

02285 AI and MAS

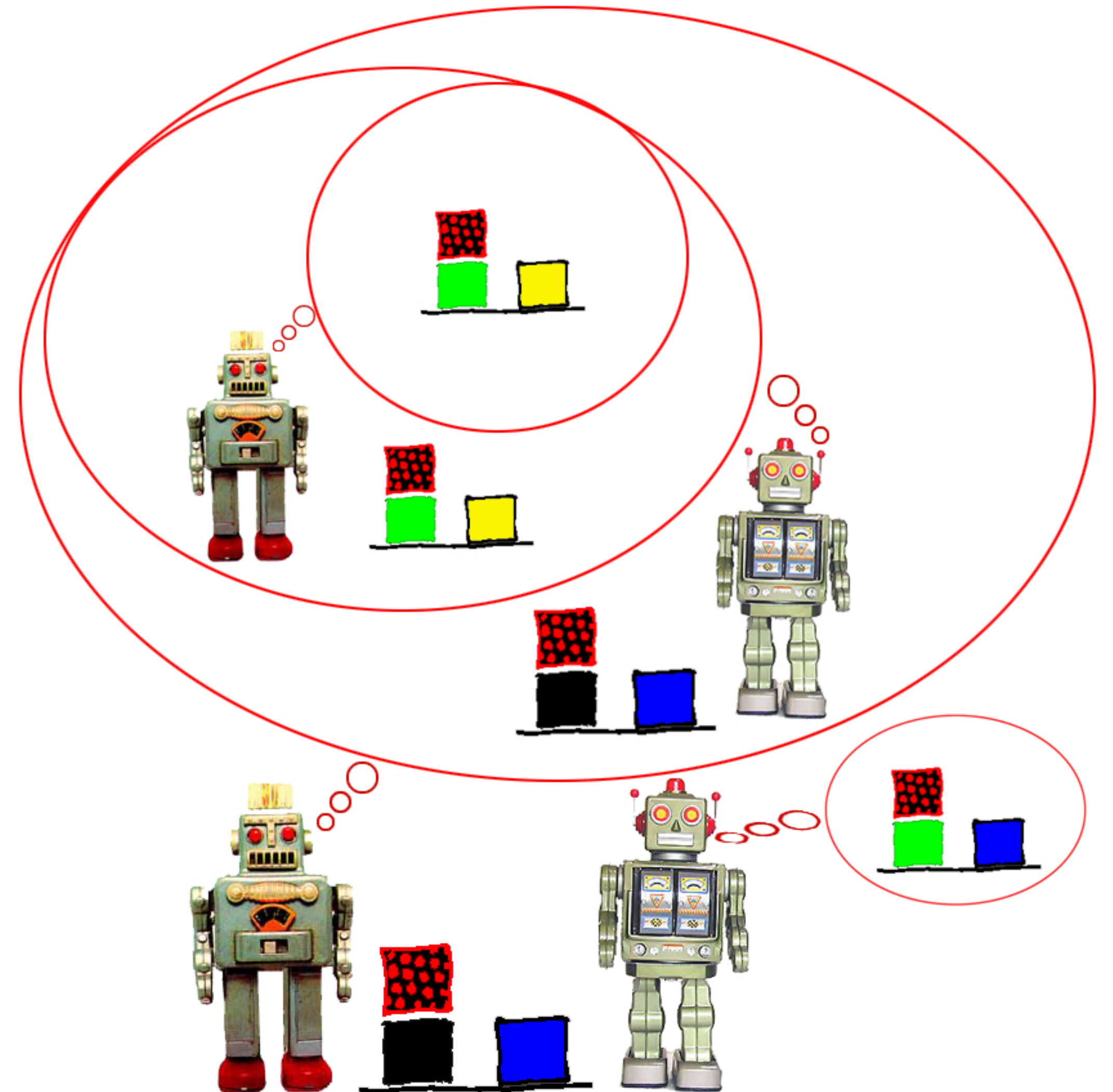
Week 1: Course introduction and AI search basics

About myself



Thomas Bolander

- Associate professor in **logic** and **AI** at **DTU Compute**.
- Current main **research topic**: To equip AI systems with a **Theory of Mind**.
- **Current teaching**:
 - 01017 Discrete Mathematics
 - 02180 Introduction to Artificial Intelligence
 - Artificial Intelligence at DIS.
 - 02285 AI and MAS.

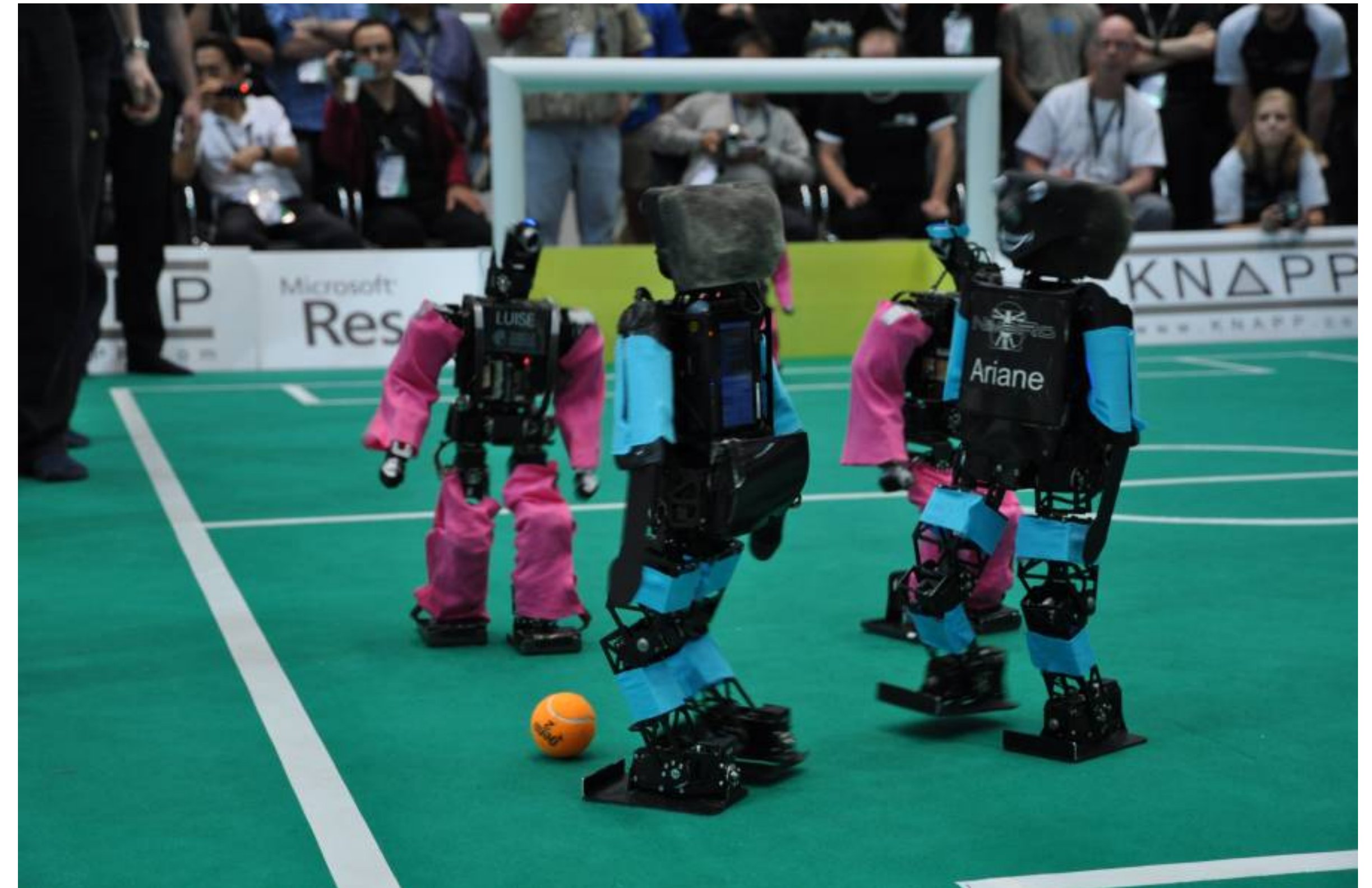


What is AI and MAS?

- **AI (Artificial Intelligence)** is “the science and engineering of making intelligent machines, especially intelligent computer programs” (John McCarthy).
- **Agent:** An autonomous entity which observes and acts upon an environment. It can e.g. be a computer program or a robot, but it can also be a human being. Usually a *goal directed* entity.
- **MAS (Multi-agent System):** A system comprised of multiple interacting agents. These agents are usually required to be autonomous (independent) and to form a decentralised system (no controlling agent).

MAS examples

- Groups of **hospital robots** working in a shared environment.
- Agents for retrieving information on the **Web**.
- Teams of **soccer-playing robots**.



RoboCup 2009

General course information

The course consists of two parts of approximately equal length and workload:

- *First half:* **Lectures, exercise classes** and **2 mandatory group assignments** (2-3 students per group).
Approximately 3.75 ECTS.
- *Second half:* **Mandatory programming project.**
Approximately 3.75 ECTS. In groups of 3-5 students.
Implementation (in programming language of your choice) and report. Concluded by a competition.

Demo of programming project

Assessment

The assessment is based exclusively on the written work, that is, the **3 mandatory assignments**. These are evaluated as a whole.

- **Assignment 1:** Groups of 2-3. Counts approximately 10%.
- **Assignment 2:** Groups of 2-3. Counts approximately 15%.
- **Assignment 3 (programming project):** Groups of 3-5. Counts approximately 75%. Assessment based on group report and detailed group declaration (who did what).

Course material

- **Main textbook** is Russell & Norvig: *Artificial Intelligence—A Modern Approach*, 3ed, 2010.
- **Supplementary chapters on MAS** from other books (will be made available through file sharing).
- **Supplementary chapters on planning** from Geffner & Bonet: *A Concise Introduction to Models and Methods for Automated Planning*. Link to e-book from CampusNet welcome page.

