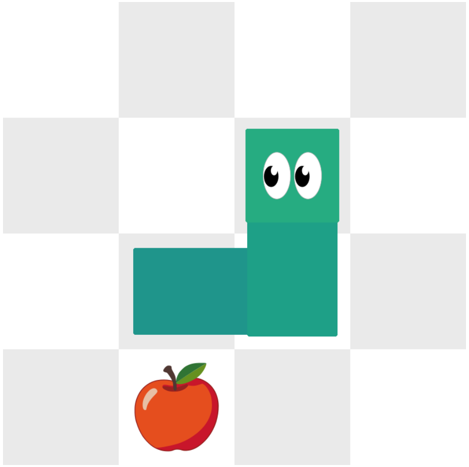

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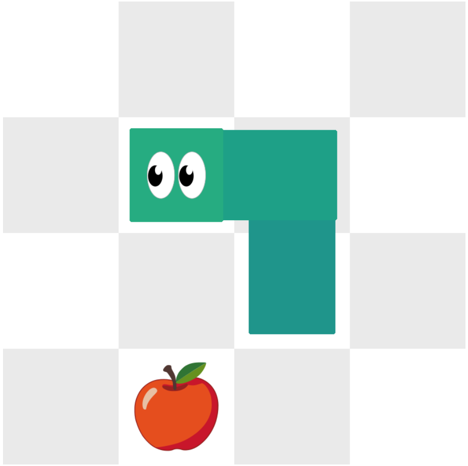

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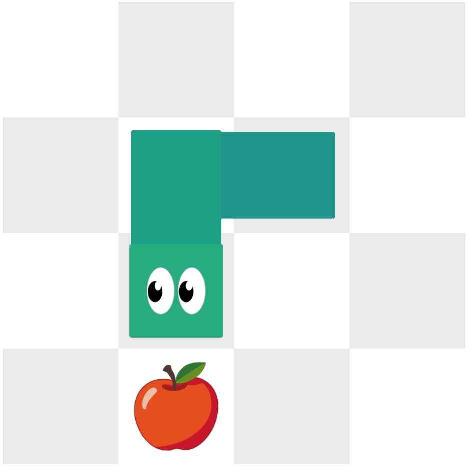

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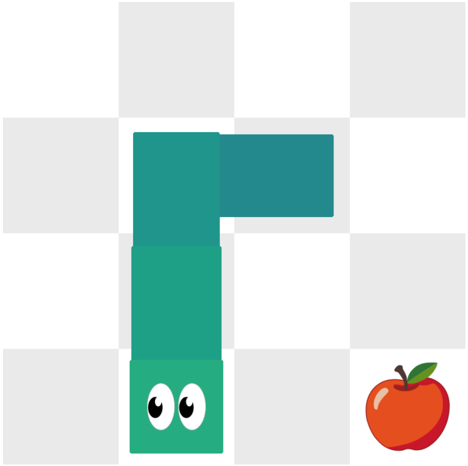

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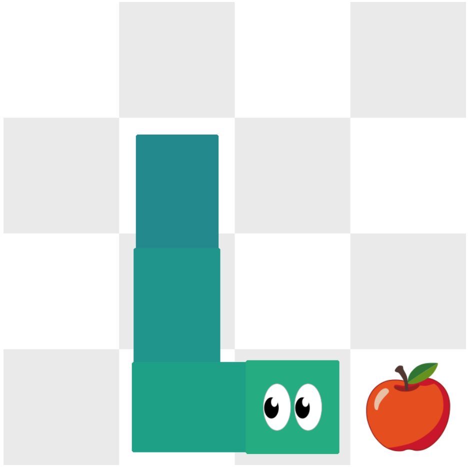

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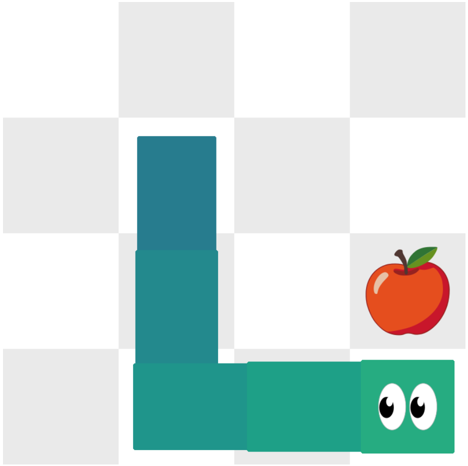

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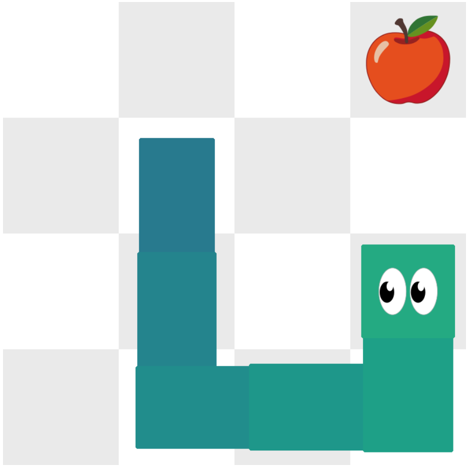

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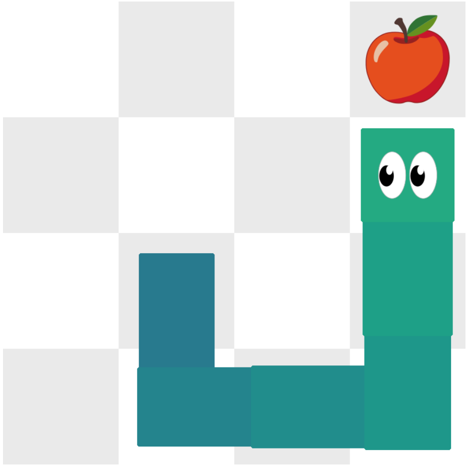

