DATA130008 Introduction to Artificial Intelligence

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Gomoku Tutorial 1

November 02th 2021

- Gomoku Rule
- Solve Gomoku
  - Board Representation
  - Monte Carlo Tree Search
  - Proof-Number Search
  - Threat-Space Search
  - Genetic Algorithm

- **Gomoku Rule**
- Solve Gomoku
  - Board Representation
  - Monte Carlo Tree Search
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Gomoku Rule

- Goal: Five in a row, 15 × 15
  - Proved: Black first leads to win (1899)
- Gomoku without forbidden shape:
  - Free: 5 or more than 5
  - Standard: only 5
  - Swap 2 Rule
- Renju: forbid some shape for Black

- Focus on: Free Gomoku

- Gomoku Rule
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Solve Gomoku

- Input
  - Current board state
- Goal
  - Search for next step

Gomoku

- Gomoku Rule
- Solve Gomoku
  - Board Representation
  - Monte Carlo Tree Search
  - Proof-Number Search
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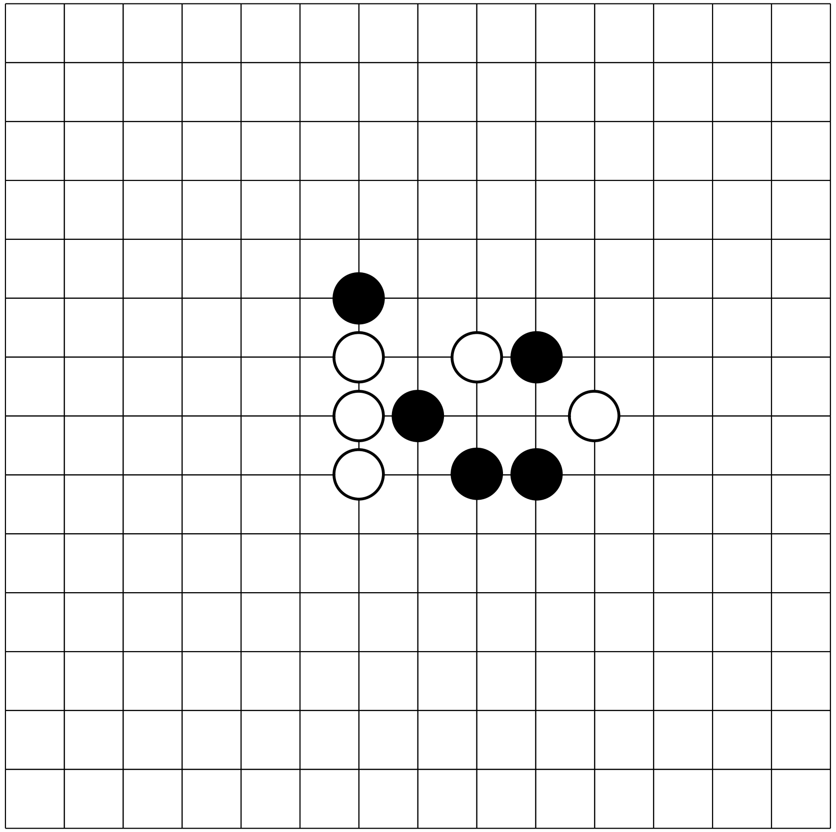
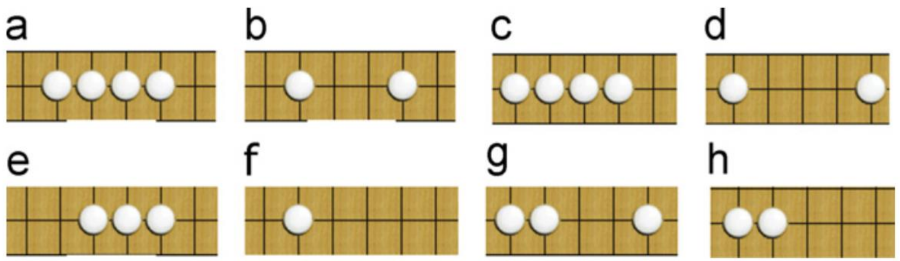
Solve Gomoku: Board Representation

- Board representation
  - Atomic
    - (x, y, ●/○/ ·)
  - Structured: Features
    - Patterns
    - Turns
    - Offensive/Defensive



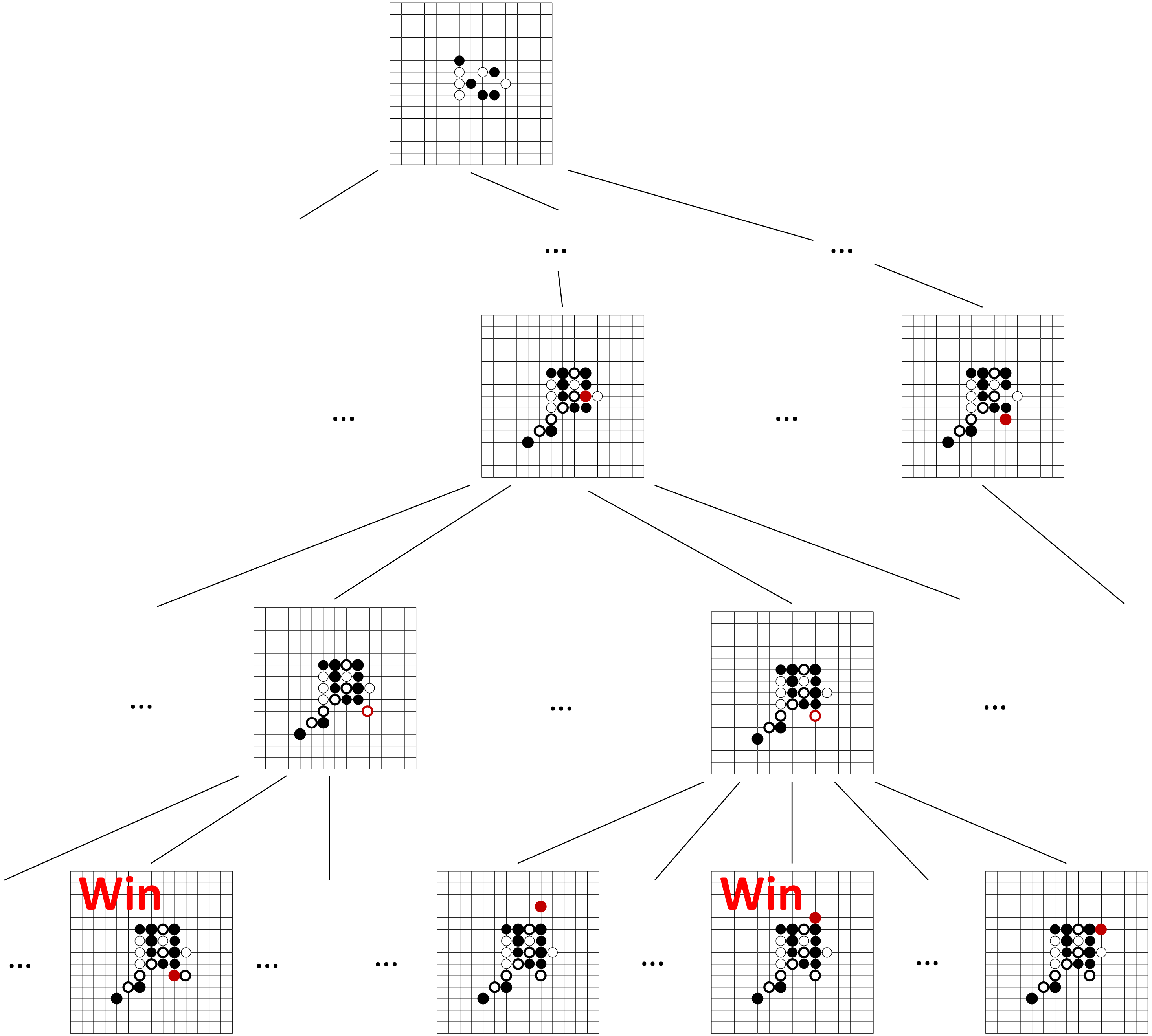


Dongbin Zhao, Zhen Zhang, and Yujie Dai.
Self-teaching adaptive dynamic programming for Gomoku.
Neurocomputing, 78(1):23–29, 2012.

Zhentao Tang, Dongbin Zhao, Kun Shao, and Le Lv.
ADP with MCTS algorithm for Gomoku.
2016 IEEE Symp. Ser. Comput. Intell. SSCI 2016, (61273136), 2017.

Solve Gomoku

- Input
  - Current board state
- Goal
  - Search for next step
    - Single agent
    - Adversarial agent
- Construct a search tree
  - Node: Gomoku board



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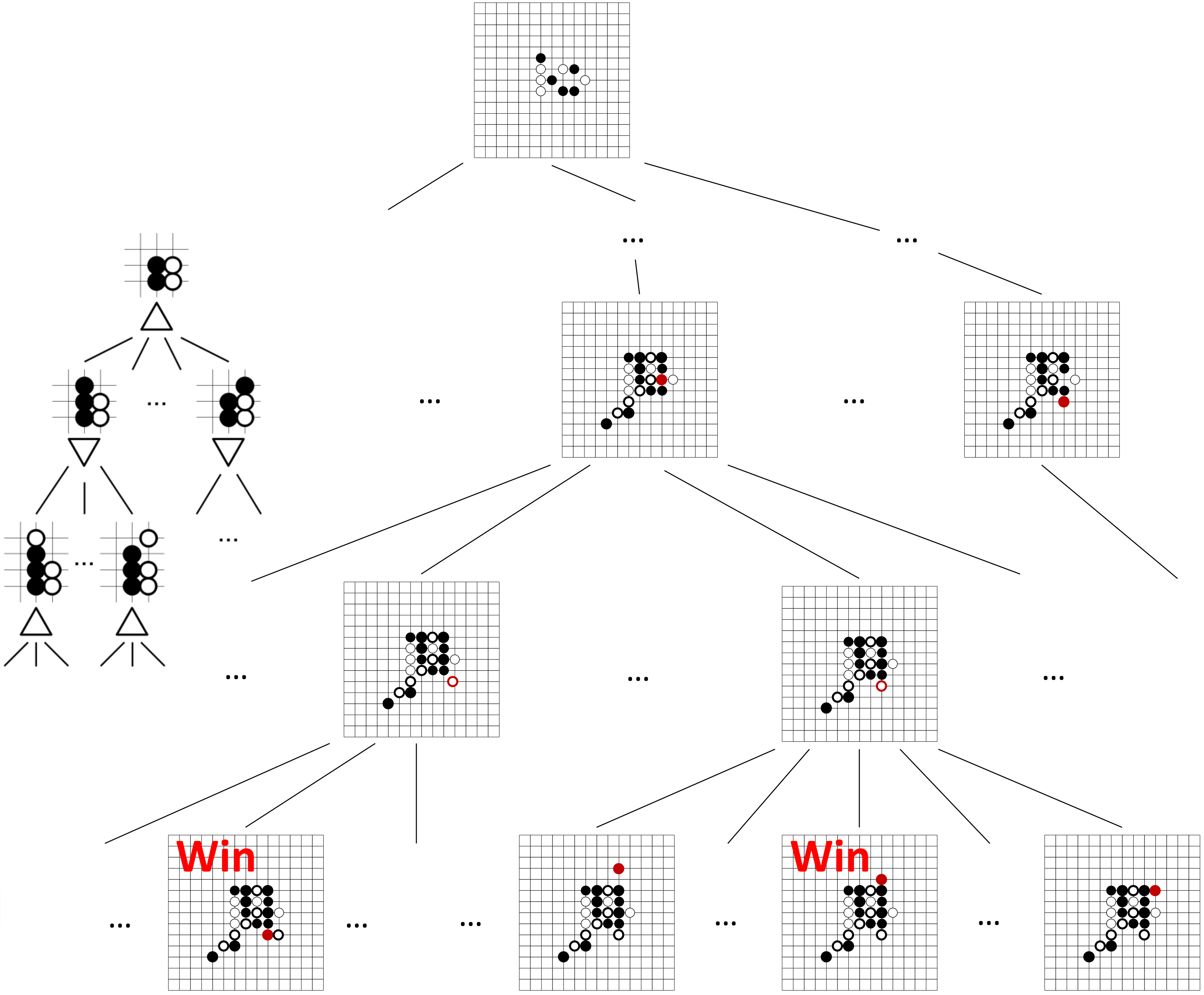