About the Russell & Norvig textbook

Advantages:

- **The** standard textbook in AI.
- Covers very **broadly**: most major areas of AI.
- Rich in **examples**.
- Most people find it **inspiring** to read.

Disadvantages:

- Many details are **left implicit**, so things might seem deceptively simple.
Read carefully.
- **Lack of technical details** and sometimes also **lack of mathematical precision** can make it more difficult to reach a deep understanding and be able to implement ideas and techniques.
- Some areas are **missing** (e.g. multi-agent systems) or **not completely up-to-date** (e.g. automated planning).

About the course curriculum

- The course deliberately prioritises **depth over breadth**.
- Major subjects covered: **automated planning** and **multi-agent systems**.
- Subjects are chosen according to **relevance for the programming project**. This means that everything covered in the course is relevant for the programming project, but not that everything covered can necessarily be *directly* applied in project.
- **Course goal**: To bridge academic AI research (often generic, domain-independent) with implementing a concrete AI system (domain-specific).
- **Trade-off** between generality and specificity in AI: computational efficiency, academic relevance, elegance, relevance for other applications, extendability, generalisability.

Other AI-relevant courses at DTU (and their relation to the Russell and Norvig textbook)

- **Advanced search methodologies** (Ch. 3-4 of R&N)
 - 02282 Algorithms for Massive Data Sets
 - 42137 Optimization Using Metaheuristics
- **Operations Research (OR)** (Ch. 4, 6 of R&N)
 - 42101 Introduction to Operations Research
 - 42114 Integer Programming
 - 42139 The Set Partitioning Optimization Model and its Application in Practical Scheduling Problems
 - 42142 Recent Research Results in Operations Research
- **Advanced logical methods in AI** (Ch. 7-9 in R&N)
 - 02156 Logical Systems and Logic Programming
 - 02281 Data Logic
 - 02287 Logical Theories for Uncertainty and Learning

Other AI-relevant courses at DTU

- **Knowledge-based reasoning** (Ch. 12 of R&N)
 - 02284 Knowledge-based Systems
- **Probabilistic reasoning and learning** (Ch. 13-21 of R&N)
 - 02417 Time Series Analysis
 - 02450 Introduction to Machine Learning and Data Modeling (general intro)
 - 02457 Non-Linear Signal Processing
 - 02460 Advanced Machine Learning
 - 02582 Computational Data Analysis
 - 02456 Deep learning
 - 02287 Logical Theories for Uncertainty and Learning
- **Natural language processing** (Ch. 21-22 of R&N)
 - 02281 Data Logic
 - 02456 Deep Learning (some)

Other AI-relevant courses at DTU

- **Image processing** (Ch. 24 of R&N)
 - 02502 Image Analysis
 - 02506 Advanced Image Analysis
 - 02504 Computer Vision
- **Robotics** (Ch. 25 of R&N)
 - 31380 Intelligent Systems
 - 31385 Autonomous Robot Systems
 - 31388 Advanced Autonomous Robots
 - 31389 Advanced Topics in Robotics and Autonomous Systems

It is a **master course**...

- Some exercises and assignments are more free and open-ended than in standard bachelor courses.
- Some exercise descriptions are less spelled out, requiring more from the reader.
- The course requires both high mathematical maturity and solid programming experience.
- You are expected to be able to independently search for relevant/additional literature.
- You are expected to independently be able to manage your time (in particular **extremely important** in the programming project).

Today's subject:

AI search basics

Essentially supposed to be repetition from
02180 Introduction to Artificial Intelligence.

GRAPH-SEARCH algorithm

Based on Figure 3.7 of Russell & Norvig

function GRAPH-SEARCH (*problem*) **returns** a solution, or failure

exploredNodes := \emptyset

initialize the frontier to be the initial state of the *problem*

loop do

if frontier is empty **then return** failure

***choose a leaf node** n* (that is, a node from the frontier)

 remove n from frontier

if n is a goal state **then return** solution

 exploredNodes := exploredNodes \cup { n }

 expand the node n (that is, compute its children)

for each child m of n

if m is not in frontier **and** $m \notin$ exploredNodes **then**

add child** m **to frontier

GRAPH-SEARCH in Java

SearchClient.java in code of Assignment 1

```
strategy.addToFrontier( this.initialState );
[...]  
while ( true ) {  
    [...]  
    if ( strategy.frontierIsEmpty() ) {  
        return null;  
    }  
  
    Node leafNode = strategy.getAndRemoveLeaf();  
  
    if ( leafNode.isGoalState() ) {  
        return leafNode.extractPlan();  
    }  
  
    strategy.addToExplored( leafNode );  
    for ( Node n : leafNode.getExpandedNodes() ) {  
        if ( !strategy.isExplored( n ) && !strategy.inFrontier( n ) ) {  
            strategy.addToFrontier( n );  
        }  
    }  
    [...]
```

Different (uninformed) search strategies with GRAPH-SEARCH

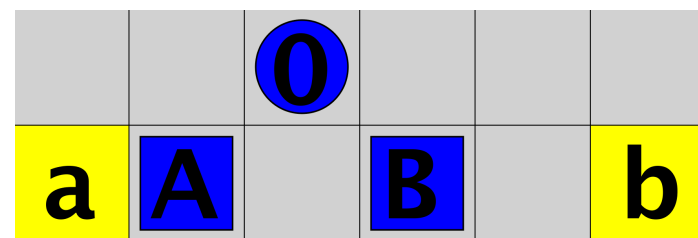
Different search strategies can be achieved by simply changing how **choose leaf node** and **add child to frontier** work.

- **Breadth-First Search (BFS):**
 - Frontier is a **queue** (FIFO).
 - **Choose leaf node**: dequeue node from frontier.
 - **Add child to frontier**: enqueue node to frontier.
- **Depth-First Search (DFS):**
 - Frontier is a **stack** (LIFO).
 - **Choose leaf node**: pop node from frontier.
 - **Add child to frontier**: push node to frontier.

BFS example (Sokoban rules = only pushing)

Order: W, S, N, E

S₁

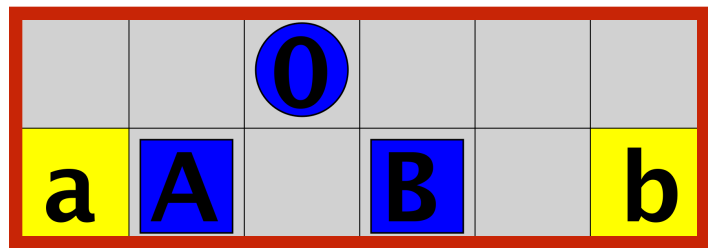


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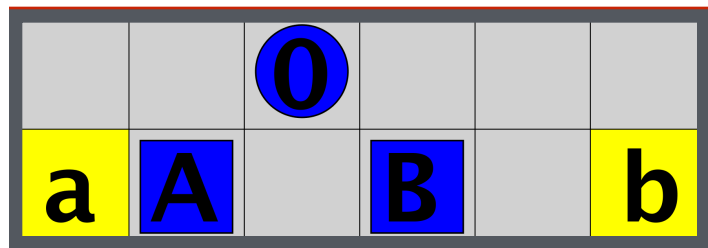