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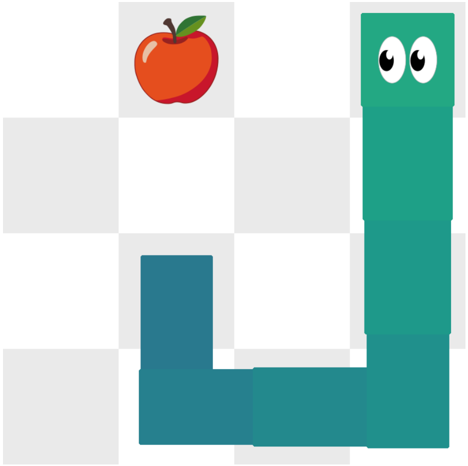

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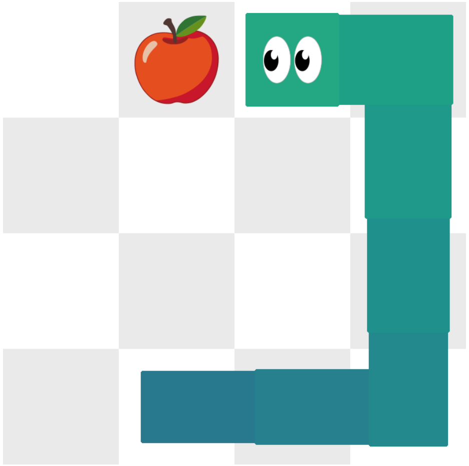

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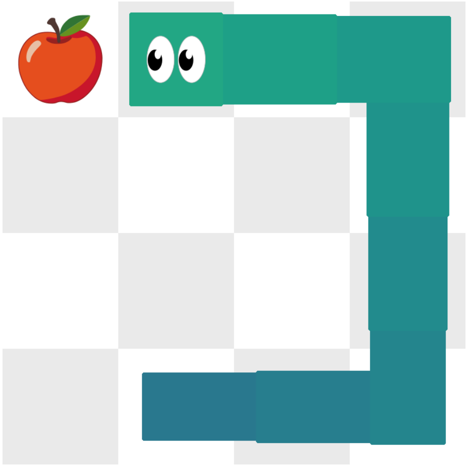

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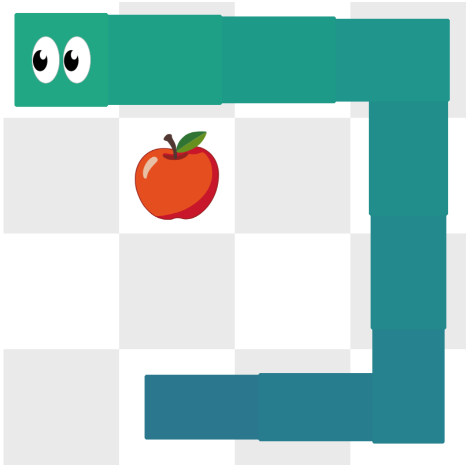

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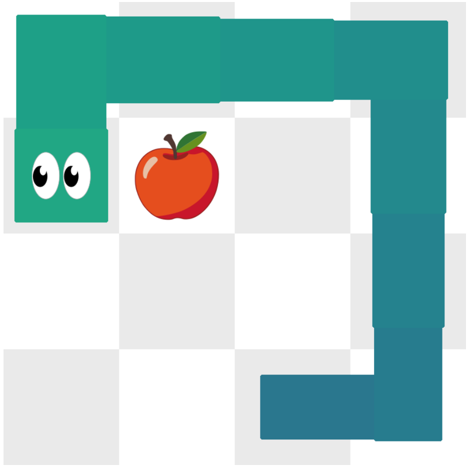

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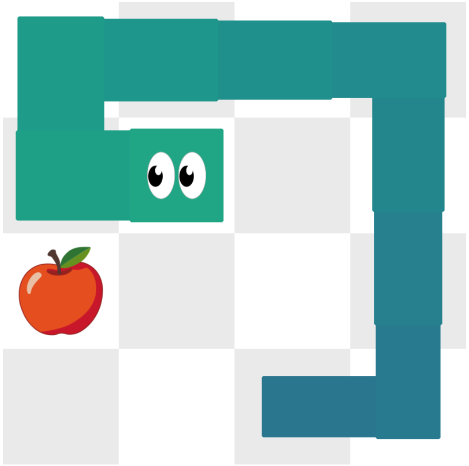

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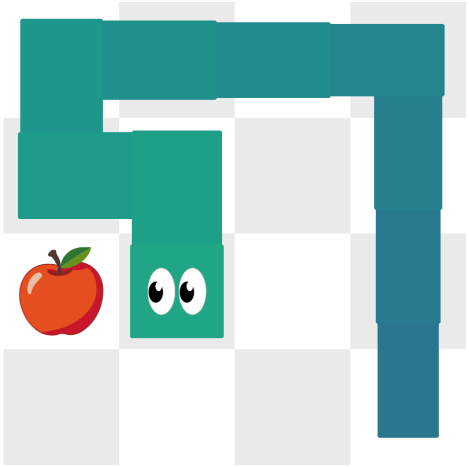