- Gomoku Rule
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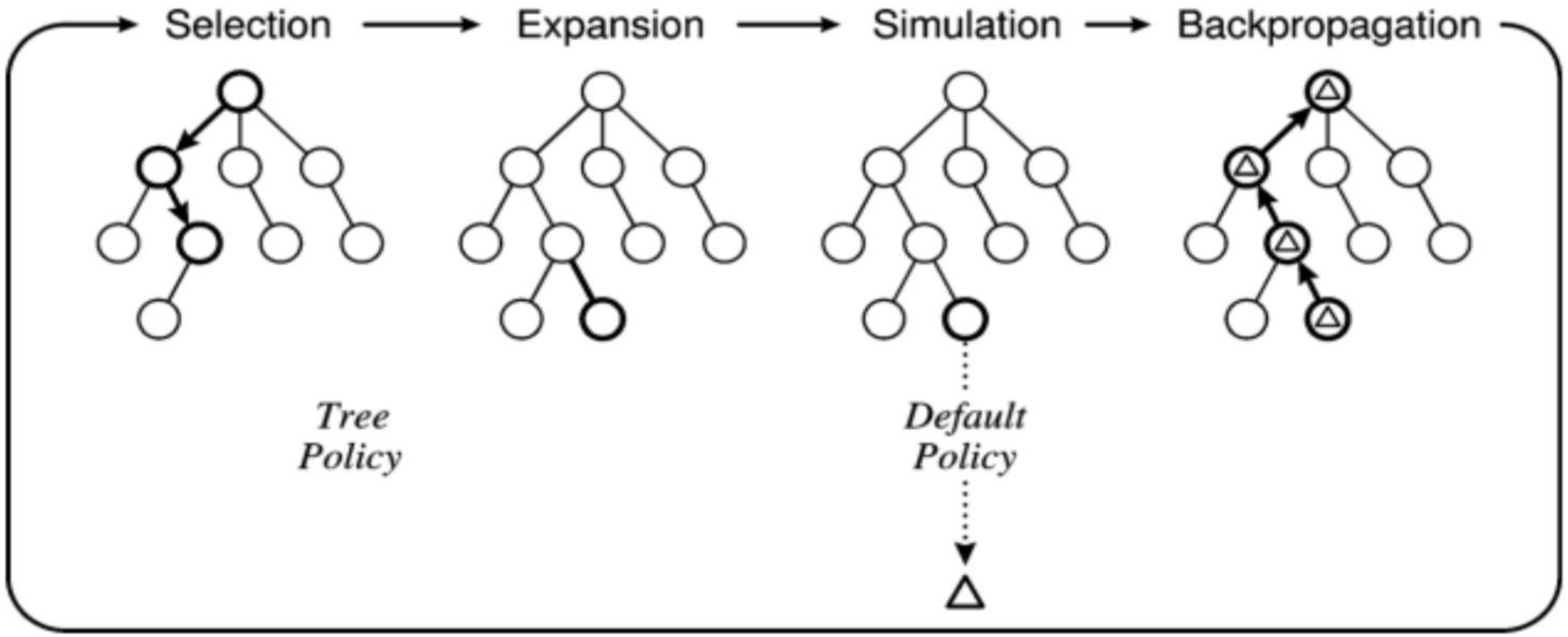
Solve Gomoku: Monte Carlo Tree Search

- Monte Carlo Tree Search
  - Simulation, Expectation
  - Steps
    - Selection
    - Expansion
    - Simulation
    - Backpropagation



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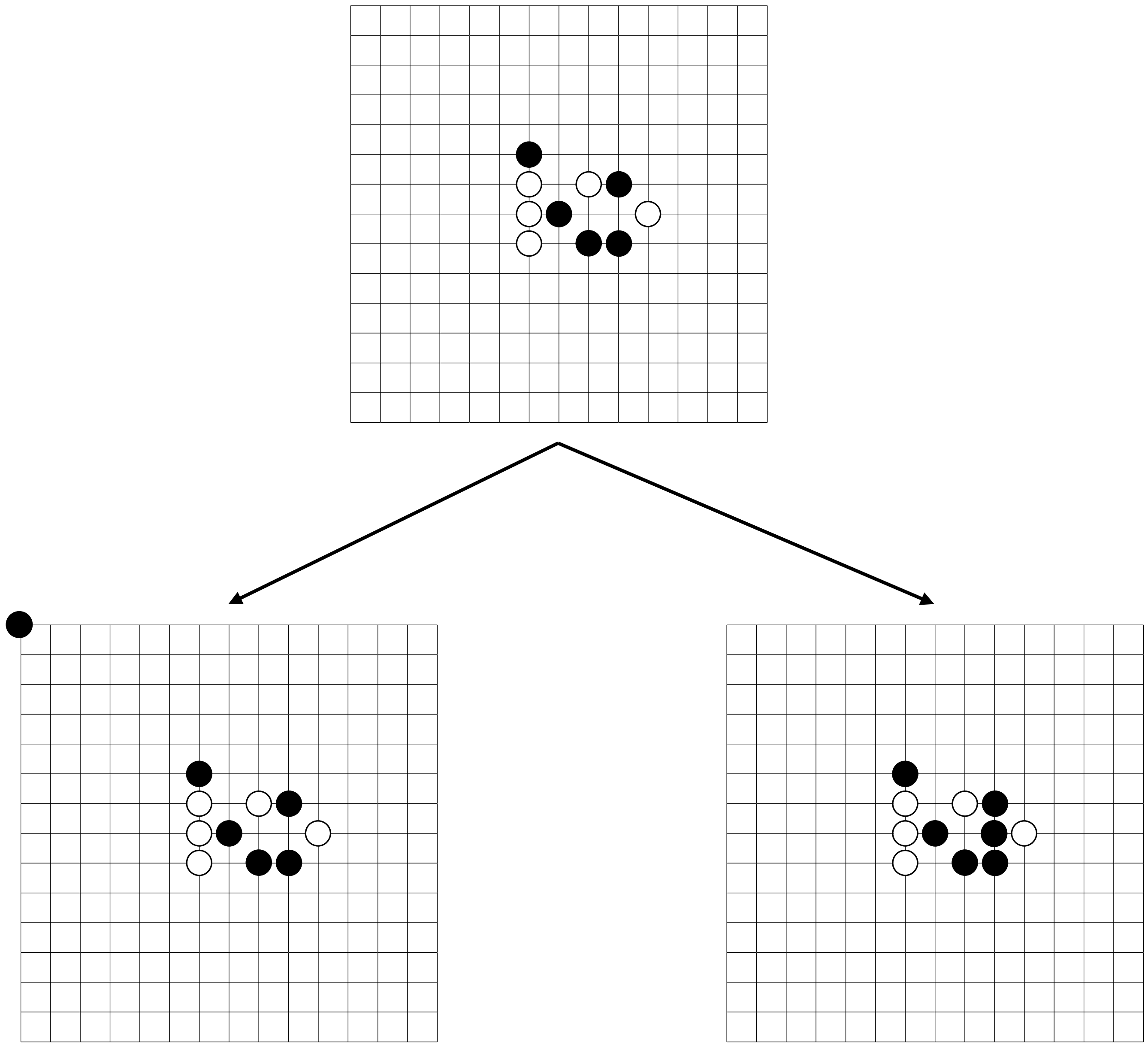

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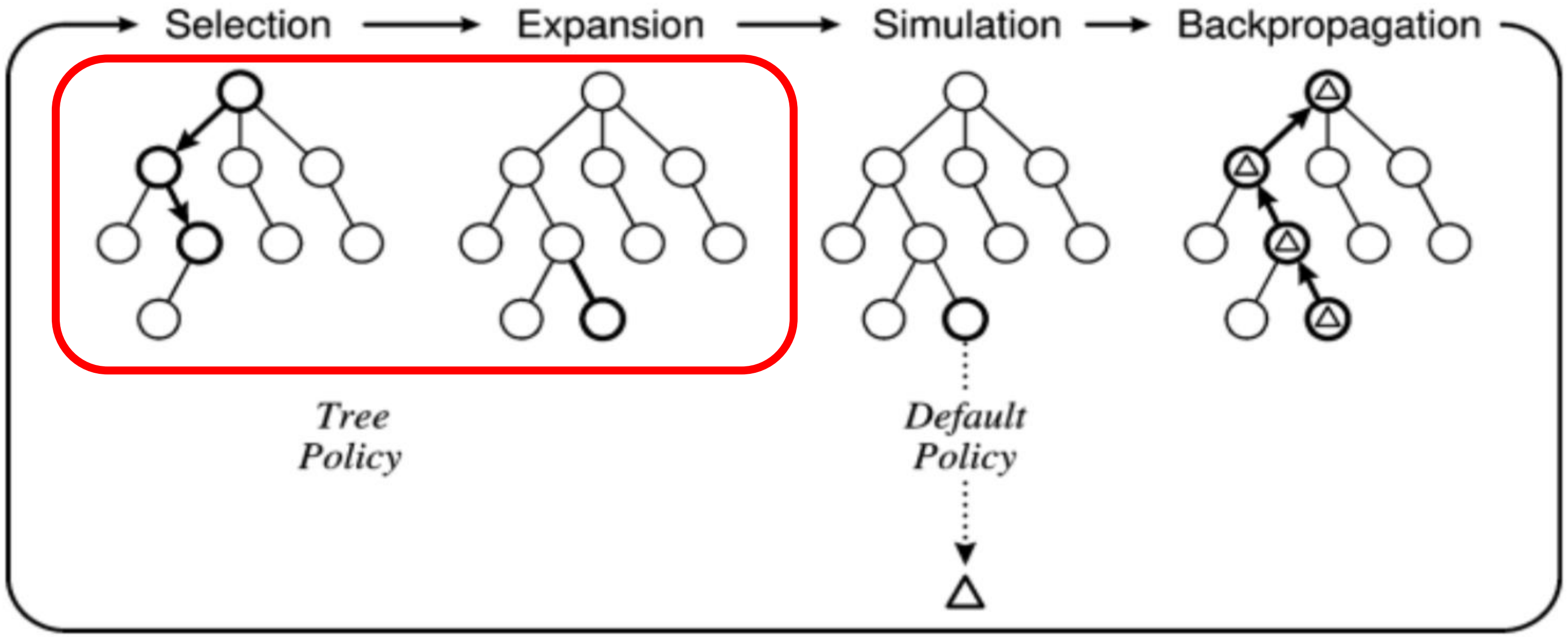