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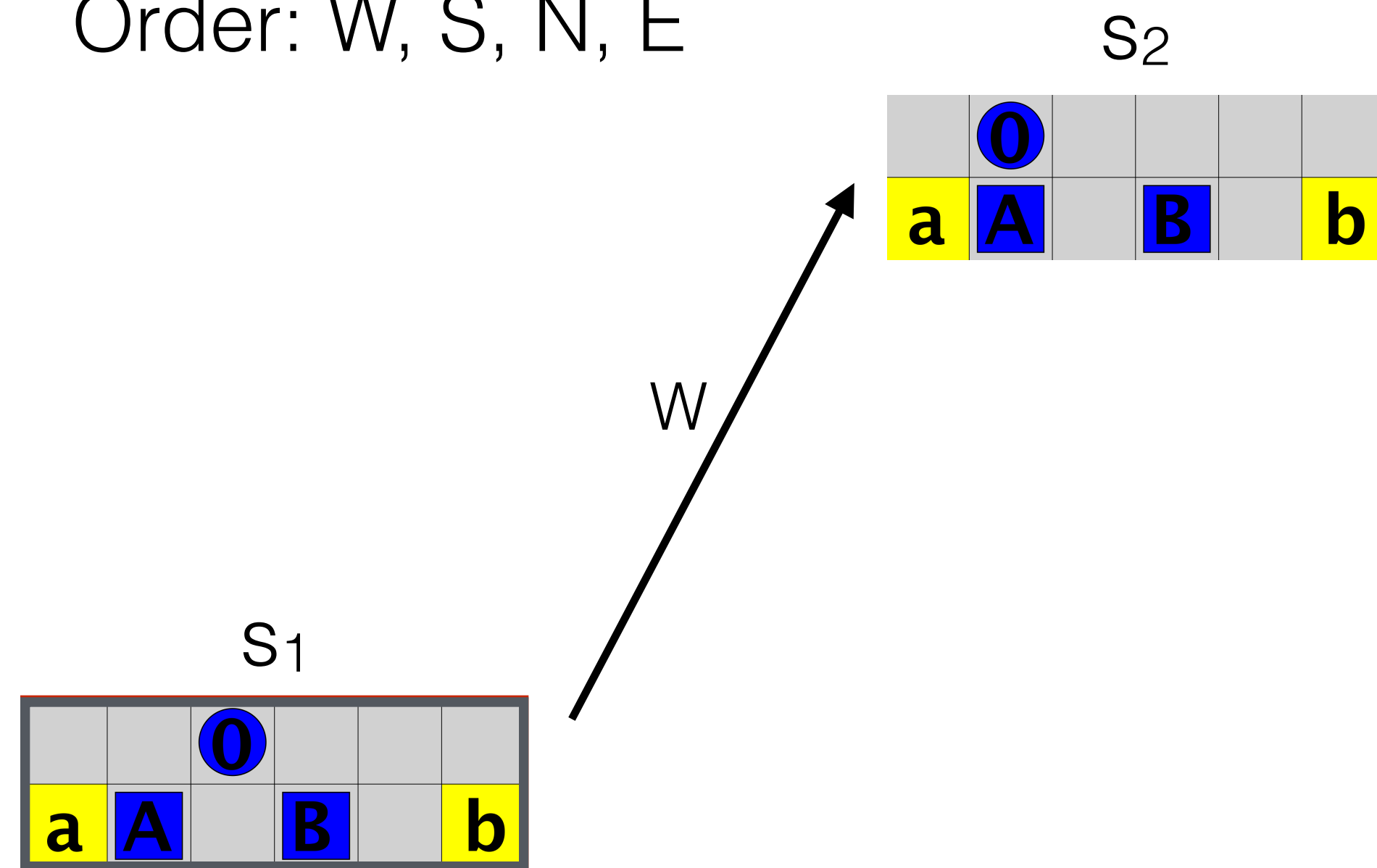
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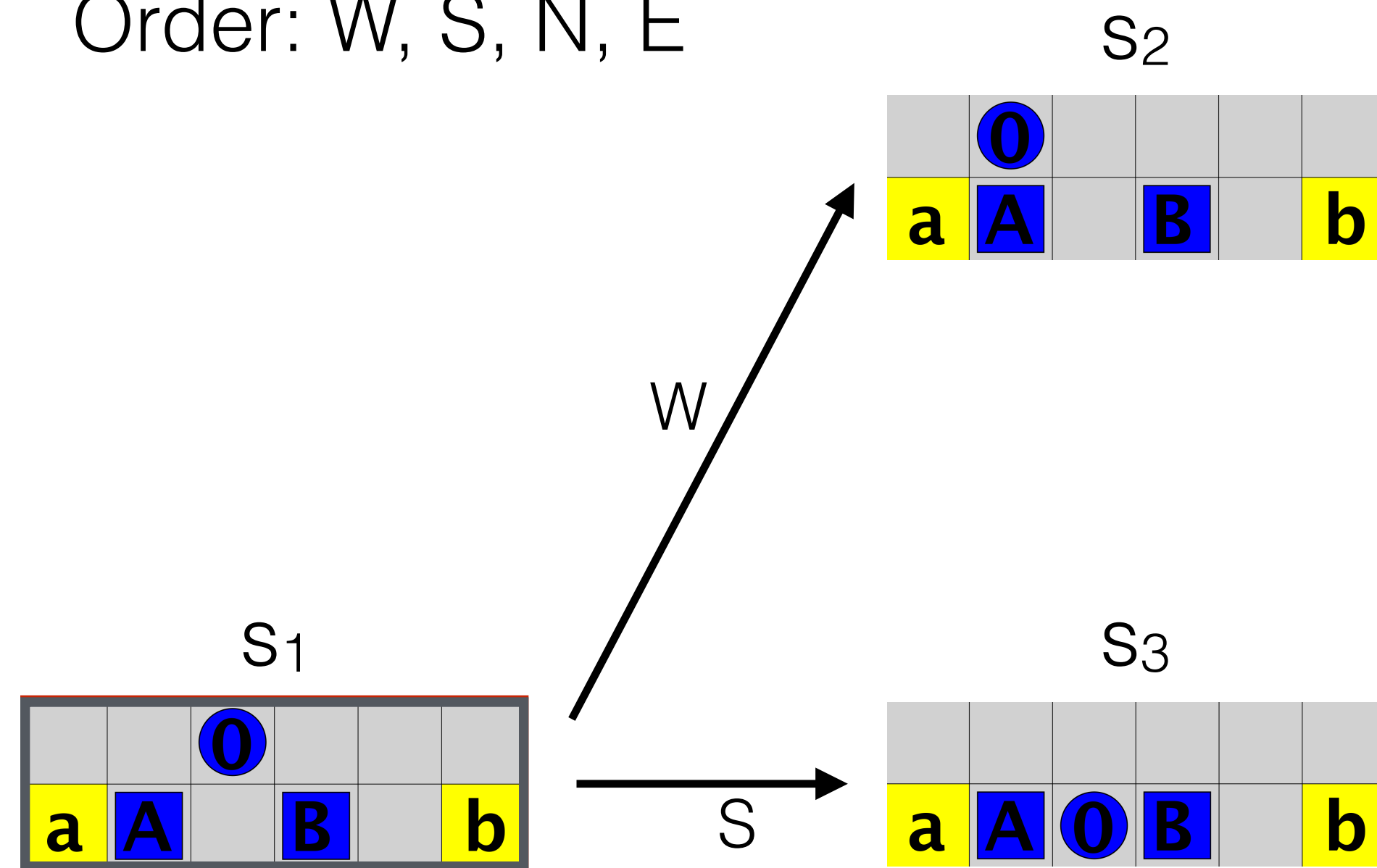
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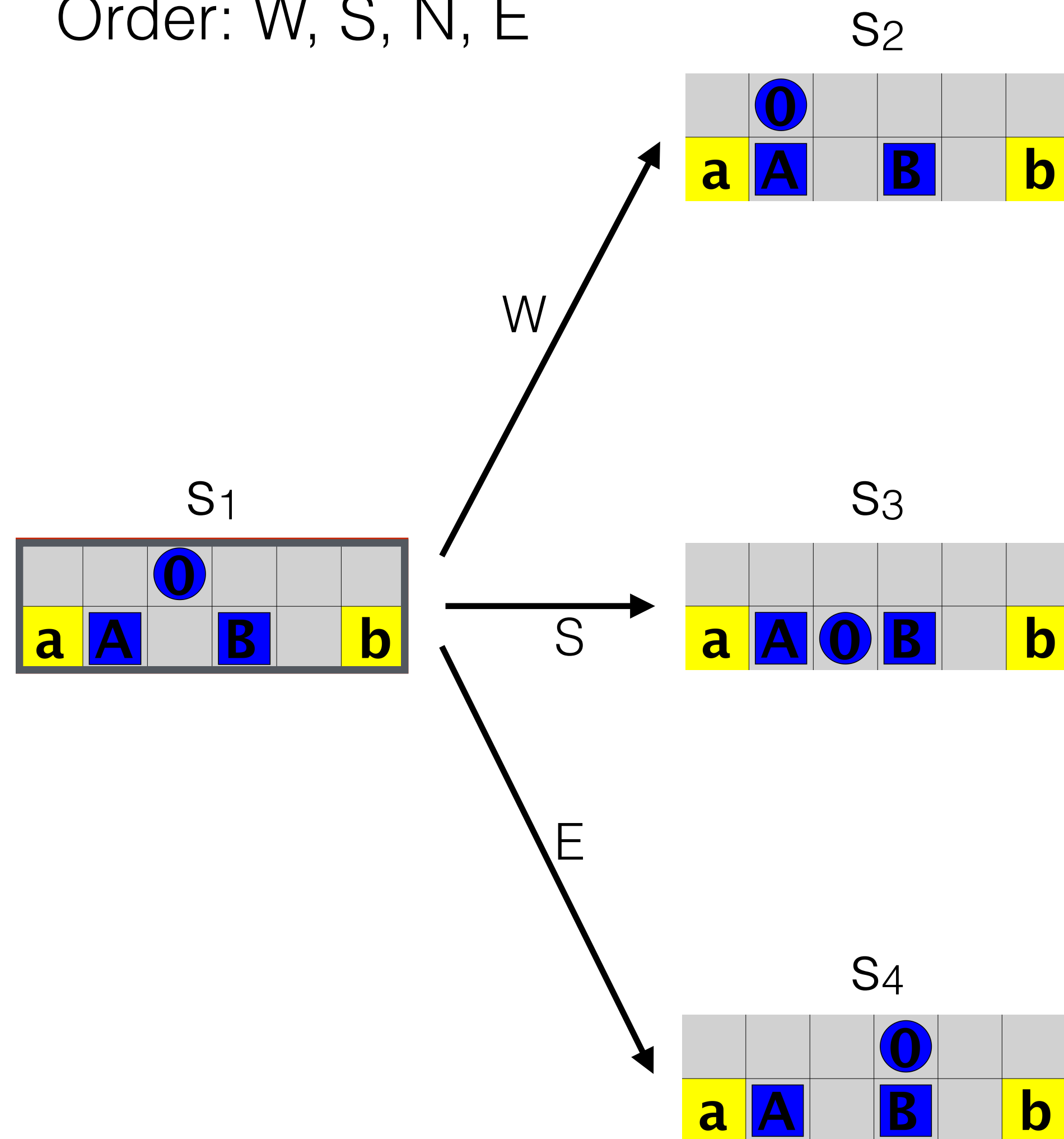