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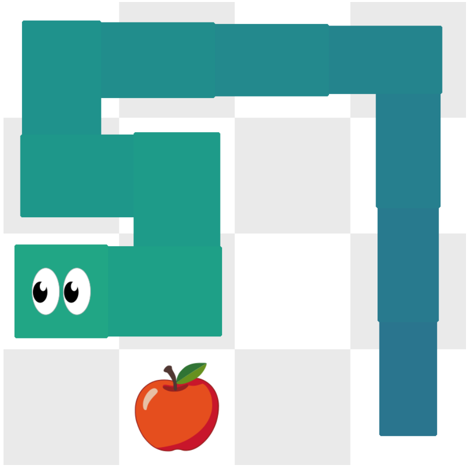

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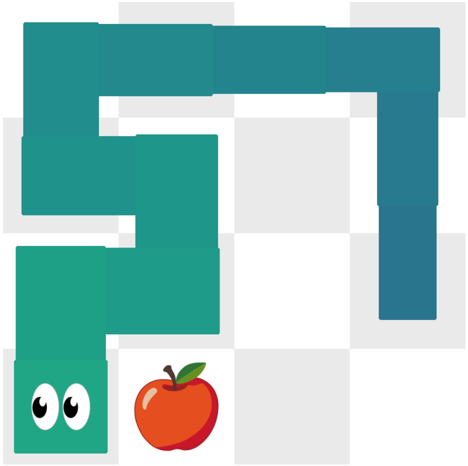

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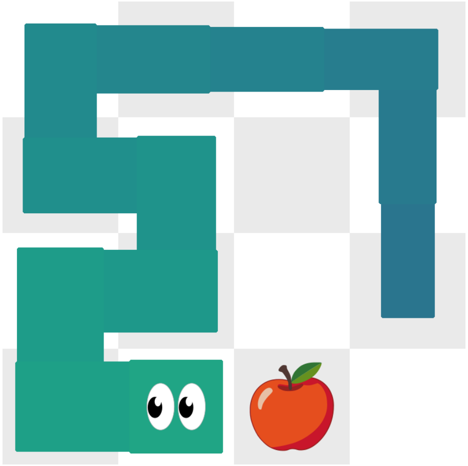

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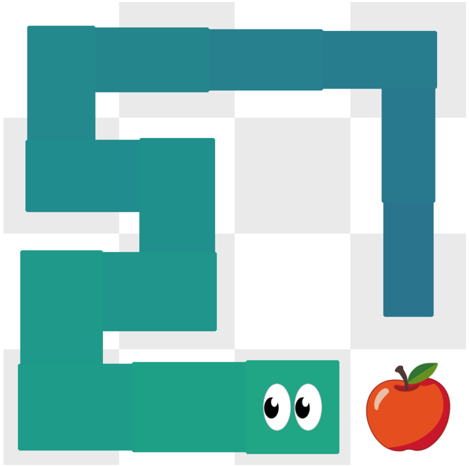

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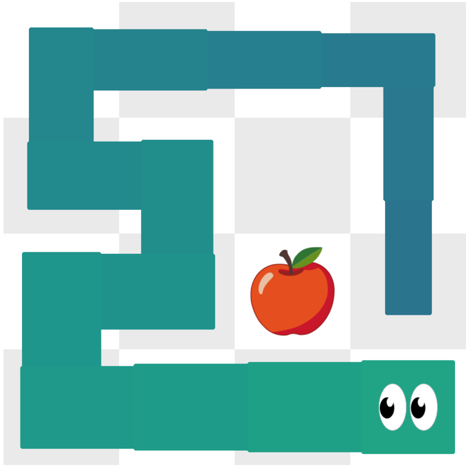

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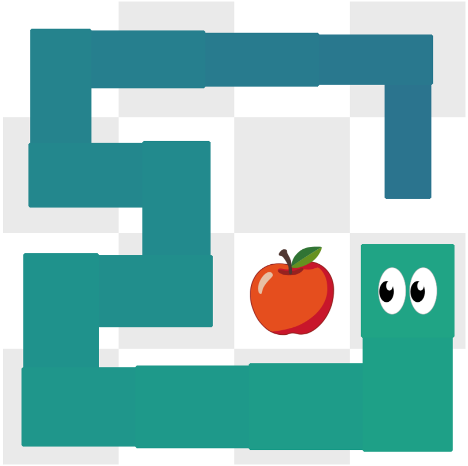

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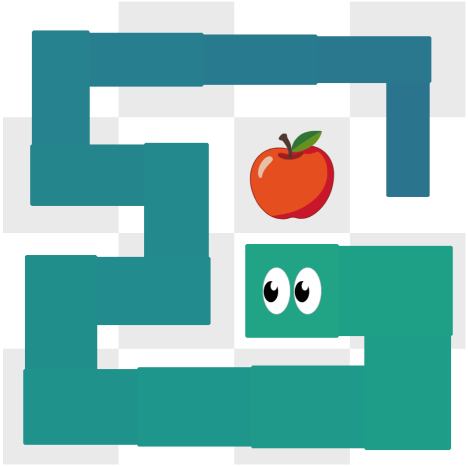

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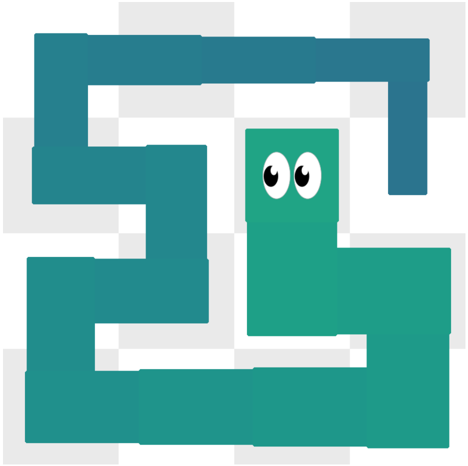