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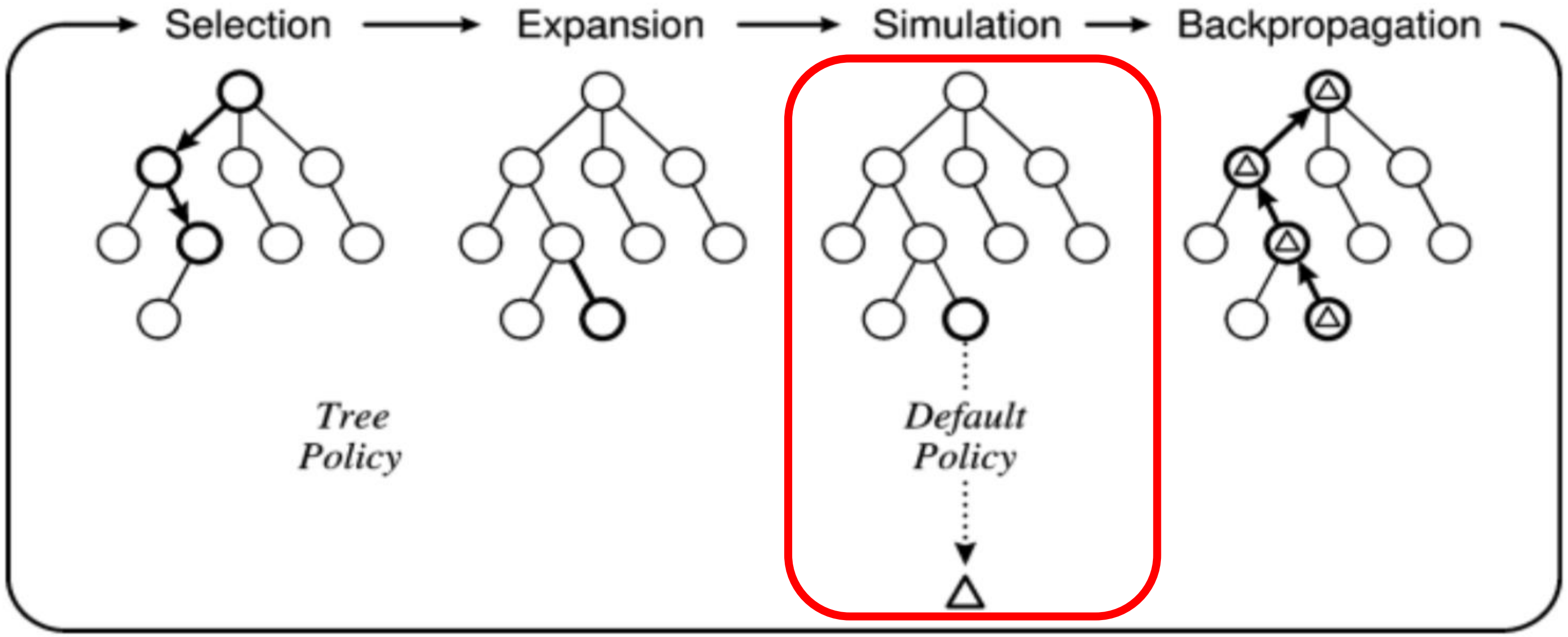

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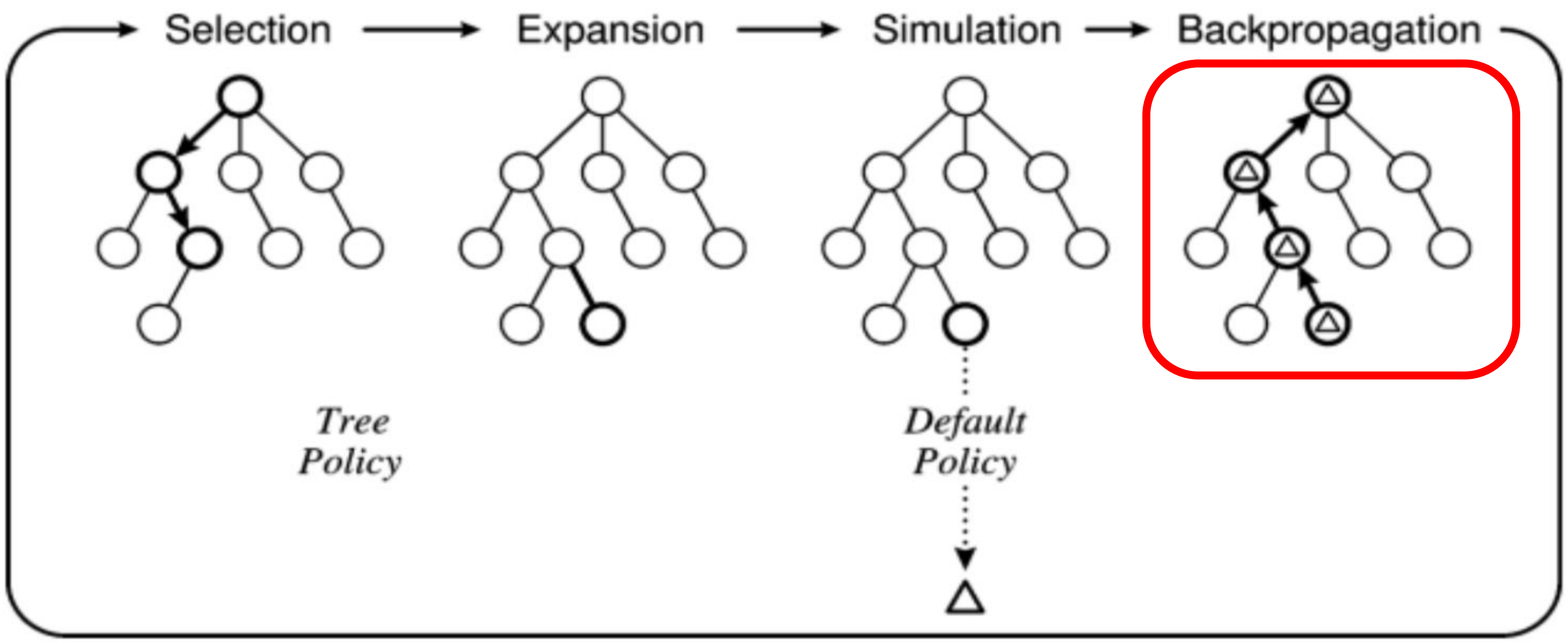

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Solve Gomoku: Monte Carlo Tree Search

- **Input** original state s0
- **Output** action a corresponding to the highest value of MCTS

add Heuristic Knowledge;
obtain possible action moves M from state s_0;
for each move m in moves M **do**
  reward $r_{total} \leftarrow 0$;
  while simulation times < assigned times **do**
    reward $r \leftarrow$ Simulation($s(m)$);
    $r_{total} \leftarrow r_{total} + r$;
    simulation times add one;
  end while
  add (m, r_{total}) into *data*;
  end for each
return action Best(*data*)

Simulation(state s_t)
  if (s_t is win **and** s_t is terminal) **then return** 1.0;
    else return 0.0;
  end if
  if (s_t satisfied with Heuristic Knowledge)
    then obtain forced action a_f;
      new state $s_{t+1} \leftarrow f(s_t, a_f)$;
    else choose random action $a_r \in$ untried actions;
      new state $s_{t+1} \leftarrow f(s_t, a_r)$;
  end if
  return Simulation(s_{t+1})

Best(*data*)
  return action a //the maximum r_{total} of m from data

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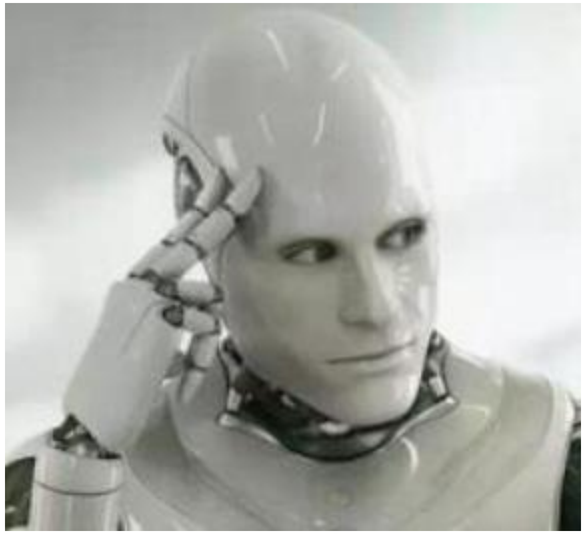
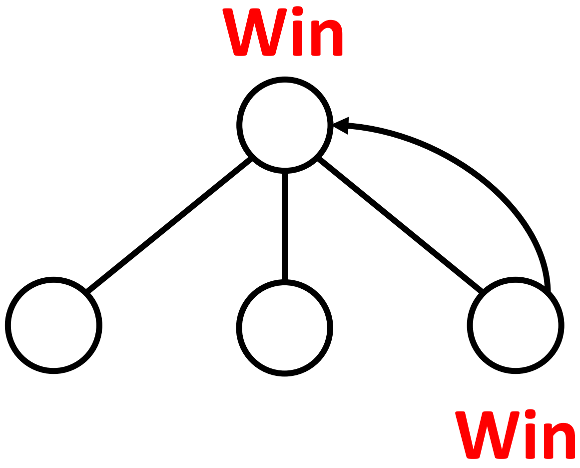
Solve Gomoku: Proof-Number Search

- When will the Black win?





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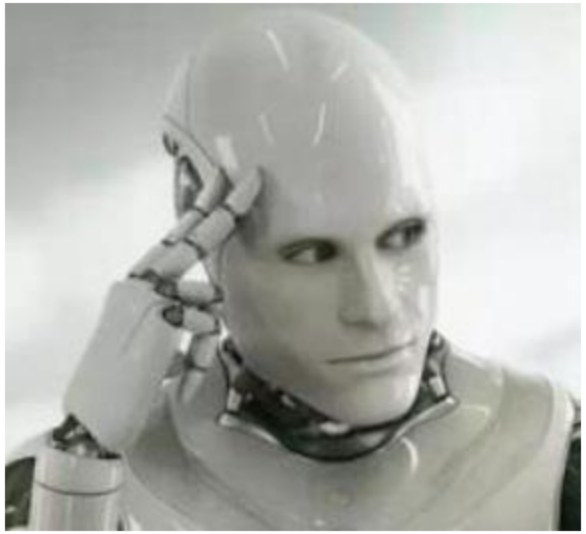
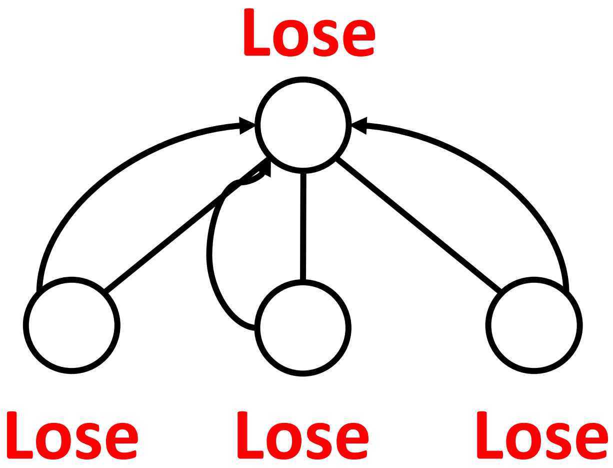
Solve Gomoku: Proof-Number Search

- When will the Black lose?