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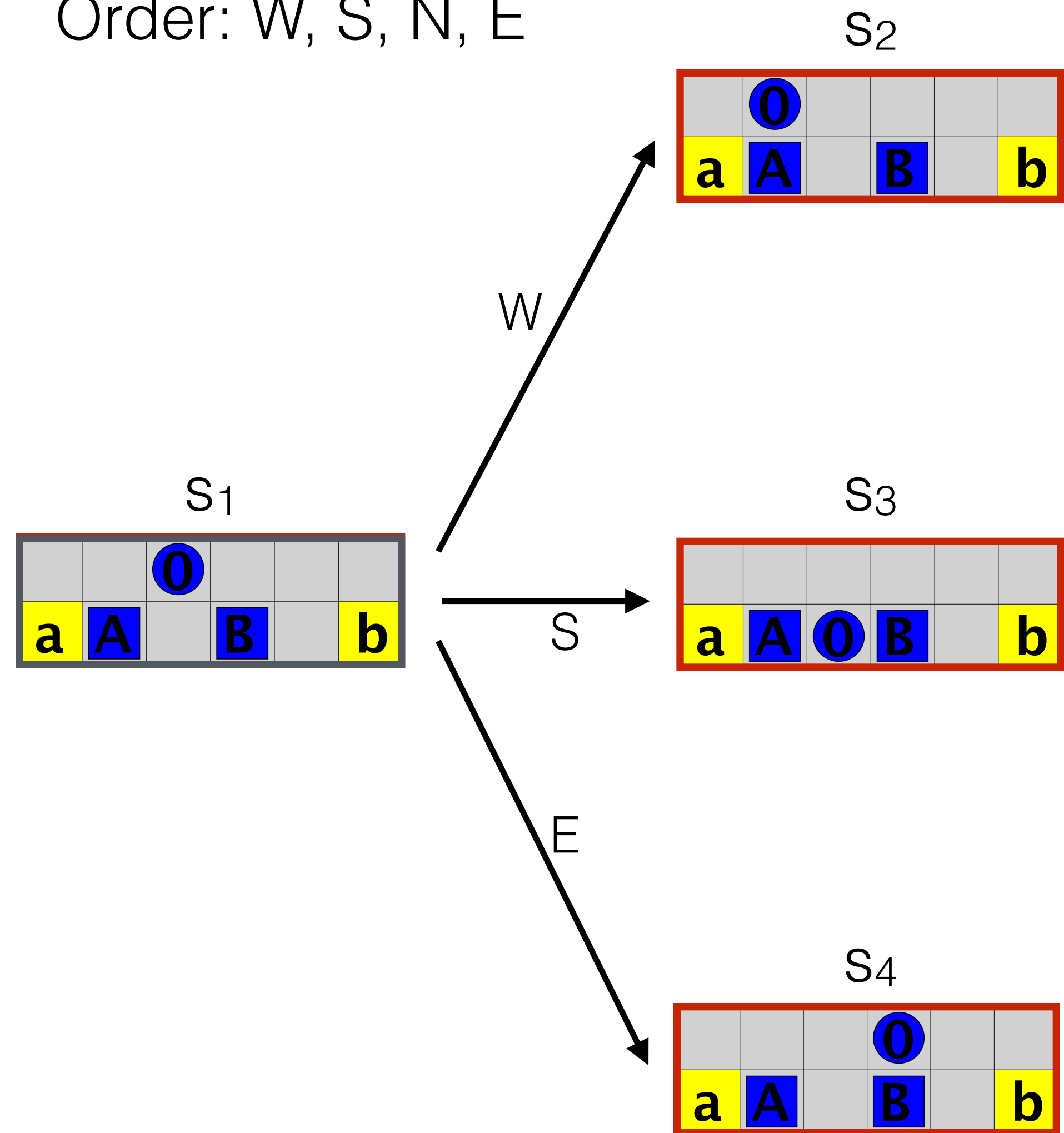
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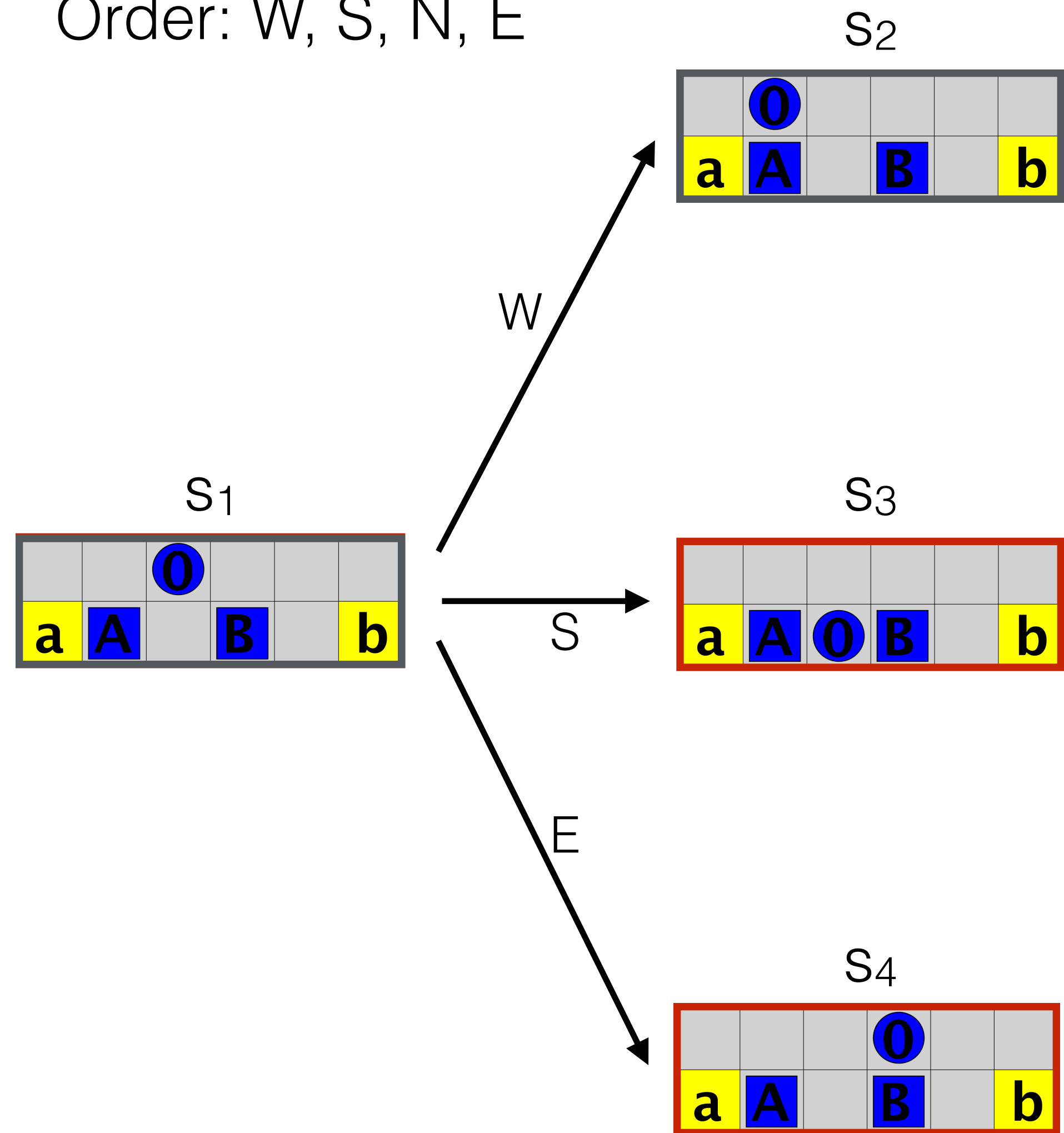
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