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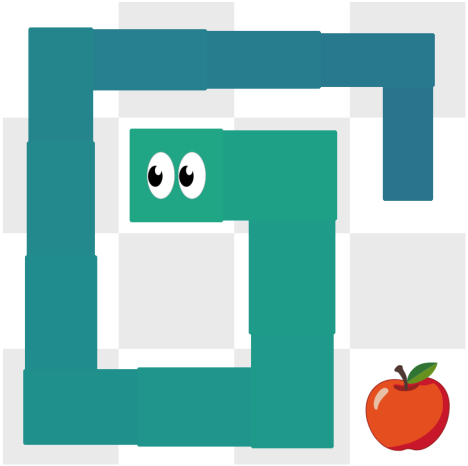
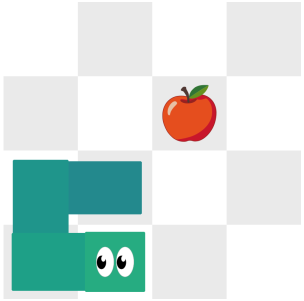


Snakes - Keypoints

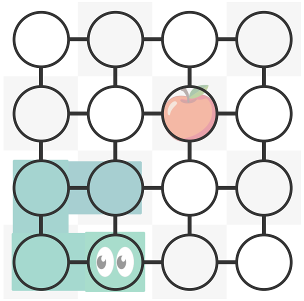
- Iterative setting
- Path from head to apple
- Solving one iteration $\not\rightarrow$ solving next iteration

Strategies



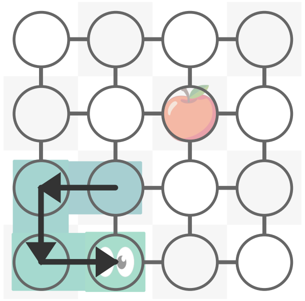
Strategies

- Interpretation as Grid Graph



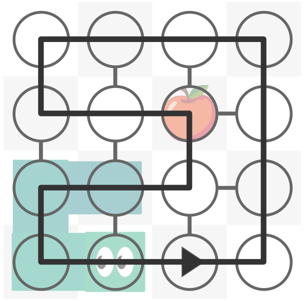
Strategies

- Interpretation as Grid Graph
- Snake placement



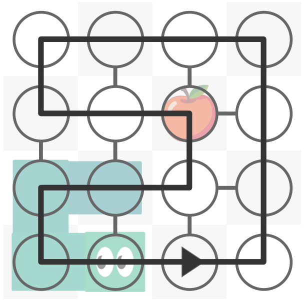
Strategies

- Interpretation as Grid Graph
- Snake placement
- Hamiltonian Cycle



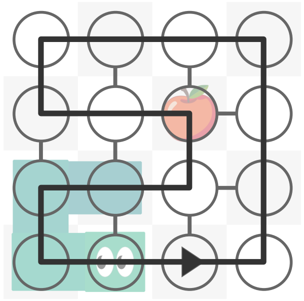
Strategies

- Interpretation as Grid Graph
- Snake placement
- Hamiltonian Cycle NP



Strategies

- Interpretation as Grid Graph
- Snake placement
- Hamiltonian Cycle NP / P



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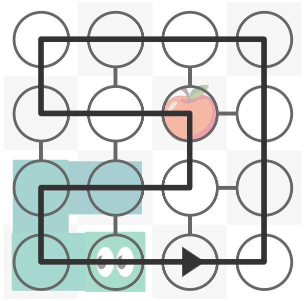
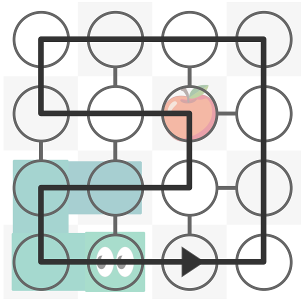


Strategies

- Interpretation as Grid Graph
- Snake placement
- Hamiltonian Cycle NP / P
- Minimize Step count NP^{NP} (conservative Strategy)



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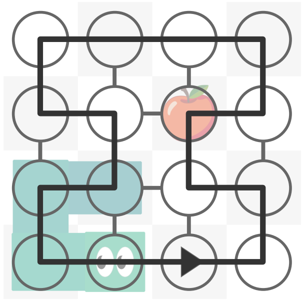

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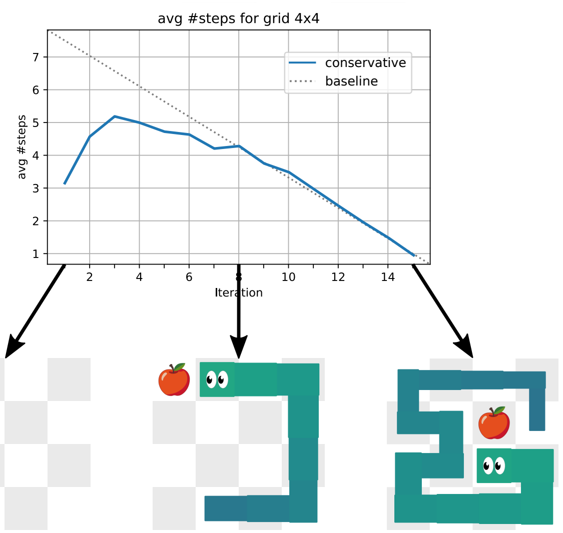


Why Snakes?