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Solve Gomoku: Proof-Number Search

- Board situation: Win, Lose, Unknown
- 2 Nodes:
  - Black Turn (OR)
    - Win if there is an action (White take) leading to Black win
    - Lose if all actions leading to Black lose
  - White (AND)
    - Win if all actions leading to Black win
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Solve Gomoku: Proof-Number Search

- Board situation: Win, Lose, Unknown
- 2 Nodes: **Win or Lose: BLACK's View**
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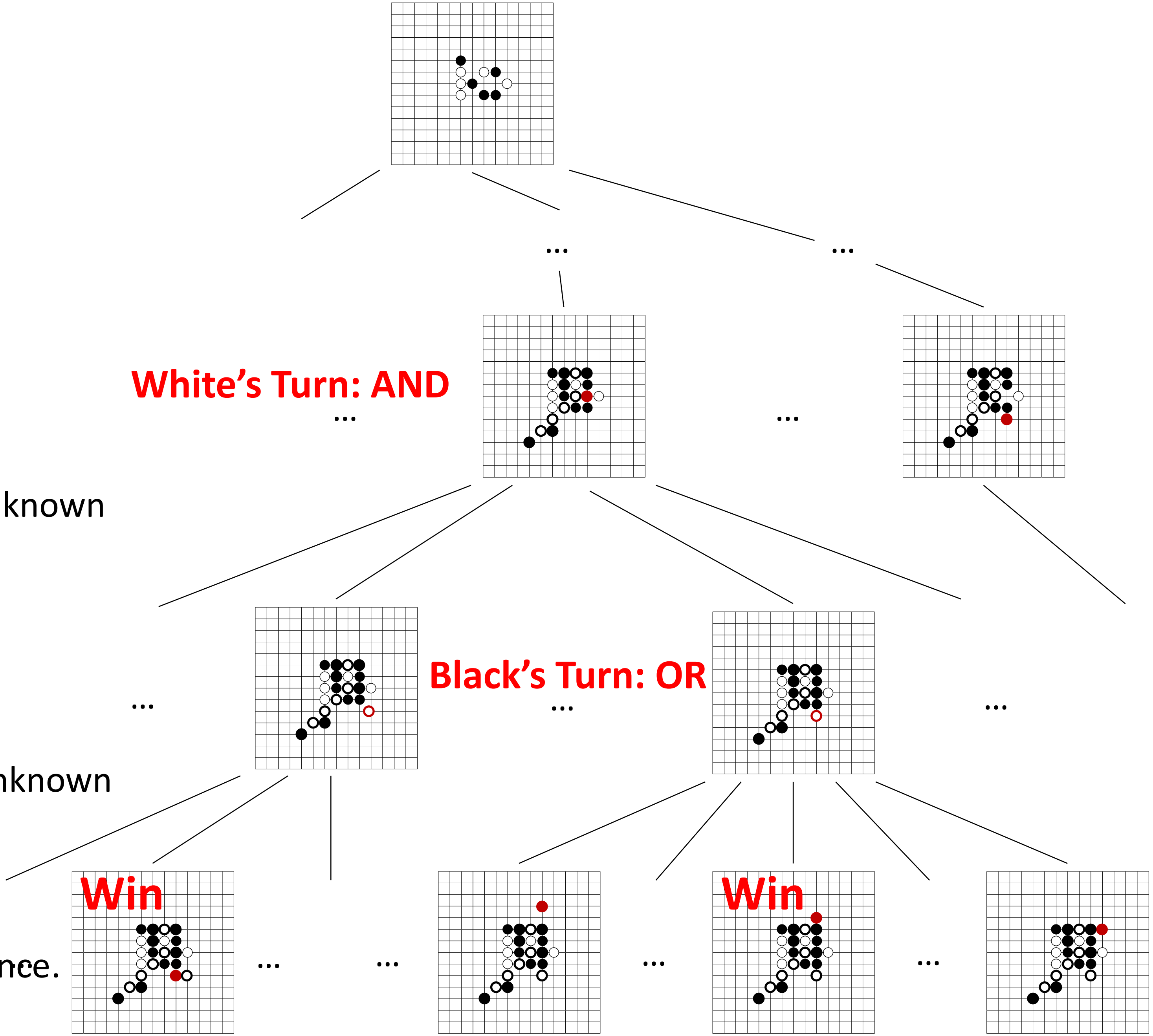
Solve Gomoku: Proof-Number Search

- AND/OR Tree
  - 3 Values: true, false, unknown
  - 2 Nodes: AND, OR
    - Black: OR
      - Win if one child is win
      - Unknown if no win and has unknown
      - Lose if all children are lose
    - White: AND
      - Lose if one child is lose
      - Unknown if no lose and has unknown
      - Win if all children are win



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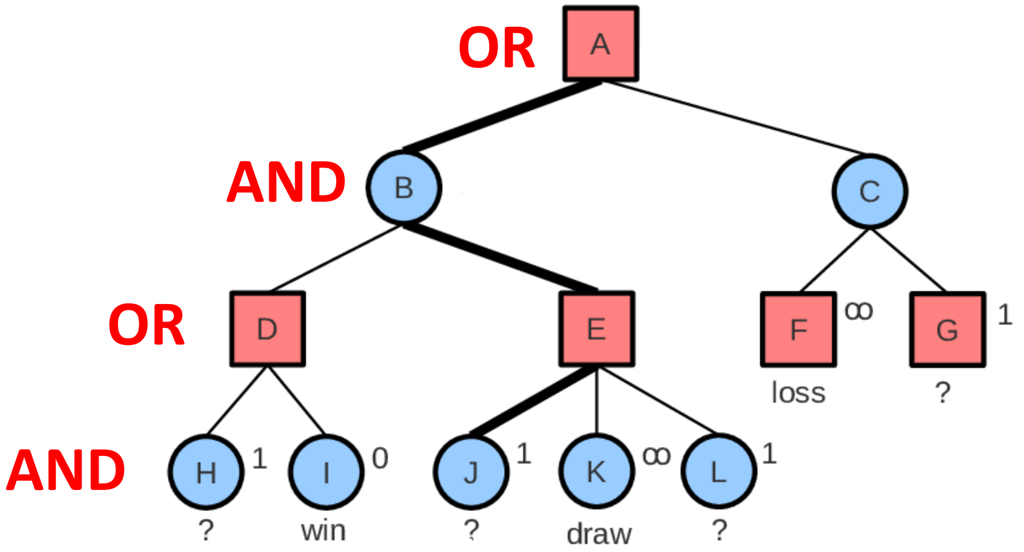
- AND/OR Tree
  - Proof set
    - Proof set: a set of frontier nodes S is a proof set if proving all nodes within S proves T
    - The proof number of T is defined as the cardinality of the smallest proof set of T
  - Disproof set
  - State of leaf nodes
    - Win: 0, ∞
    - Lose: ∞, 0
    - Unknown: 1, 1

AND: Circle; OR: Square



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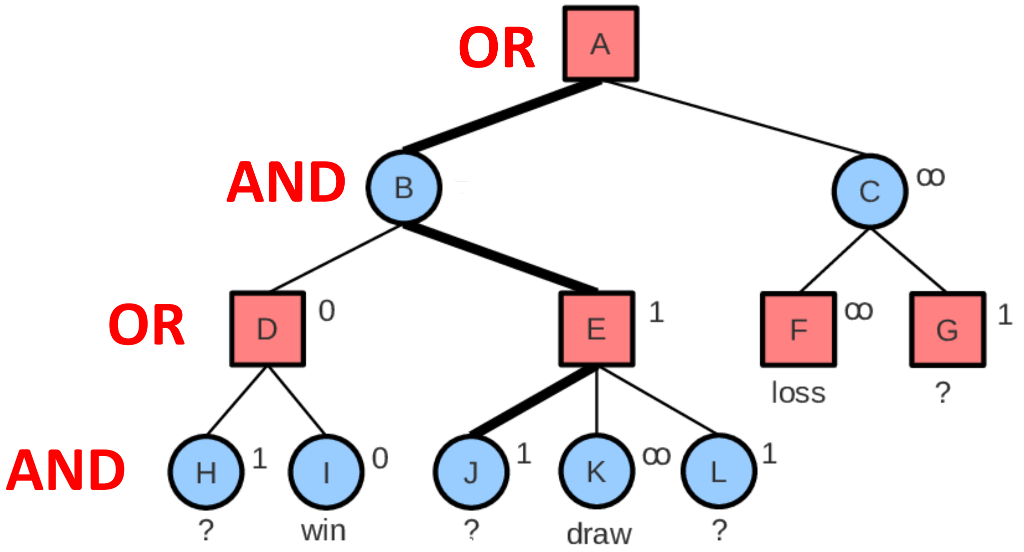

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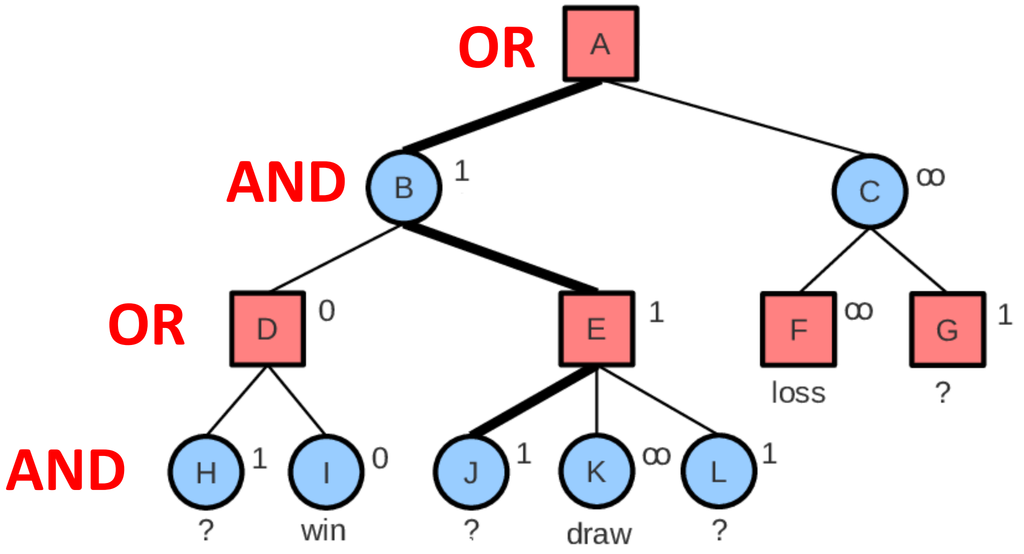

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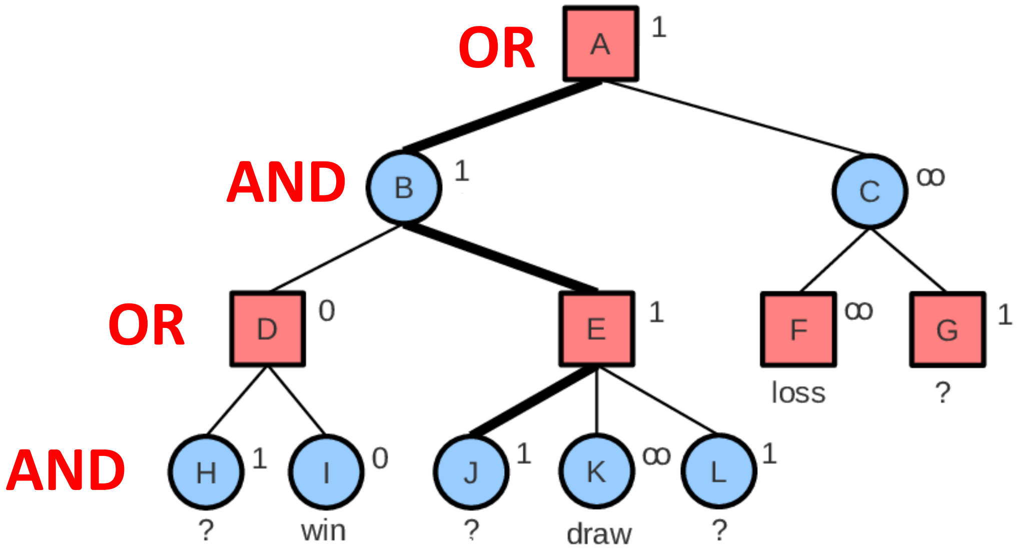

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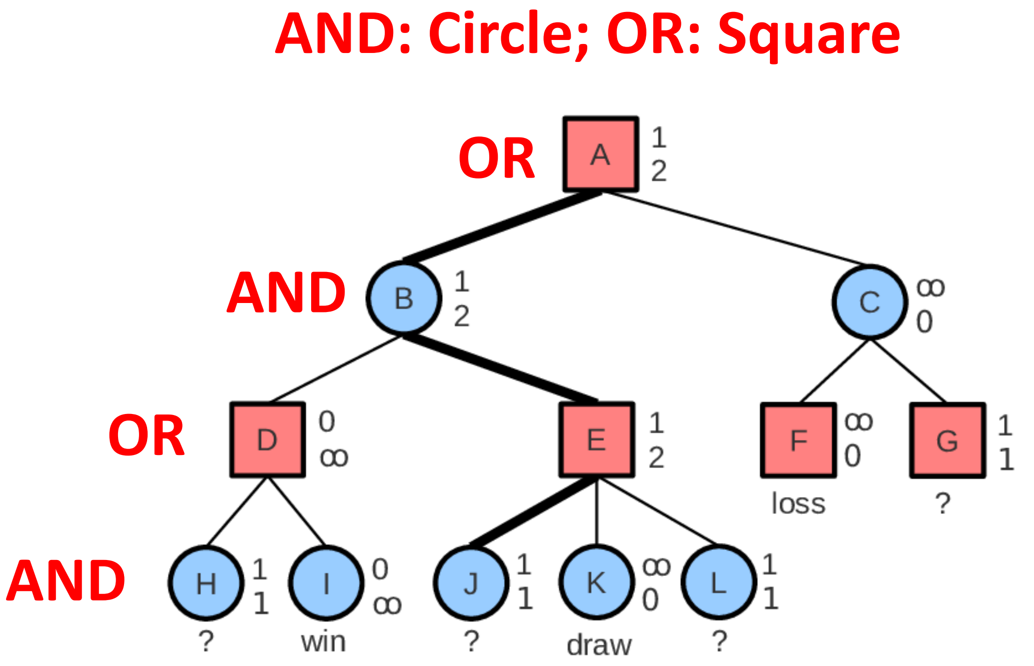
Solve Gomoku: Proof-Number Search