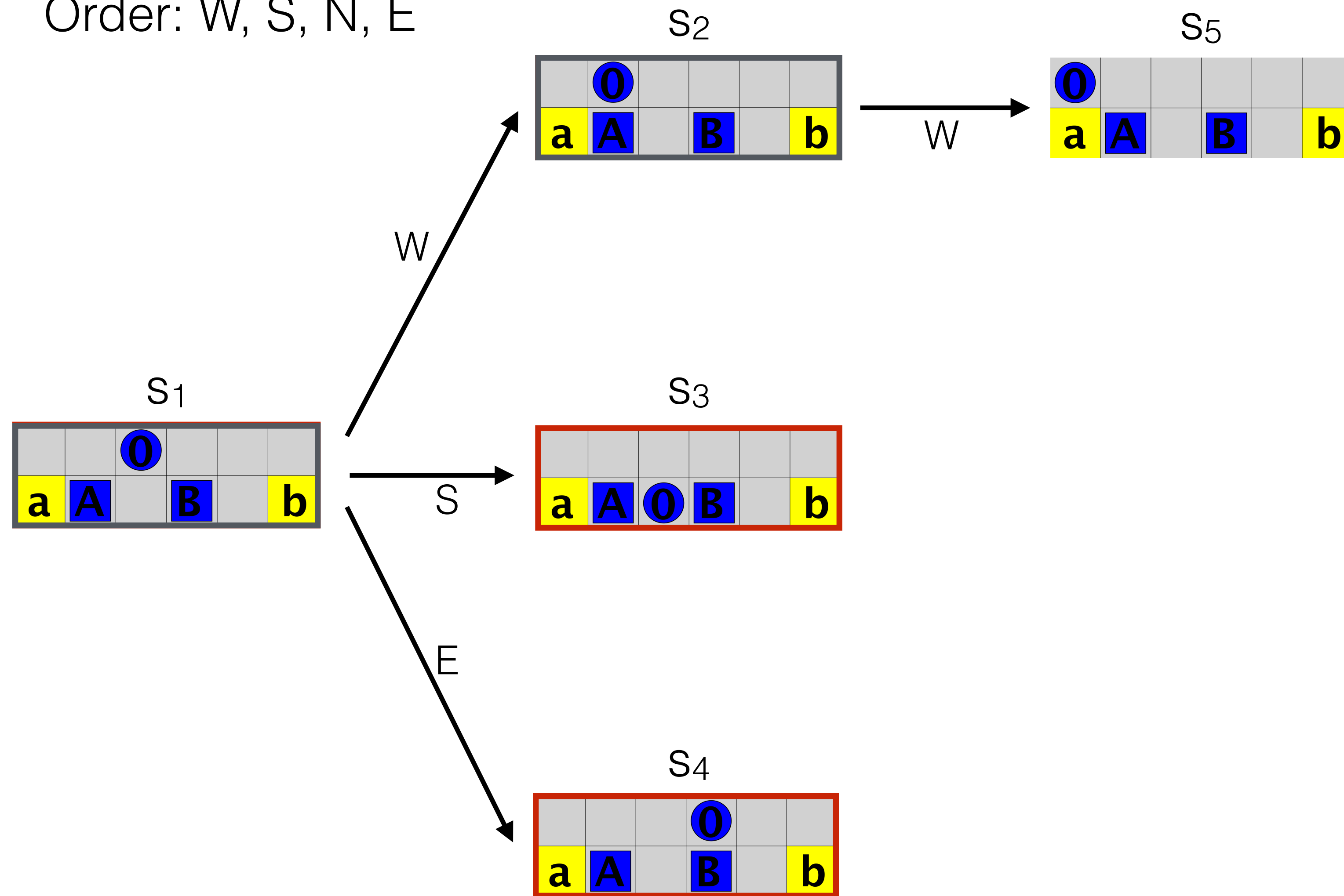
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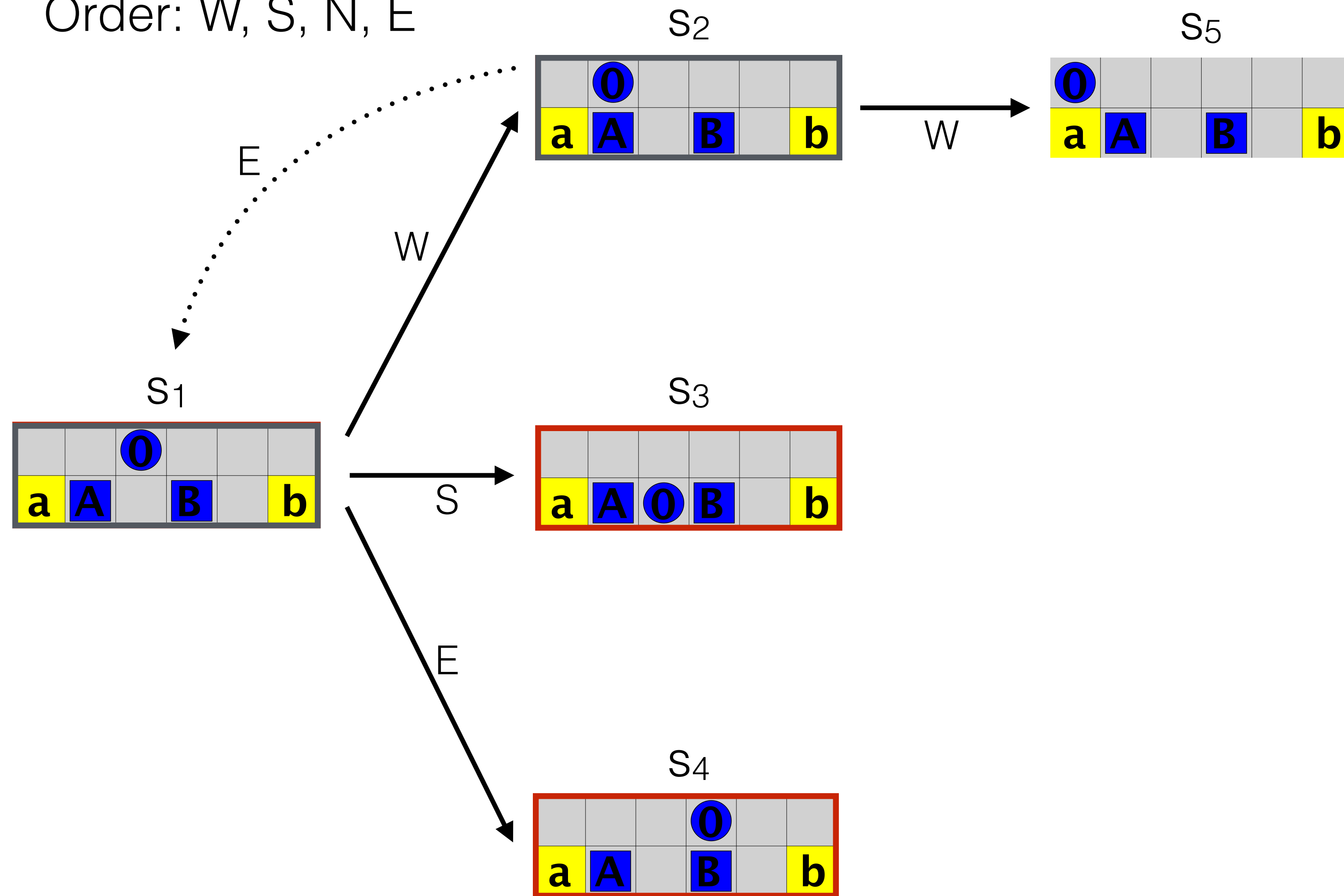
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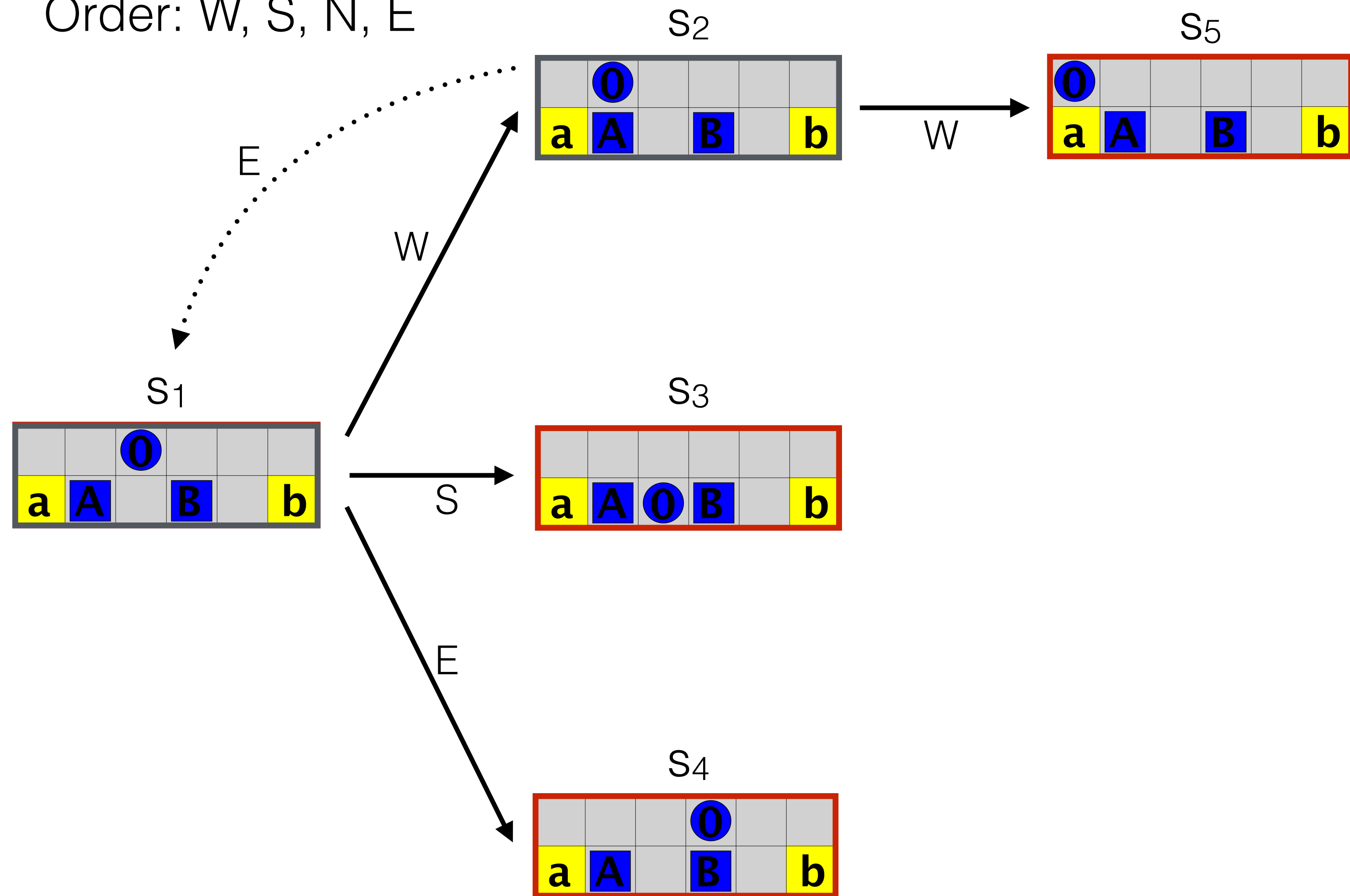