- Popular, easy to grasp yet hard
- Problem class well suited for ASP
- Iterative setting (multi-shot ASP)
- Minimalistic ASP-Encoding

Snake logic program class

Input: grid dimension n × m, position of head (head/1) and apple (apple/1)

```
field((X,Y)) :- X=1..n, Y=1..m.
conn((X,Y1),(X,Y2)) :- |Y1-Y2|=1, field((X,Y1)), field((X,Y2)).
conn((X1,Y),(X2,Y)) :- |X1-X2|=1, field((X1,Y)), field((X2,Y)).

1 { next(XY,XY') : field(XY ), conn(XY,XY') } 1 :- field(XY').
1 { next(XY,XY') : field(XY'), conn(XY,XY') } 1 :- field(XY ).

path(XY) :- field(XY), head(XY).
path(Next) :- path(XY), next(XY,Next).
:- field(XY), not path(XY).

mark(XY) :- field(XY), head(XY).
mark(Next) :- mark(XY), next(XY,Next), not apple(XY).
#minimize{ 1,XY : mark(XY) }.
```

Answer Set Programming

- Logic programming under stable model semantics
- Established problem solving paradigm
- Advanced programming techniques required
- Specific mechanisms for `clingo`

Implementation

$$\left.\begin{array}{l}\text{ad hoc}\\ \text{preground}\\ \text{assume}\\ \text{nogoods}\end{array}\right\}\ \text{multi-shot}$$

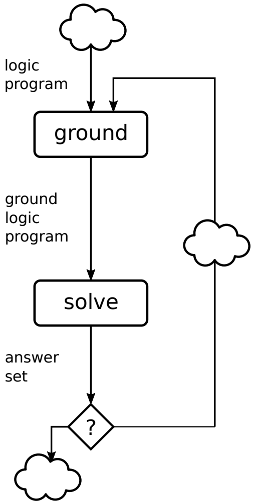
- oneshot
- ad hoc
- preground
- assume
- nogoods

Implementation

- oneshot
- ad hoc
- preground
- assume
- nogoods

$\left.\begin{array}{l}\text{ad hoc}\\\text{preground}\\\text{assume}\\\text{nogoods}\end{array}\right\}$ multi-shot

Workflow - Oneshot ⌖

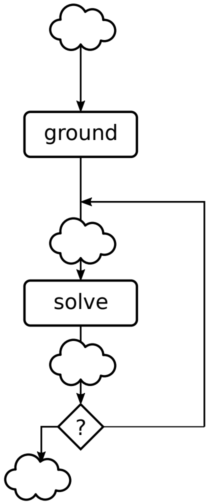


```
Input: grid dimension $n \times m$
$🐍 \leftarrow [(1,1)]$
do:
    $● \leftarrow \mathit{generate\_apple}((n,m), 🐍)$
    $\Pi \leftarrow \mathit{ground}($
            $\mathit{base\_lp}(n,m)$
            $\cup\ \{\texttt{apple(●).}\quad \texttt{head(}🐍_1\texttt{).}\}$
            $\cup\ \bigcup_{i=1..|🐍|-1}\{\texttt{next(}🐍_i\texttt{,}🐍_{i+1}\texttt{).}\})$
    $\mathit{model} \leftarrow \mathit{solve}(\Pi)$
    $\mathit{path} \leftarrow \mathit{extract\_path}(\mathit{model})$
    $🐍 \leftarrow \mathit{follow\_path}(🐍, \mathit{path}, ●)$
while $|🐍| < n \cdot m$
```

Workflow - Oneshot ⌖

- fast and straight forward implementation
- flexible design, easy debugging
- redundant steps
- suboptimal resource use

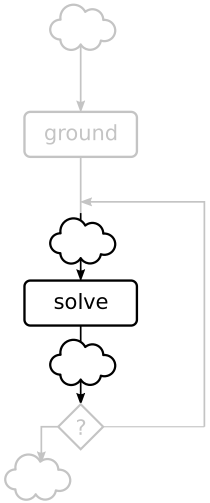
Workflow - Multi-shot



Input: grid dimension $n \times m$

```
$\Pi \leftarrow$ ground({#external apple(X) : field(X).
                         #external head(X) : field(X).}
                         $\cup$ base_lp$(n, m)$)
🐍 $\leftarrow [(1,1)]$
do :
    🍎 $\leftarrow$ generate_apple($(n, m)$, 🐍)
    $\Pi \leftarrow$ set_external($\Pi$, apple(🍎), True)
    $\Pi \leftarrow$ set_external($\Pi$, head(🐍$_1$), True)
    $\Pi$, path $\leftarrow$ retrieve($\Pi$, 🐍)
    $\Pi \leftarrow$ set_external($\Pi$, apple(🍎), False)
    $\Pi \leftarrow$ set_external($\Pi$, head(🐍$_1$), False)
    🐍 $\leftarrow$ follow_path(🐍, path, 🍎)
while |🐍| $< n \cdot m$
```