- AND/OR Tree
  - Set proof number
    - AND: sum OR: min
  - Set disproof number
    - AND: min OR: sum



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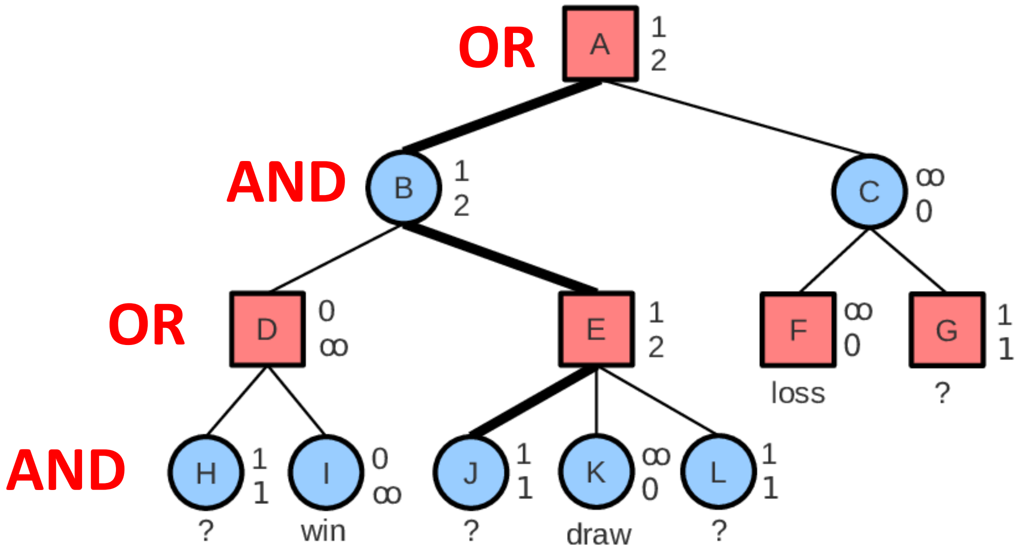
Solve Gomoku: Proof-Number Search

- AND/OR Tree
  - Most-proving node
    - Proved: each pair consisting of a smallest proof set and a smallest disproof set has a non-empty intersection.
    - i.e. There must exist at least one most-proving node.

AND: Circle; OR: Square



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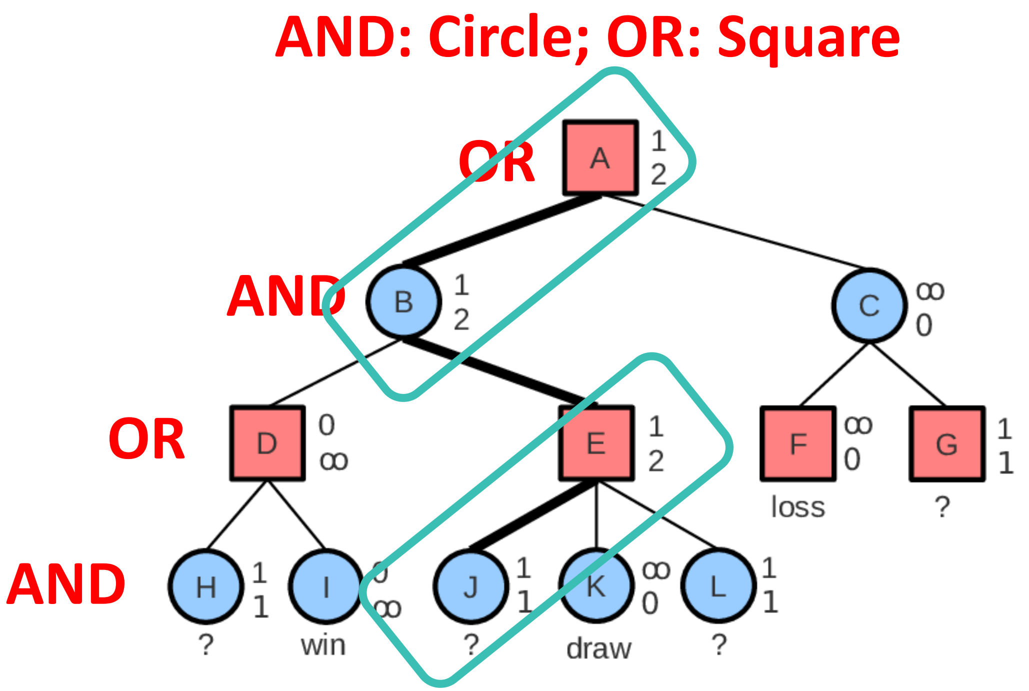

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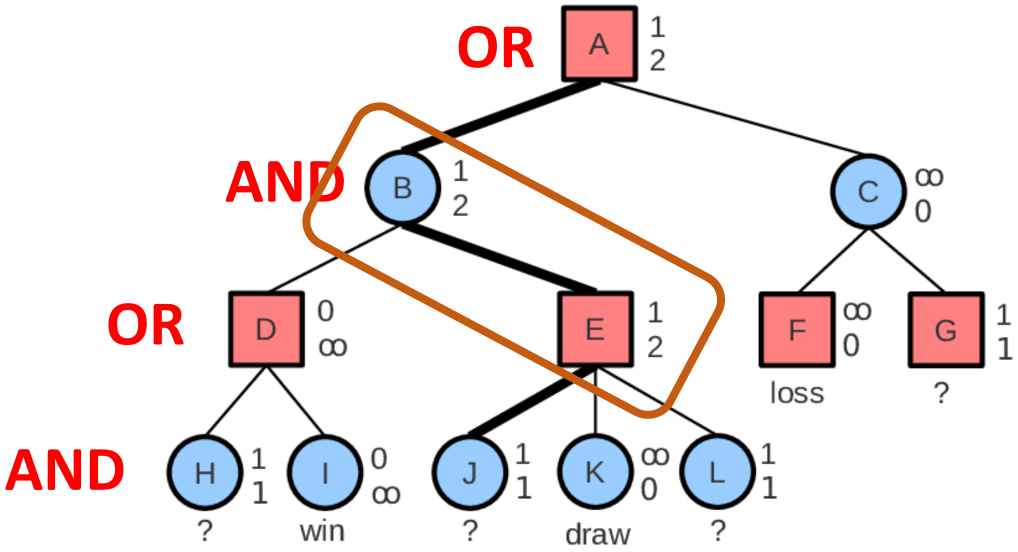

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- Algorithm

```
procedure ProofNumberSearch(root);
    Evaluate(root);
    SetProofAndDisproofNumbers(root);
    while root.proof ≠ 0 and root.disproof ≠ 0 and
            ResourcesAvailable() do
        mostProvingNode := SelectMostProving(root);
        DevelopNode(mostProvingNode);
        UpdateAncestors(mostProvingNode)
    od ;
    if root.proof = 0 then root.value := true
    elseif root.disproof = 0 then root.value := false
    else root.value := unknown
    fi
end
```

```
function SelectMostProving(node);
    while node.expanded do
        case node.type of
            or :
                i := 1;
                while node.children[i].proof ≠ node.proof do
                    i := i+1
                od
            and :
                i := 1;
                while node.children[i].disproof ≠ node.disproof do
                    i := i+1
                od
        esac ;
        node := node.children[i]
    od ;
    return node
end
```

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Solve Gomoku: Proof-Number Search

- Algorithm

```
procedure SetProofAndDisproofNumbers(node);
    if node.expanded then
        case node.type of
            and :
                node.proof := Σ_{N∈Children(node)} N.proof;
                node.disproof := Min_{N∈Children(node)} N.disproof
            or :
                node.proof := Min_{N∈Children(node)} N.proof;
                node.disproof := Σ_{N∈Children(node)} N.disproof
        esac
    elseif node.evaluated then
        case node.value of
            false : node.proof := ∞; node.disproof := 0
            true : node.proof := 0; node.disproof := ∞
            unknown : node.proof := 1; node.disproof := 1
        esac
    else node.proof := 1; node.disproof := 1
    fi
end
```

```
procedure DevelopNode(node);
    GenerateAllChildren(node);
    for i := 1 to node.numberOfChildren do
        Evaluate(node.children[i]);
        SetProofAndDisproofNumbers(node.children[i])
    od
end
```

```
procedure UpdateAncestors(node);
    while node ≠ nil do
        SetProofAndDisproofNumbers(node);
        node := node.parent
    od
end
```

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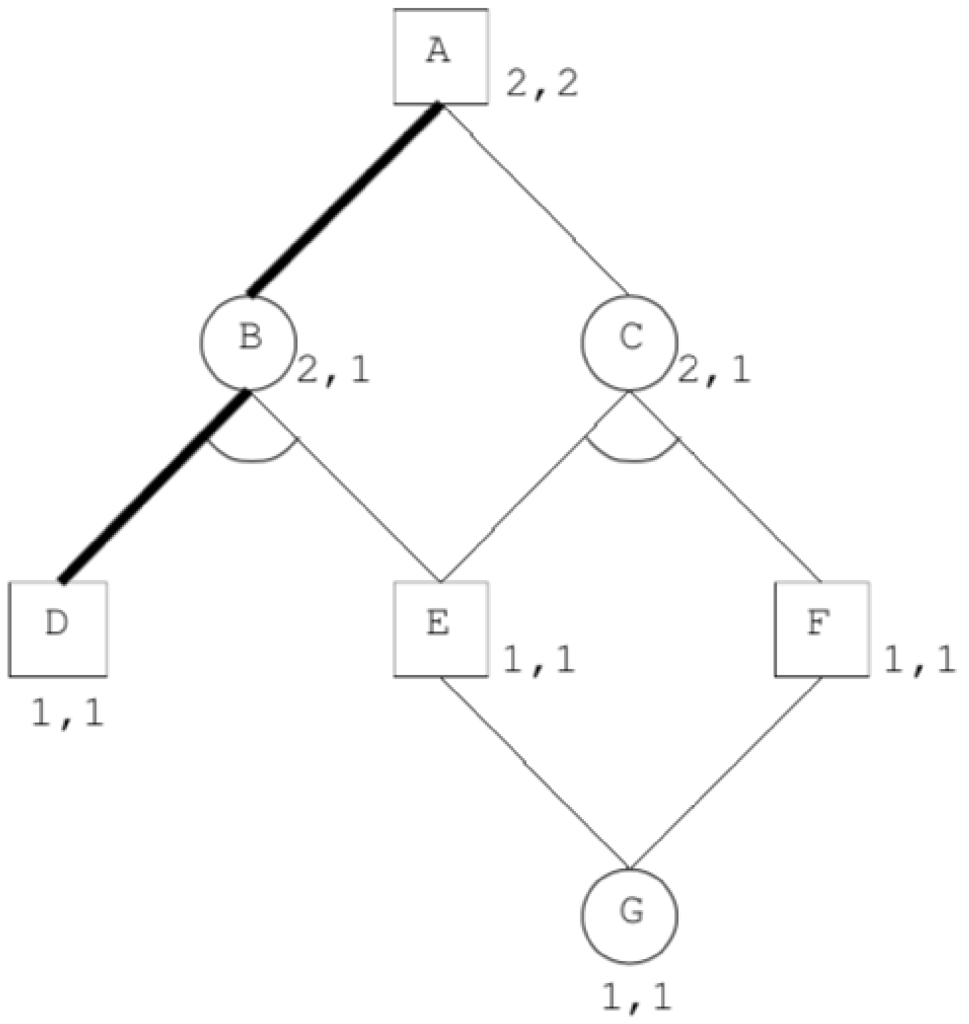
Solve Gomoku: Proof-Number Search