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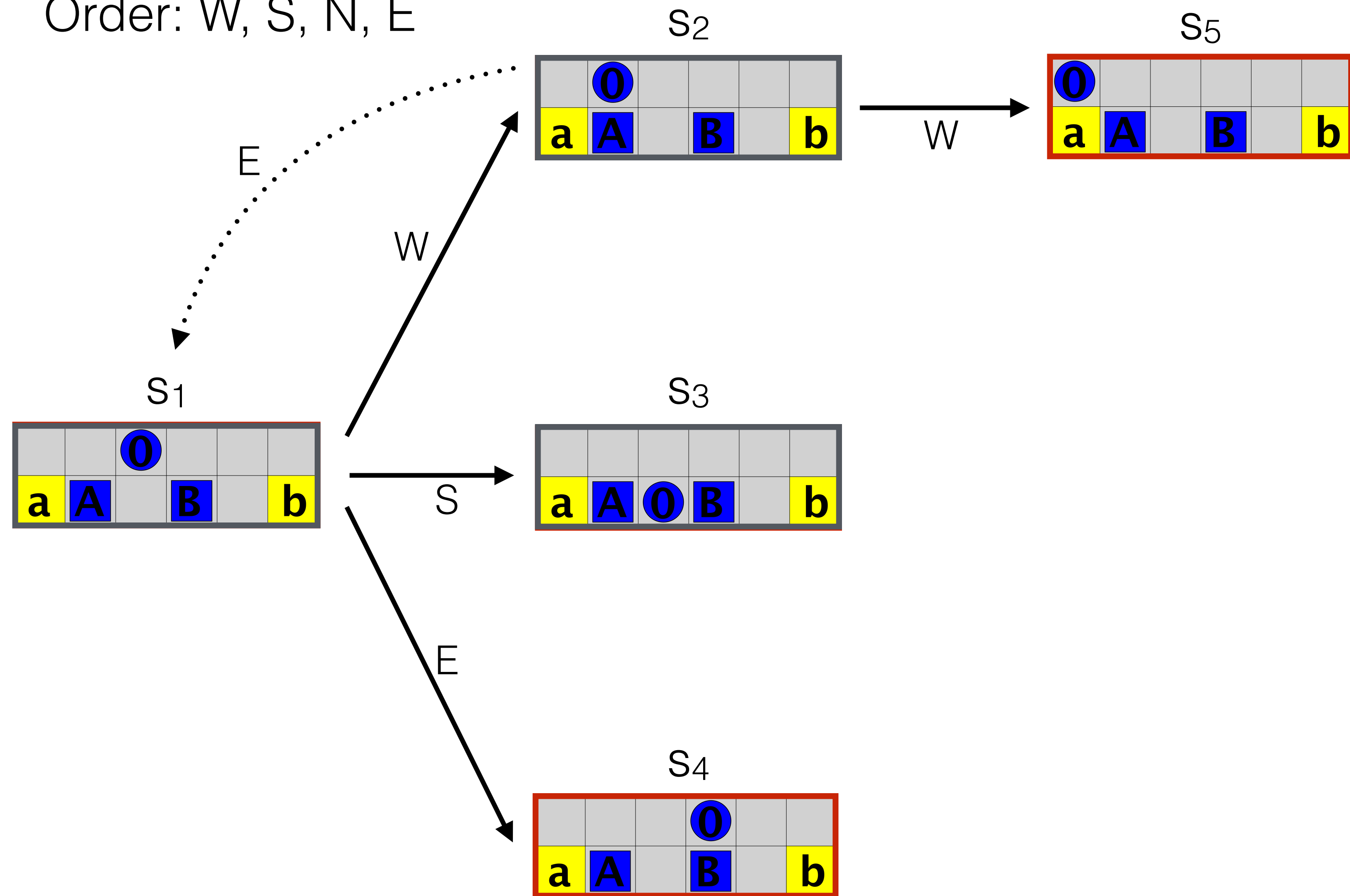
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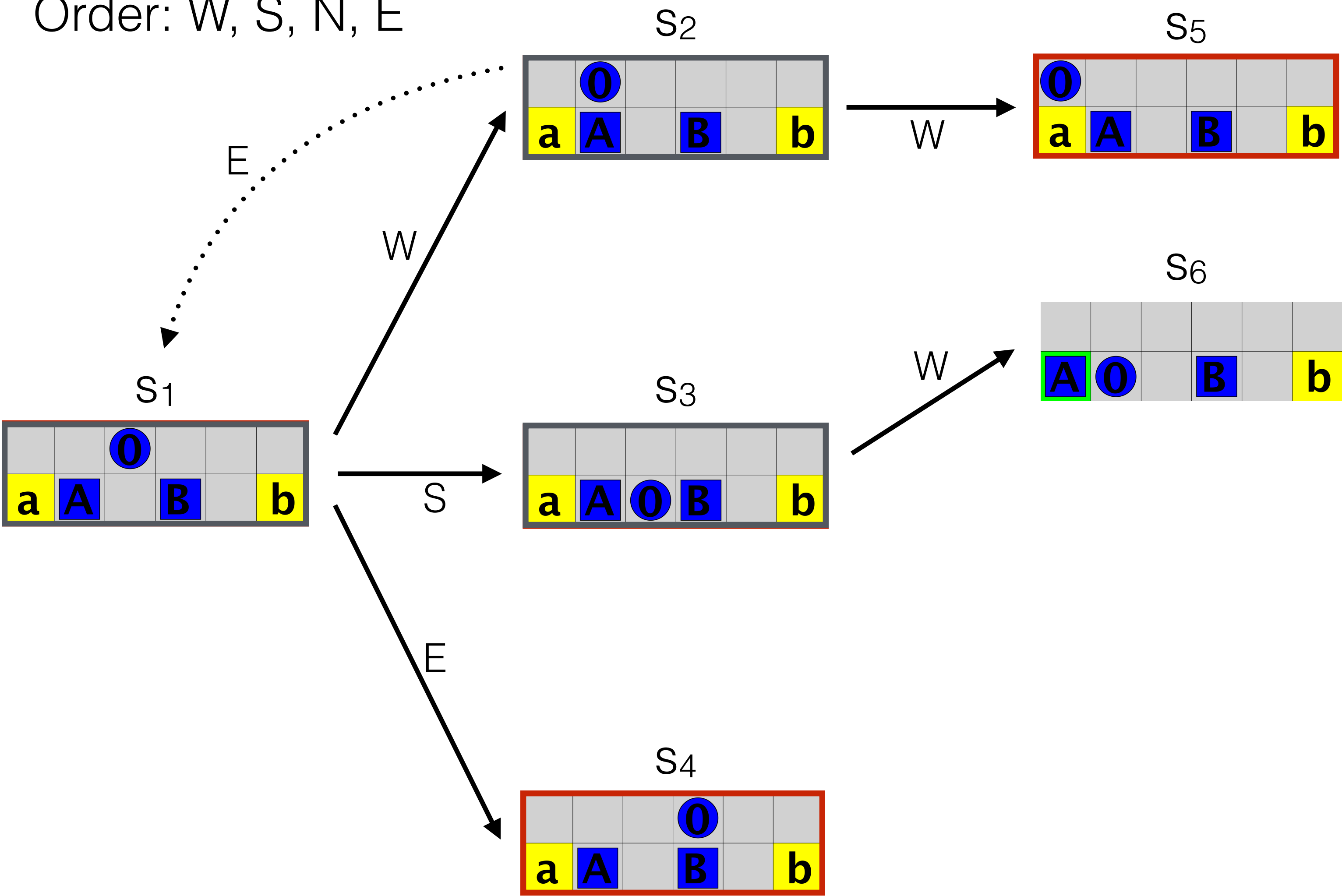
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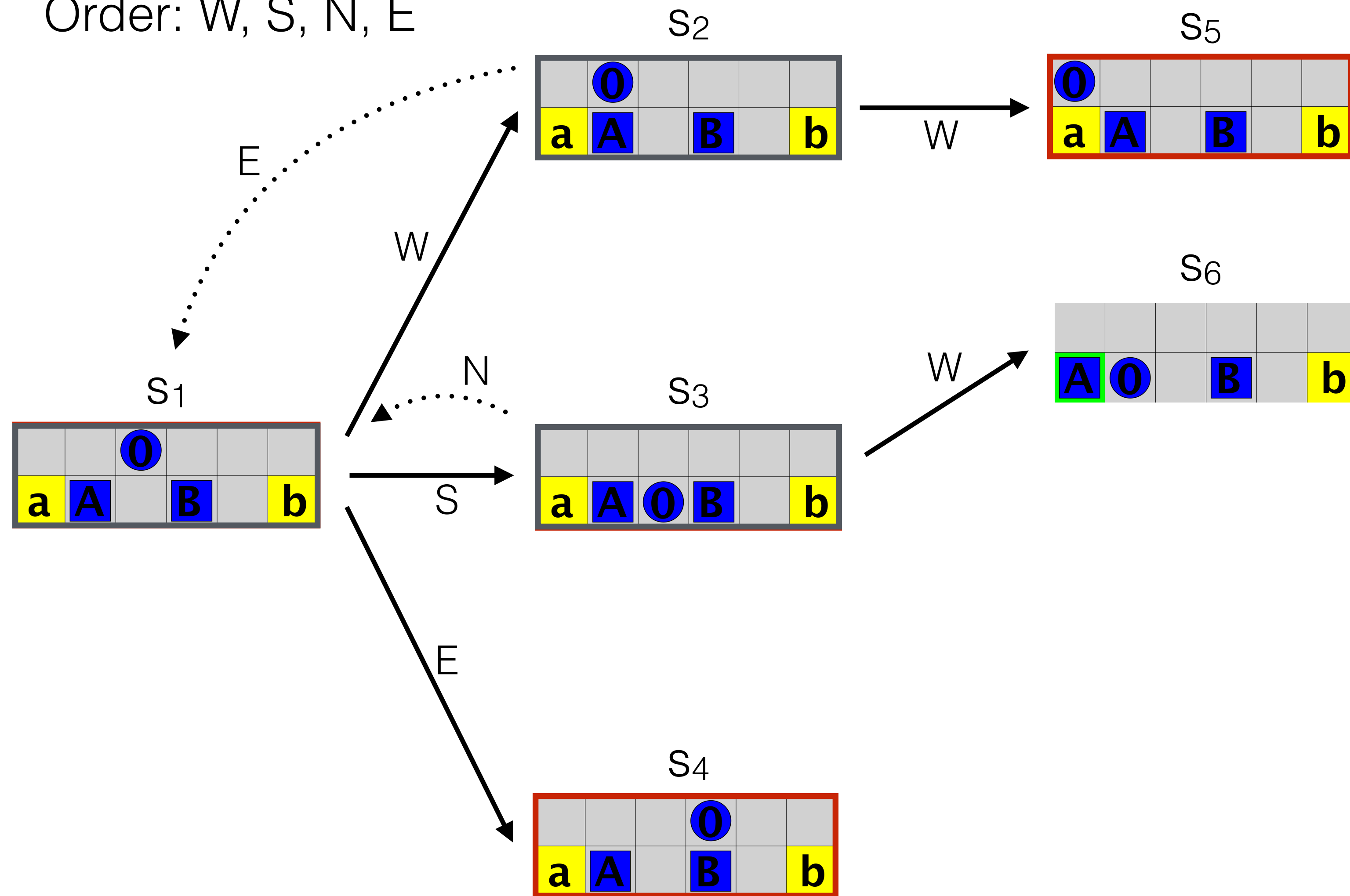