Workflow - Multi-shot



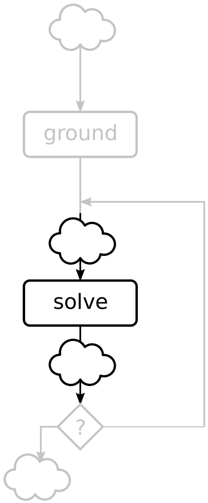
```
Input: grid dimension $n \times m$
$\Pi \leftarrow ground(\{$#external apple(X) : field(X).
                        #external head(X) : field(X).$\}$
                        $\cup\ base\_lp(n,m))$
🐍 $\leftarrow [(1,1)]$
do :
    🍎 $\leftarrow generate\_apple((n,m),$ 🐍$)$
    $\Pi \leftarrow set\_external(\Pi,$ apple(🍎), $True)$
    $\Pi \leftarrow set\_external(\Pi,$ head(🐍$_1$), $True)$
    $\Pi, path \leftarrow$ retrieve$(\Pi,$ 🐍$)$
    $\Pi \leftarrow set\_external(\Pi,$ apple(🍎), $False)$
    $\Pi \leftarrow set\_external(\Pi,$ head(🐍$_1$), $False)$
    🐍 $\leftarrow follow\_path($🐍$, path,$ 🍎$)$
while |🐍| $< n \cdot m$
```

Implementation

- oneshot
- ad hoc
- preground
- assume
- nogoods

$\left.\begin{array}{l}\text{ad hoc}\\\text{preground}\\\text{assume}\\\text{nogoods}\end{array}\right\}$ multi-shot

Workflow - Ad hoc ±



Algorithm 1: *retrieve* for ad hoc; Input: Π, 🐍; Output: Π, *path*

```
1 $\Pi \leftarrow \Pi \cup ground(\{$#external step(|🐍|).$\})$
2 for $i = 1 .. |🐍|-1$ :
3     $\Pi \leftarrow \Pi \cup ground(\{$:- step(|🐍|), not next(🐍$_i$,🐍$_{i+1}$).$\})$
4 $\Pi \leftarrow set\_external(\Pi,$ step(|🐍|)$, True)$
5 $model \leftarrow solve(\Pi)$
6 $\Pi \leftarrow release\_external(\Pi,$ step(|🐍|)$)$
7 $\Pi \leftarrow cleanup(\Pi)$
8 return $\Pi, extract\_path(model)$
```

Workflow - Ad hoc ±

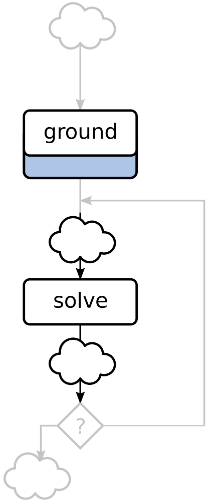
- full flexibility, introduce new atoms
- easy implementation vs. code reusing
- applied standard in current publications

Implementation

- oneshot

$$\left.\begin{array}{l}\text{ad hoc}\\ \text{preground}\\ \text{assume}\\ \text{nogoods}\end{array}\right\}\ \text{multi-shot}$$

Workflow - Preground



logic program extension:

```
#external prenext(X,Y) : connected(X,Y).
:- prenext(X,Y), not next(X,Y), connected(X,Y).
```

Algorithm 2: *retrieve* for preground; Input: Π, 🐍; Output: Π, *path*

```
1 for $i = 1..|🐍| - 1$:
2     $\Pi \leftarrow set\_external(\Pi, \texttt{prenext(}🐍_i\texttt{,}🐍_{i+1}\texttt{)}, True)$
3 $model \leftarrow solve(\Pi)$
4 for $i = 1..|🐍| - 1$:
5     $\Pi \leftarrow set\_external(\Pi, \texttt{prenext(}🐍_i\texttt{,}🐍_{i+1}\texttt{)}, False)$
6 return $\Pi, extract\_path(model)$
```

Workflow - Preground

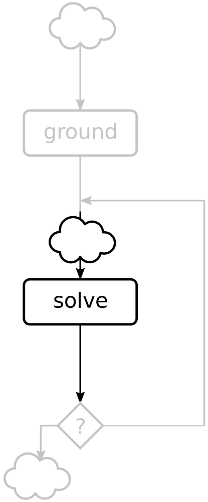
- easy interface
- complex expressions possible
- for a compact extensions
- least flexible

Implementation

- oneshot
- ad hoc
- preground
- assume
- nogoods

$\left.\begin{array}{l}\text{ad hoc}\\ \text{preground}\\ \text{assume}\\ \text{nogoods}\end{array}\right\}$ multi-shot

Workflow - Assume



Algorithm 3: retrieve for assume; Input: Π, 🐍; Output: Π, *path*

```
1 assume ← [ ]
2 for $i = 1..|🐍| - 1$:
3     assume.append((next(🐍$_i$, 🐍$_{i+1}$), True))
4 model ← solve($\Pi$, assumption = assume)
5 return $\Pi$, extract_path(model)
```

Workflow - Assume

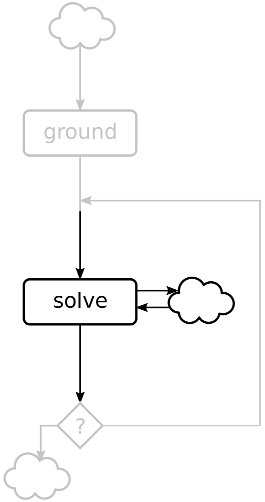
- manipulate any atom
- no reset required
- logic program stays untouched
- least expressivity
- no interface identifiers

Implementation

- oneshot
- ad hoc
- preground
- assume
- nogoods

multi-shot

Workflow - Nogoods



Algorithm 4: code snipped to add 🐍 as search restriction

Input: model *model*

```
1 ...
2 if dummy ∈ model:
3     for $i = 1..|🐍| - 1$:
4         model.context.add_clause(next(🐍_i, 🐍_{i+1}), True)
5 ...
```