- Transposition
  - Hash table
  - Directed Acyclic Graphs



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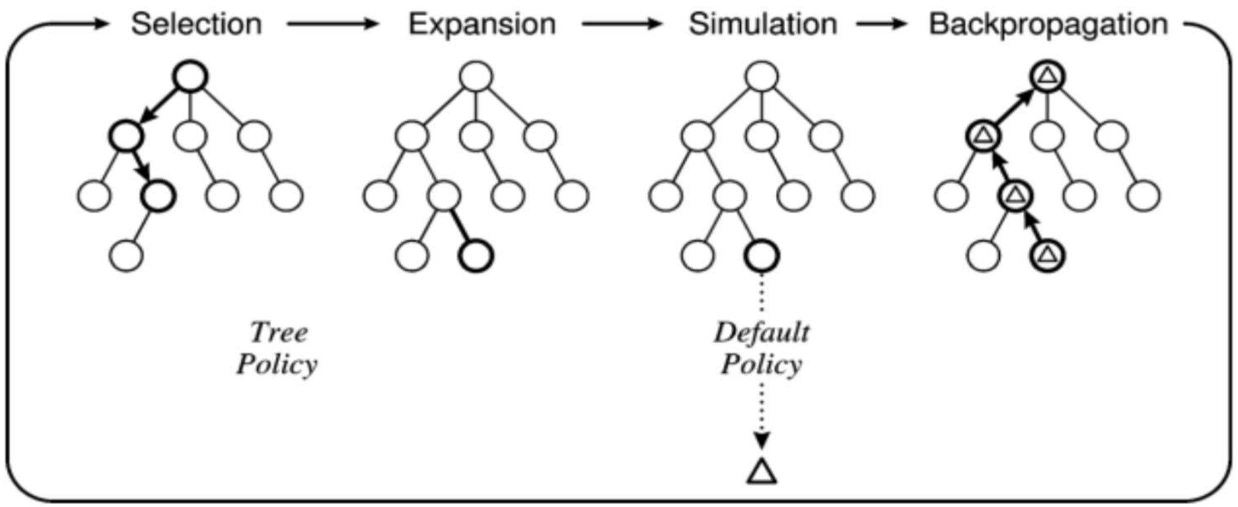
Solve Gomoku: Monte Carlo Tree Search



- Monte Carlo Tree Search
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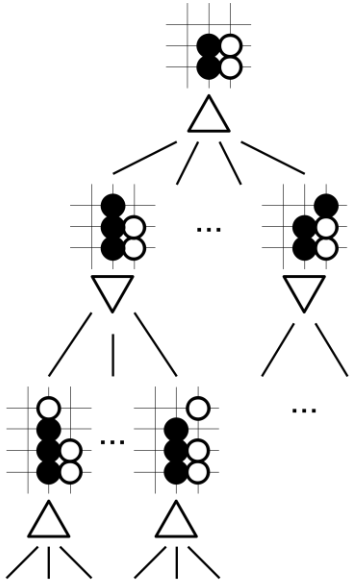
Proof-Number Search

Threat-Space Search, Genetic Algorithm



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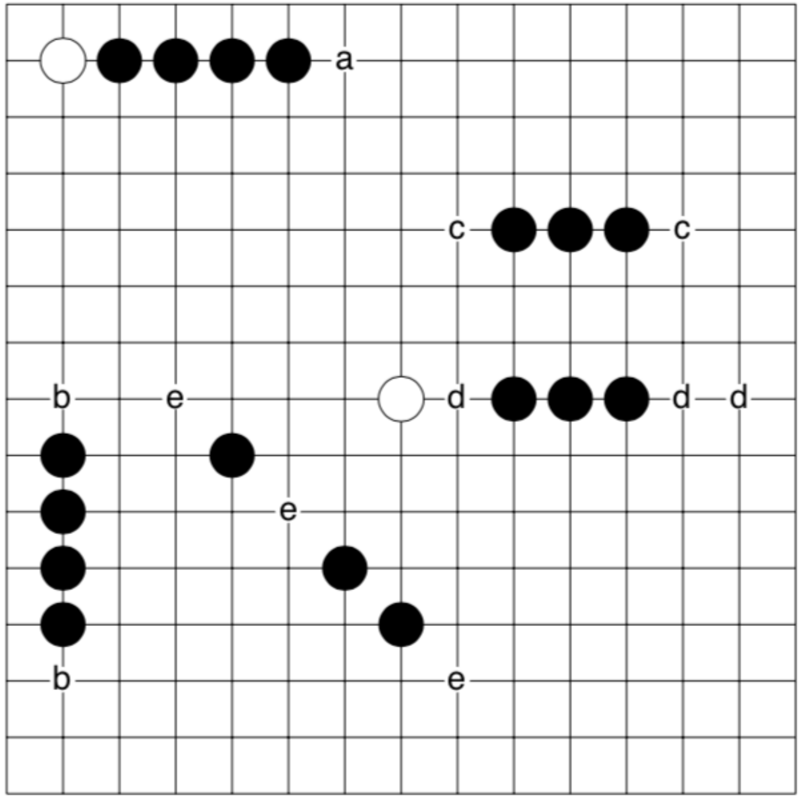
Solve Gomoku: Threat-Space Search

- Goal: Five in a row

Four in a row
Three in a row
…

Threat

Threat Sequence



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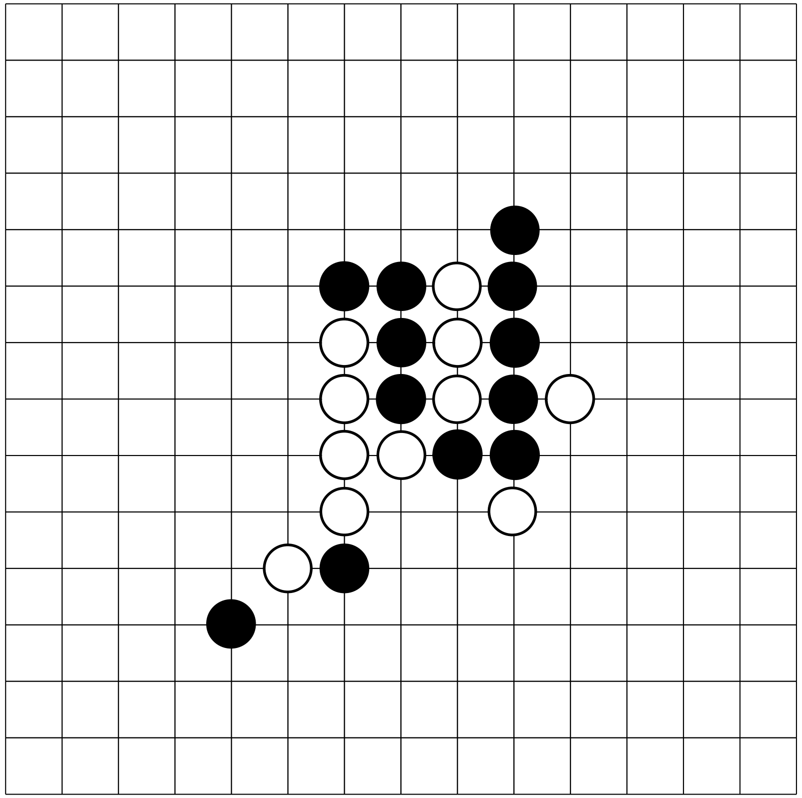
. Ist. Psu. Edu/, 1993.

Solve Gomoku: Threat-Space Search

- Threat Sequence
- Winning Threat Sequence



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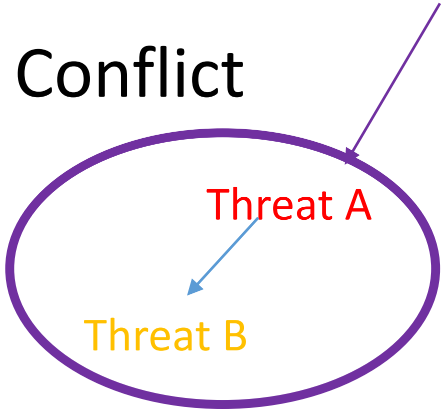
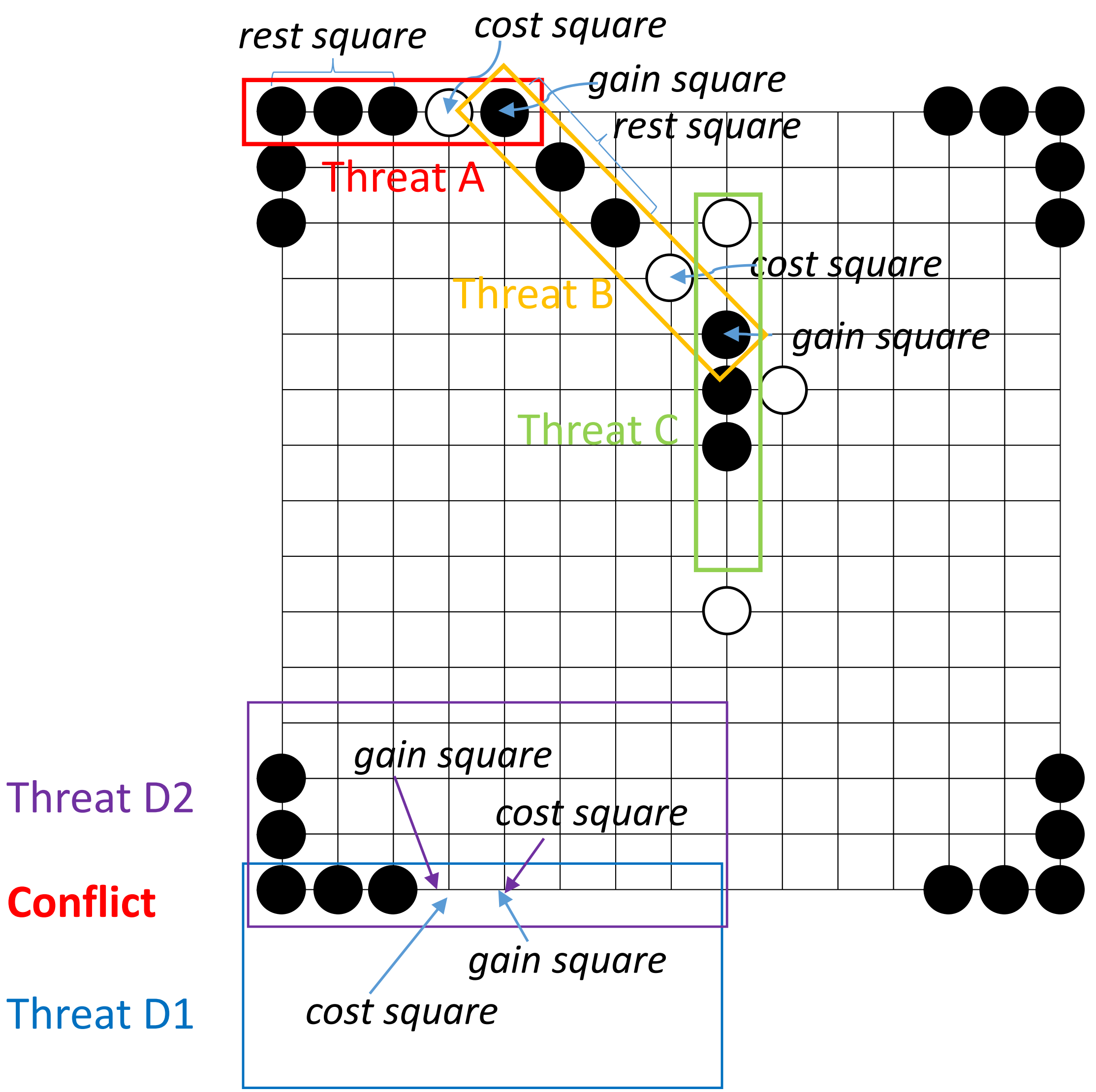
Solve Gomoku: Threat-Space Search