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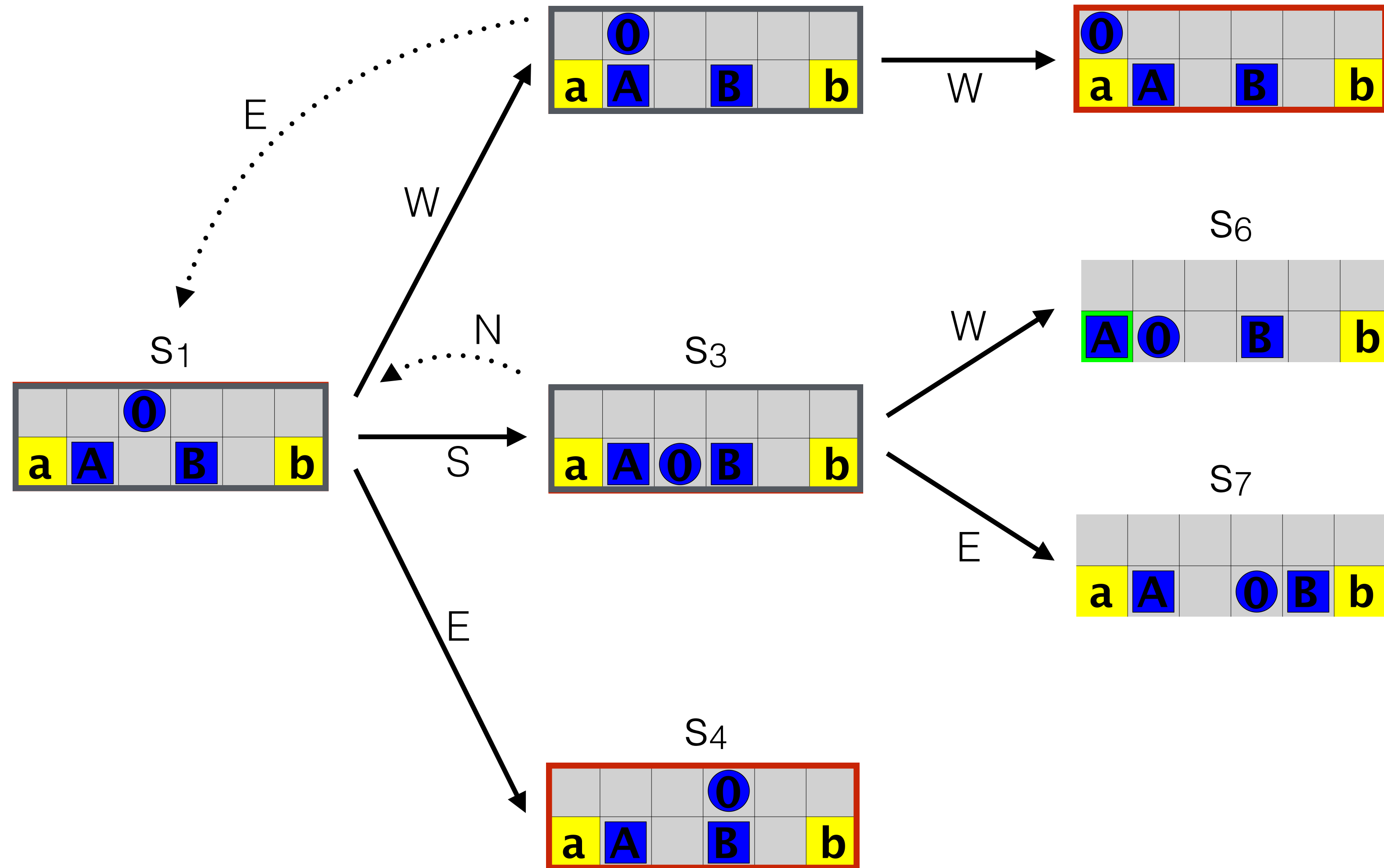
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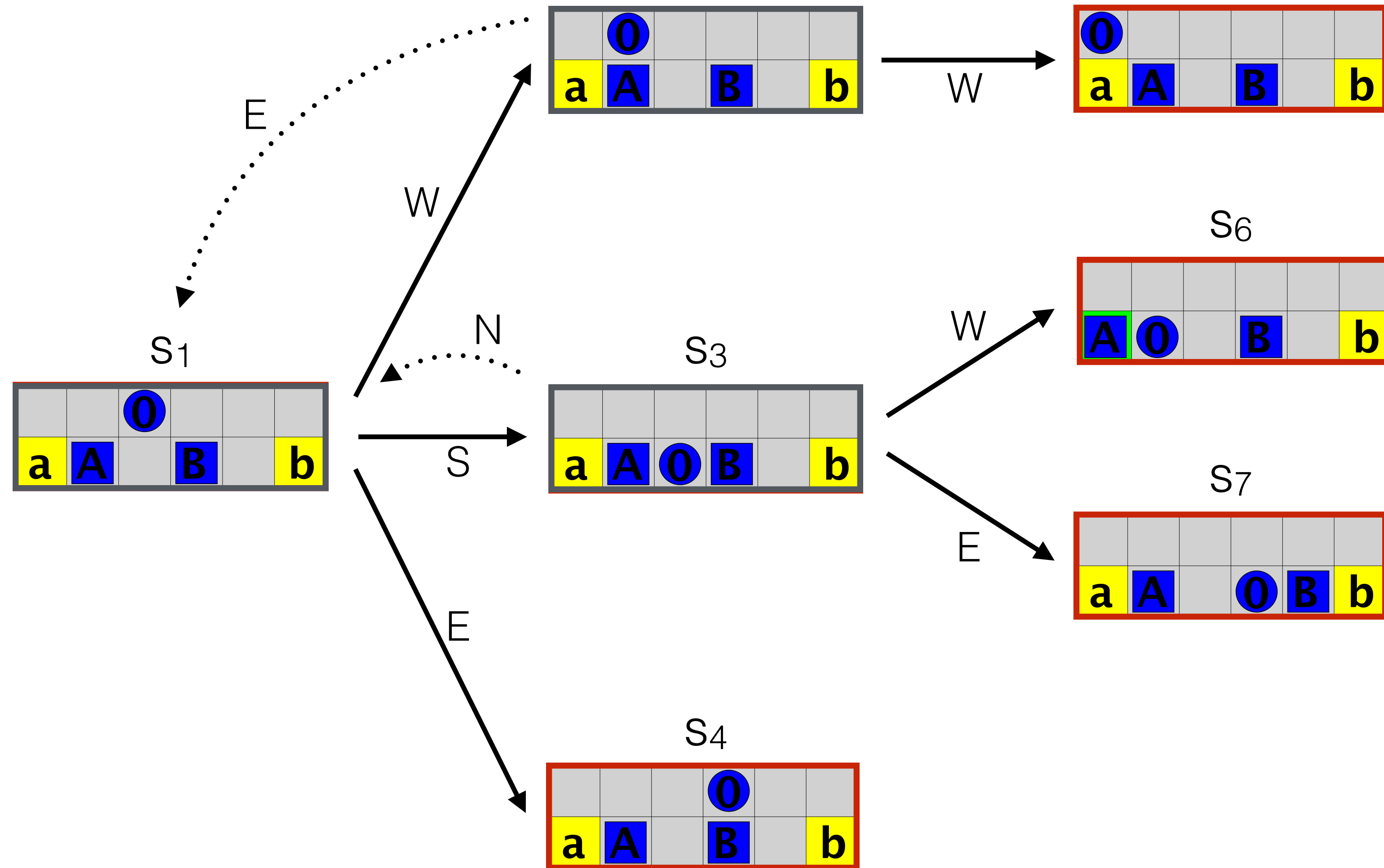
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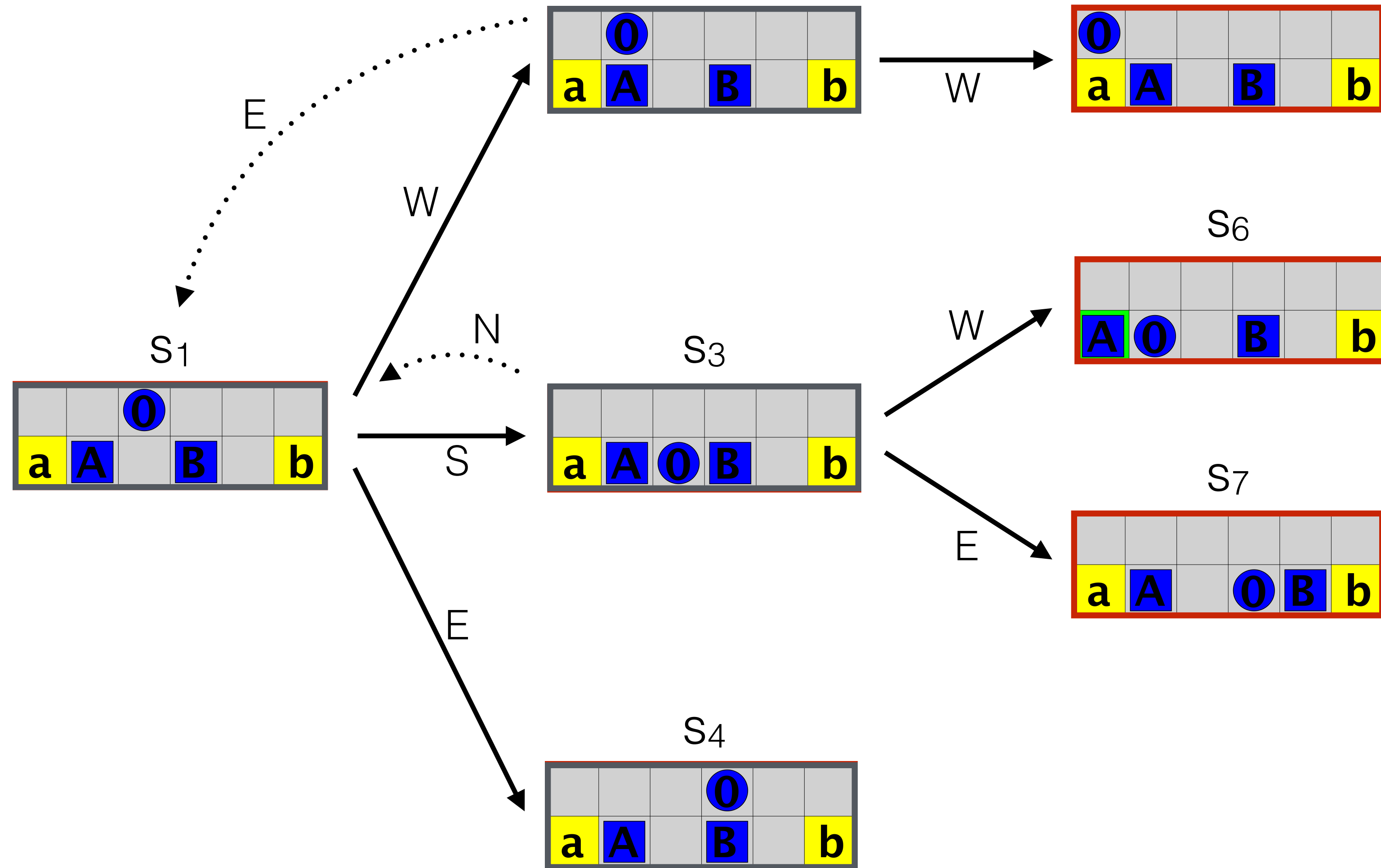