Workflow - Nogoods

- manipulate any clause
- logic program stays untouched
- no interface identifiers
- complex access
- initial model problem

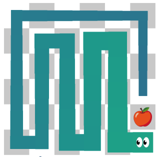
Attribute summary

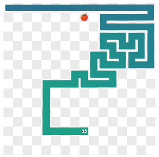
- prototyping/debugging: oneshot
- resource optimization: multi-shot

	ad hoc	preground	assume	nogood
flexibility	introduce rules	predefined	predefined	predefined
expressivity	rules	constraints	atoms	clauses
program alternation	every iteration	once	none/once	none
interface	NA	good	depends	depends
accessibility	good	good	good	hidden

Experiments - Setup

- 6 different square grid sizes ($n = m, n \in \{6, 8, 10, 12, 14, 16\}$)
- 100 repetitions per grid size and approach
- 60s timeout for solve per iteration
- average number of steps, average total time
- MacBook Pro (2017, 16 GB RAM, Intel Core i7, 2.8 GHz)
- clingo v. 5.4.0, python v. 3.7.4
- ASP-Chef for prototyping, `clingraph` for graphics
- github.com/elbo4u/asp-snake-ms





Experiments - Evaluation

average total Time (grounding and solving) in seconds

	$n \times m$	6×6	8×8	10×10	12×12	14×14	16×16
	one-shot	0.159	**2.28**	**71.83**	621	2216	4359
	ad hoc	0.066	3.42	90.07	674	1966	3869
time	preground	0.060	3.32	94.71	**620**	1978	3870
	assume	**0.059**	4.78	97.48	628	**1944**	**3853**
	nogood	0.061	3.16	94.70	702	1951	3877

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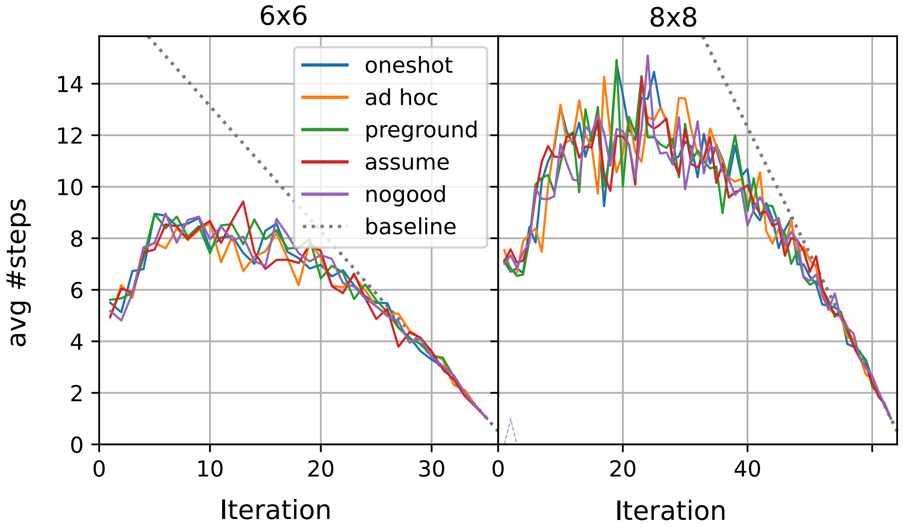
	nogood	0.061	3.16	94.70	702	1951	3877
	one-shot	213	576	1235	2441	<u>5519</u>	<u>10157</u>
	ad hoc	208	572	1226	2411	4582	7445
steps	preground	216	563	1236	2374	4540	7482
	assume	210	563	1234	2396	4508	7540
	nogood	212	559	1240	2428	4580	7523

Experiments - Evaluation - Steps



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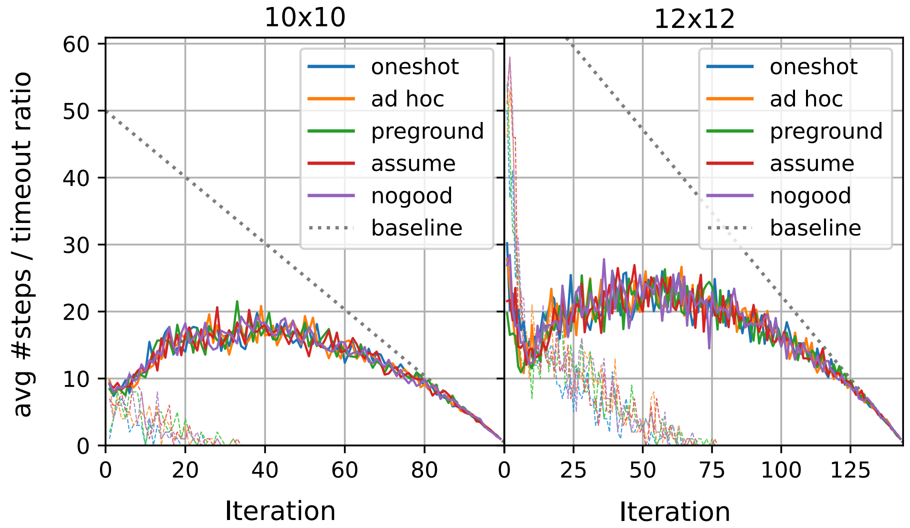