- Gain square
- Cost square
- Rest square
- Dependent
  - Dependency tree
- Conflict





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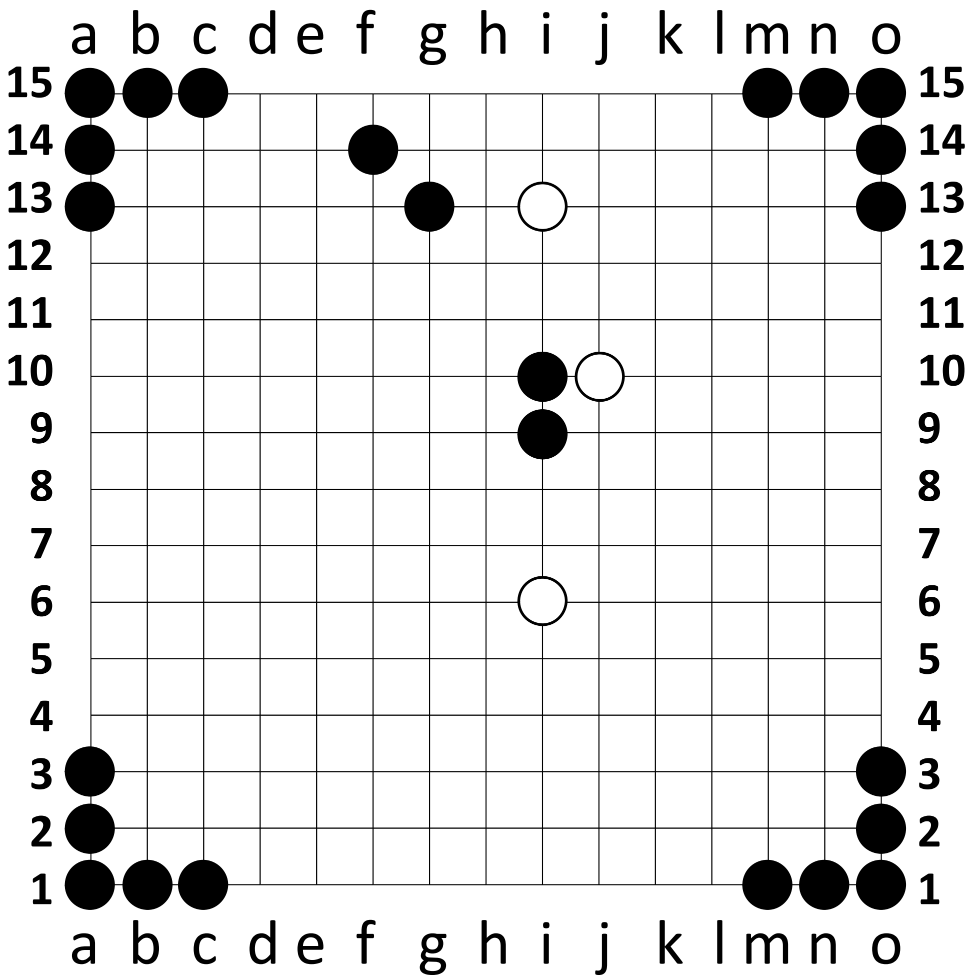
Solve Gomoku: Threat-Space Search

- Threat Search tree:
  - Threat A being independent of threat B is not allowed to occur in the search tree of threat B.
  - Only threats for the attacker are included.

Depth	Type of threat	Gain square	Cost squares
1	Four	*l15*	*k15*
1	Four	*k15*	*l15*
1	Four	*e15*	*d15*
2	Four	*i11*	*h12*
3	Straight Four	*i8*	*i7*
2	Four	*h12*	*i11*
1	Four	*d15*	*e15*
1	Four	*o12*	*o11*
1	Four	*o11*	*o12*
1	Four	*a12*	*a11*
1	Four	*a11*	*a12*
1	Three	*i11*	*i7,i8,i12*
2	Four	*h12*	*e15*
2	Four	*e15*	*h12*
3	Five	*d15*	
1	Three	*i8*	*i7,i11,i12*
1	Four	*o5*	*o4*
1	Four	*o4*	*o5*
1	Four	*l1*	*k1*
1	Four	*k1*	*l1*
1	Four	*e1*	*d1*
1	Four	*d1*	*e1*
1	Four	*a5*	*a4*
1	Four	*a4*	*a5*



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Solve Gomoku: Threat-Space Search

- Victoria
  - Threat-space search
  - Proof-number search
- Threat-Space Search
  - a module capable of quickly determining whether a winning threat sequence exists
  - used as a first evaluation function
    - Win for the attacker
    - No win: proof-number search
  - a heuristic evaluation procedure

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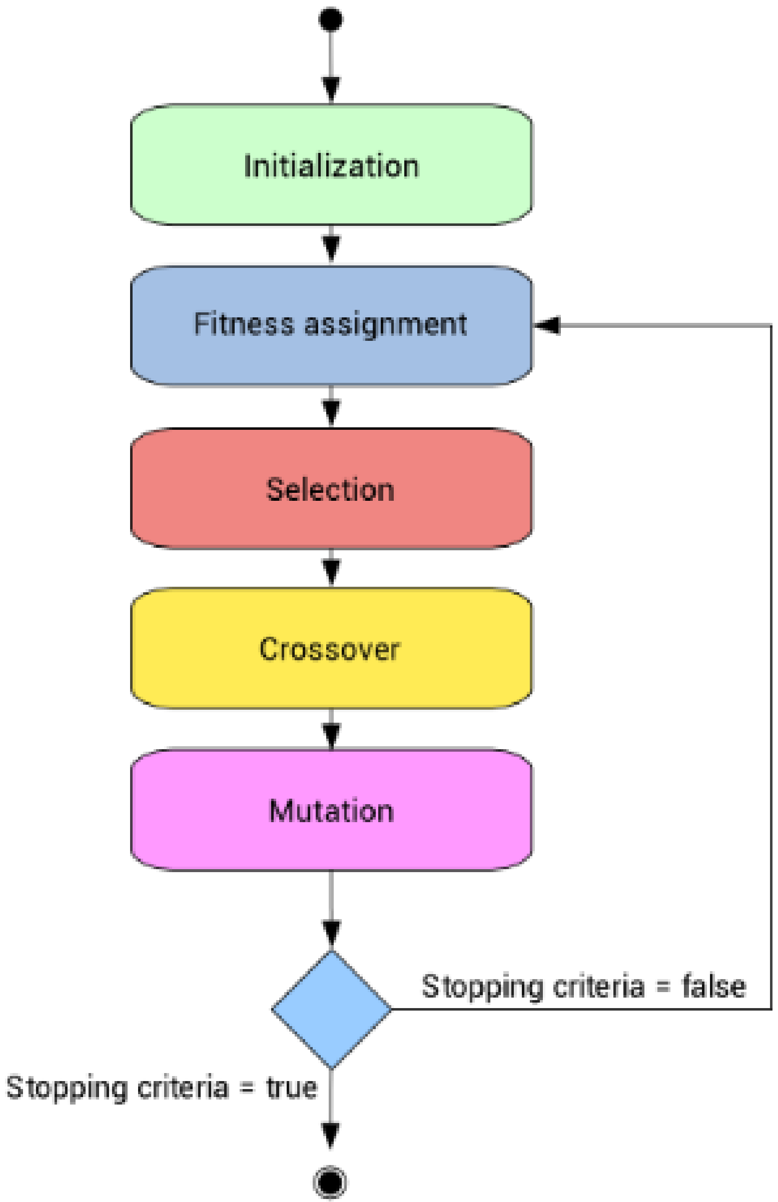
- Gomoku Rule
- Solve Gomoku
  - Board Representation
  - Monte Carlo Tree Search
  - Proof-Number Search
  - Threat-Space Search
  - Genetic Algorithm

Solve Gomoku: Genetic Algorithm

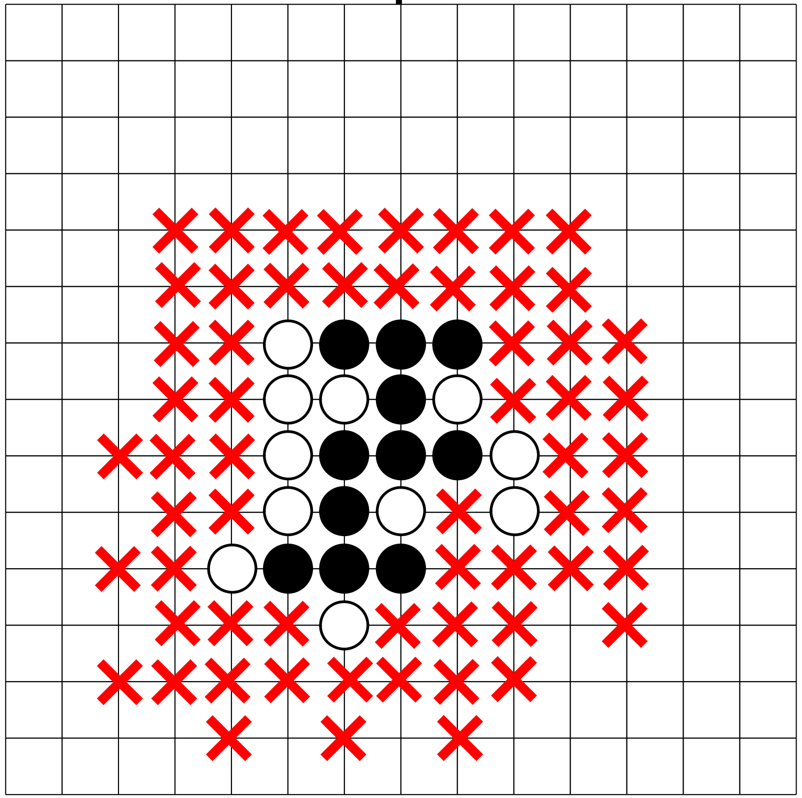
- Initialization: Coding Scheme
- Fitness assignment
- Selection
- Crossover
- Mutation

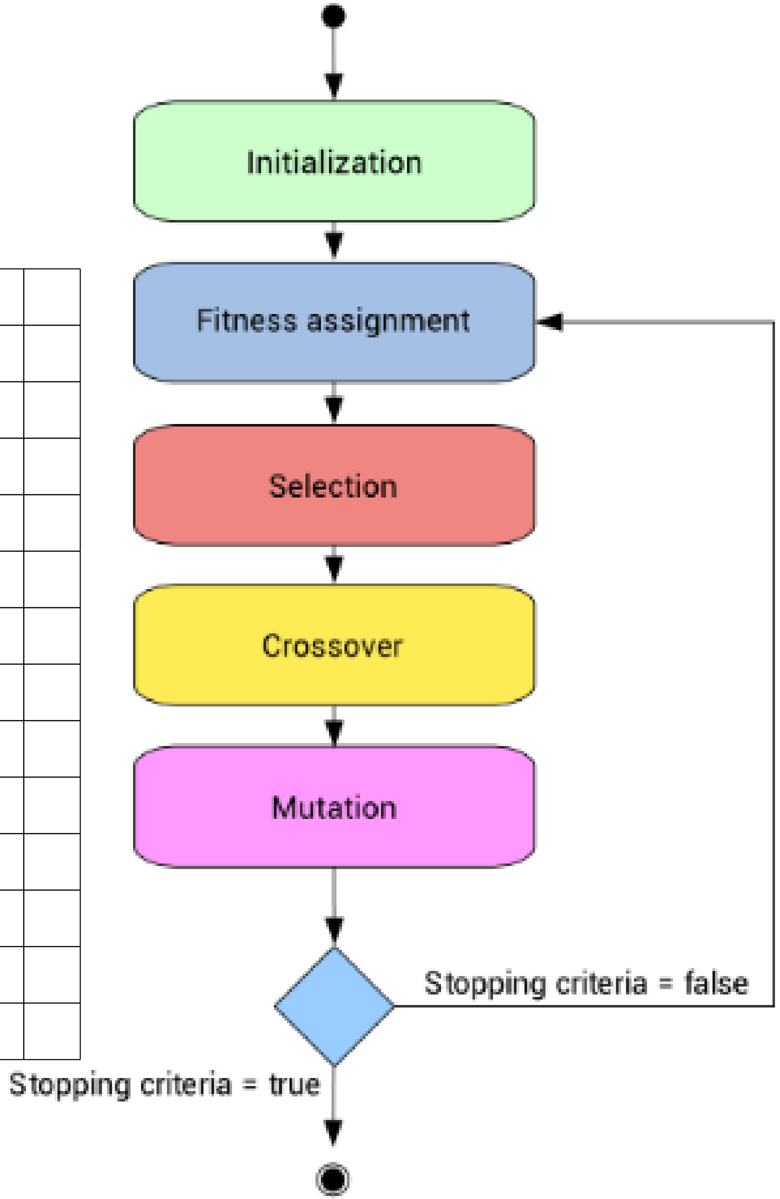


Solve Gomoku: Genetic Algorithm

- Initialization: Coding Scheme
  - Coordinates of consecutive K steps
  - N sequences
  - Representation:
    - $A_2A_1A_7A_3A_8A_5A_6$
    - $A_5A_3A_1A_4A_9A_2A_8$
    - $A_1A_6A_8A_2A_5A_3A_4$
    - $A_2A_9A_3A_4A_7A_8A_6$
    - $A_1A_4A_7A_6A_5A_8A_2$

Both you and the enemy





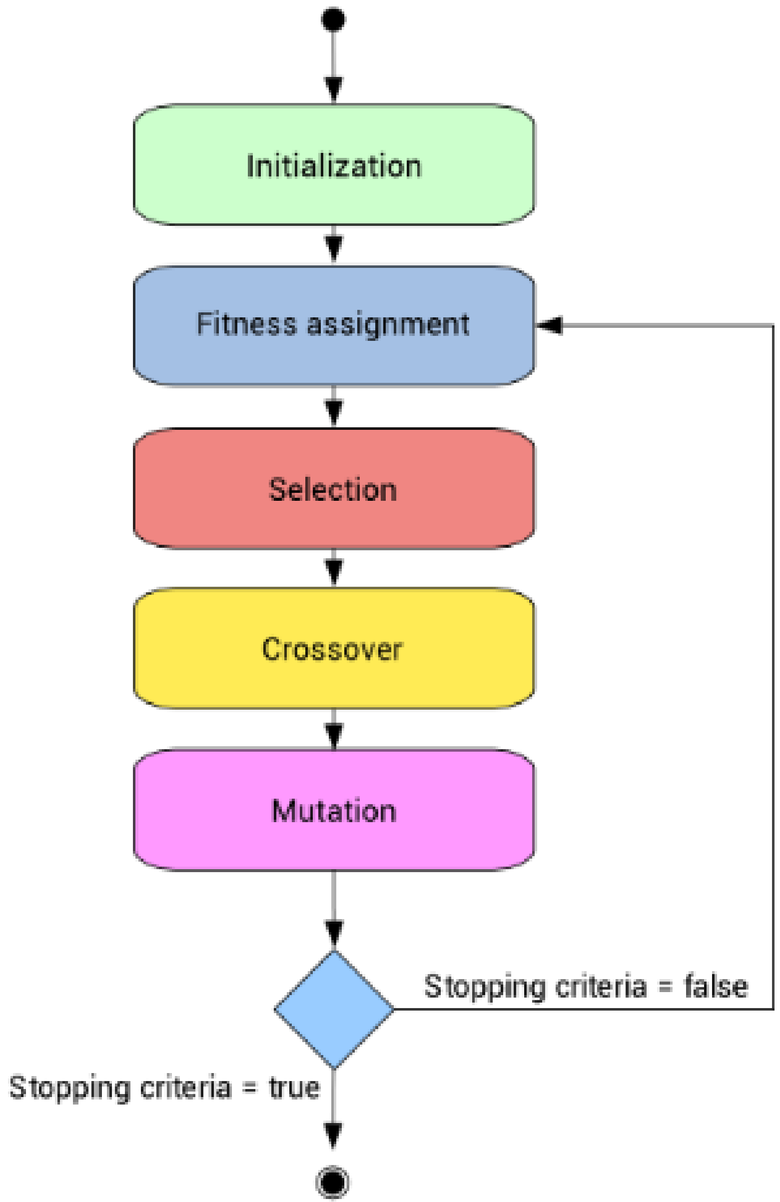
Solve Gomoku: Genetic Algorithm

- Initialization: Coding Scheme
- Fitness assignment
    - Example：

      f(s) = 4800 * (number of four structures in neighborhood)

      + 97 * (number of three structures in neighborhood)

      + 17 * (number of two structures in neighborhood)
- Selection

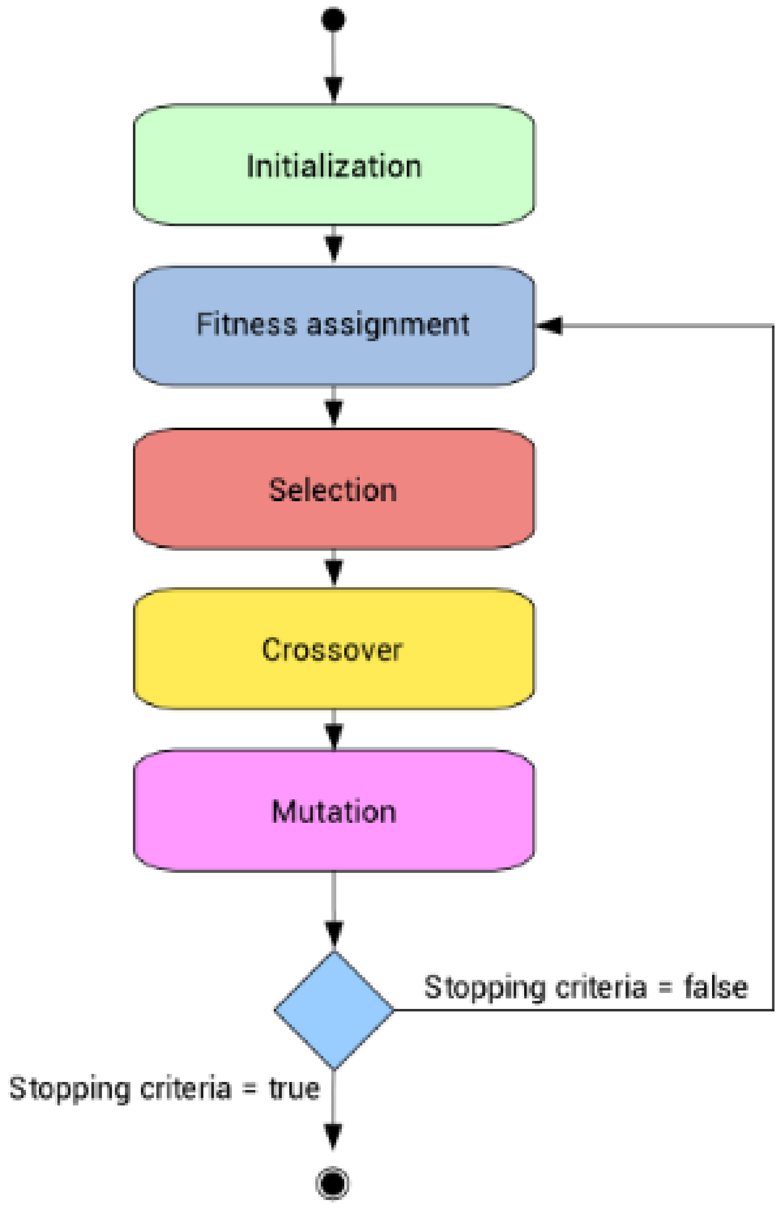


Solve Gomoku: Genetic Algorithm

- Initialization: Coding Scheme
- Fitness assignment
- Selection
- Crossover
  - Parents: $A_2A_1A_7A_3A_8A_5A_6$
    $A_5A_3A_1A_4A_9A_2A_8$
  - Children: $A_2A_1A_7A_3A_9A_2A_8$
    $A_5A_3A_1A_4A_8A_5A_6$
- Mutation

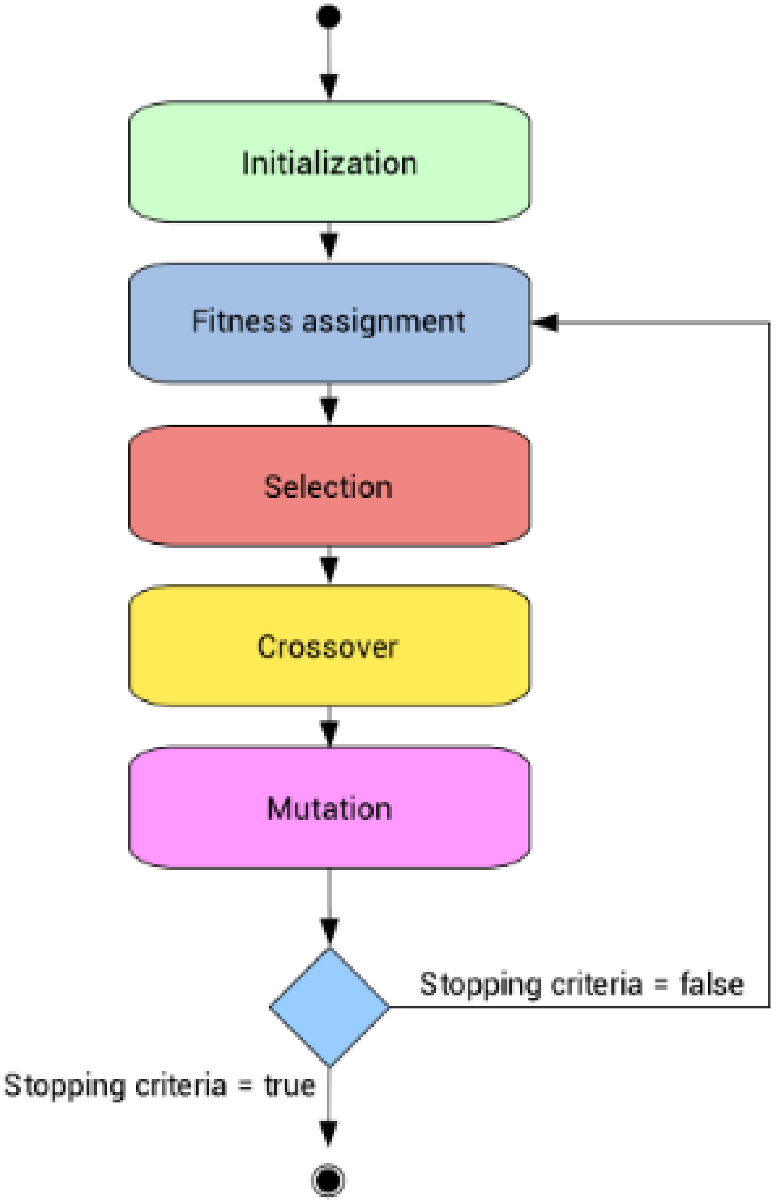
$A_2A_9A_3A_4A_7A_8A_6$

$A_2A_9A_7A_8A_3A_4A_6$



Solve Gomoku: Genetic Algorithm

- Initialization: Coding Scheme
- Fitness assignment
- Selection
- Crossover
- Mutation



Gomoku Competition

- Gomoku manager
  - http://gomocup.org/download-gomocup-manager/
- AI
  - http://gomocup.org/download-gomoku-ai/
- Python Template
  - https://github.com/stranskyjan/pbrain-pyrandom
- Gomocup
  - http://gomocup.org/