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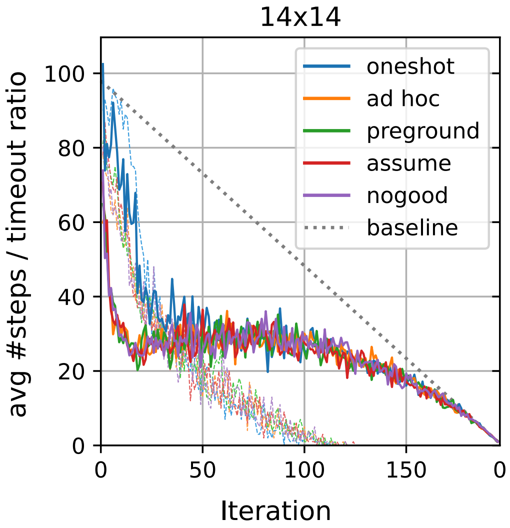

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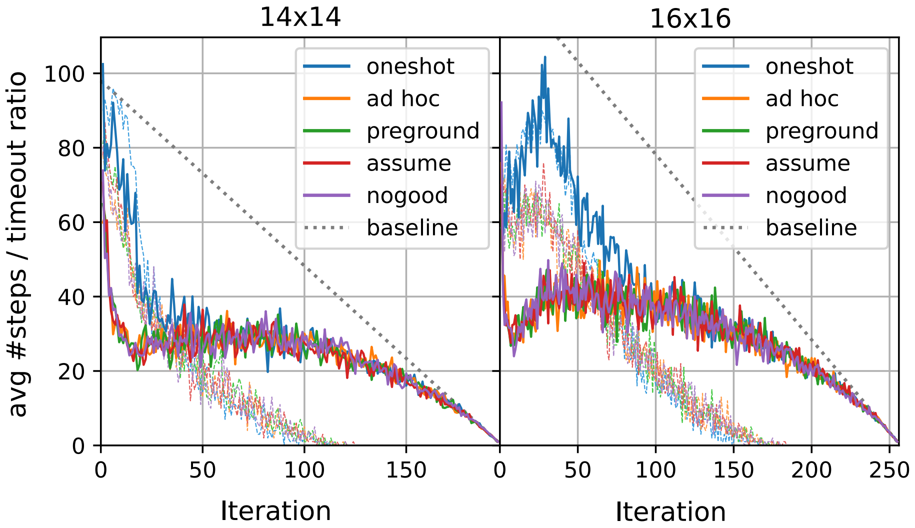
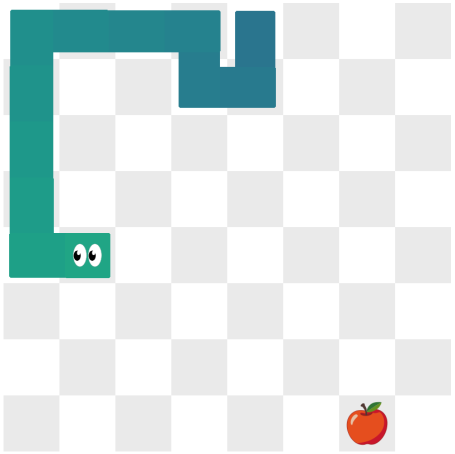


Experiments - Evaluation - Nogoods



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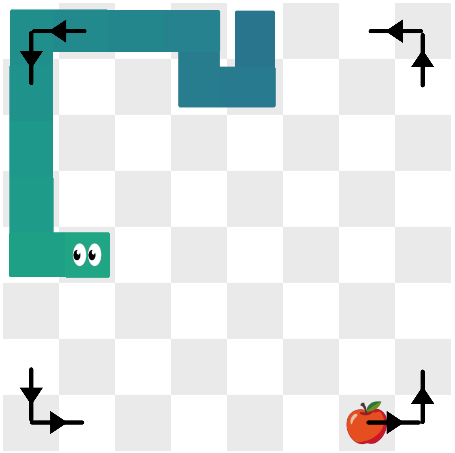

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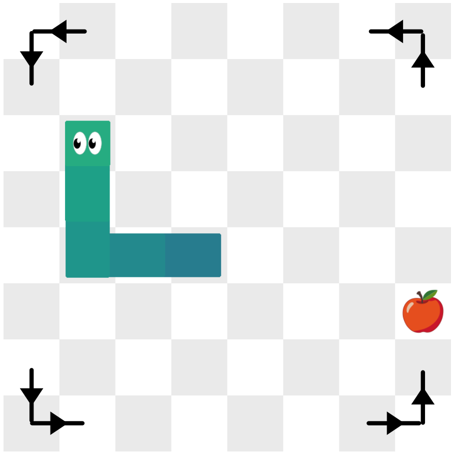

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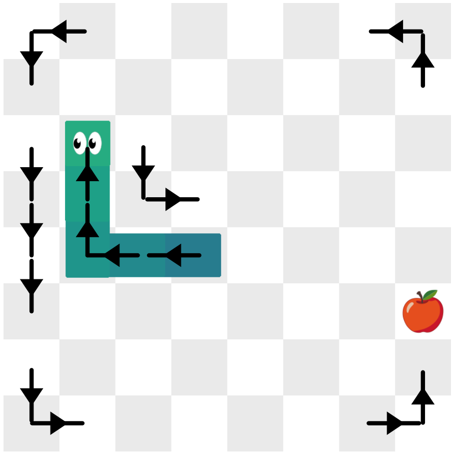

Conclusion and Future Work

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- Different approaches to implement multi-shot in `clingo`
- Snakes as suited showcase benchmark
- Multi-shot as reasonable technique for limited resources

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