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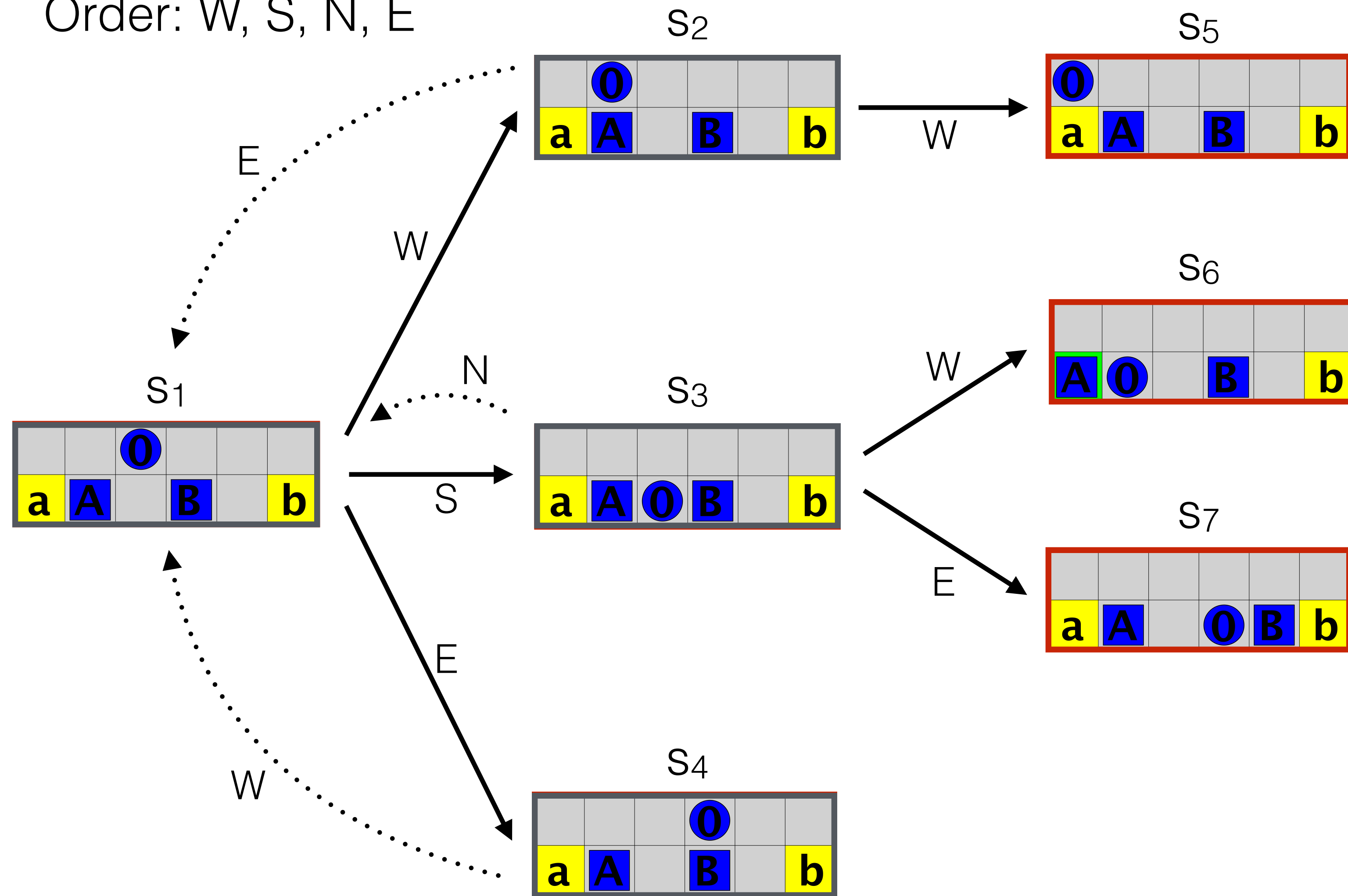
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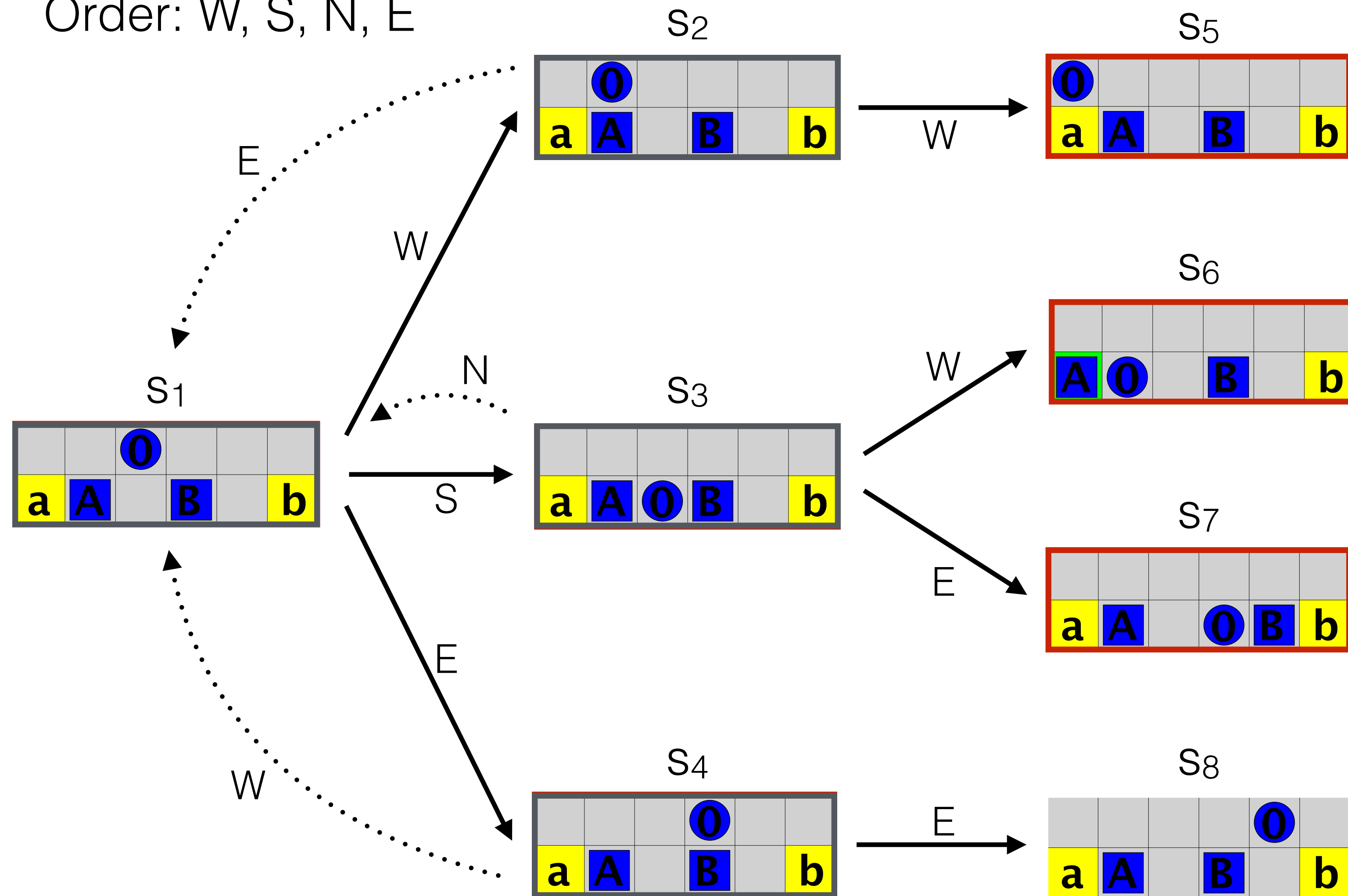
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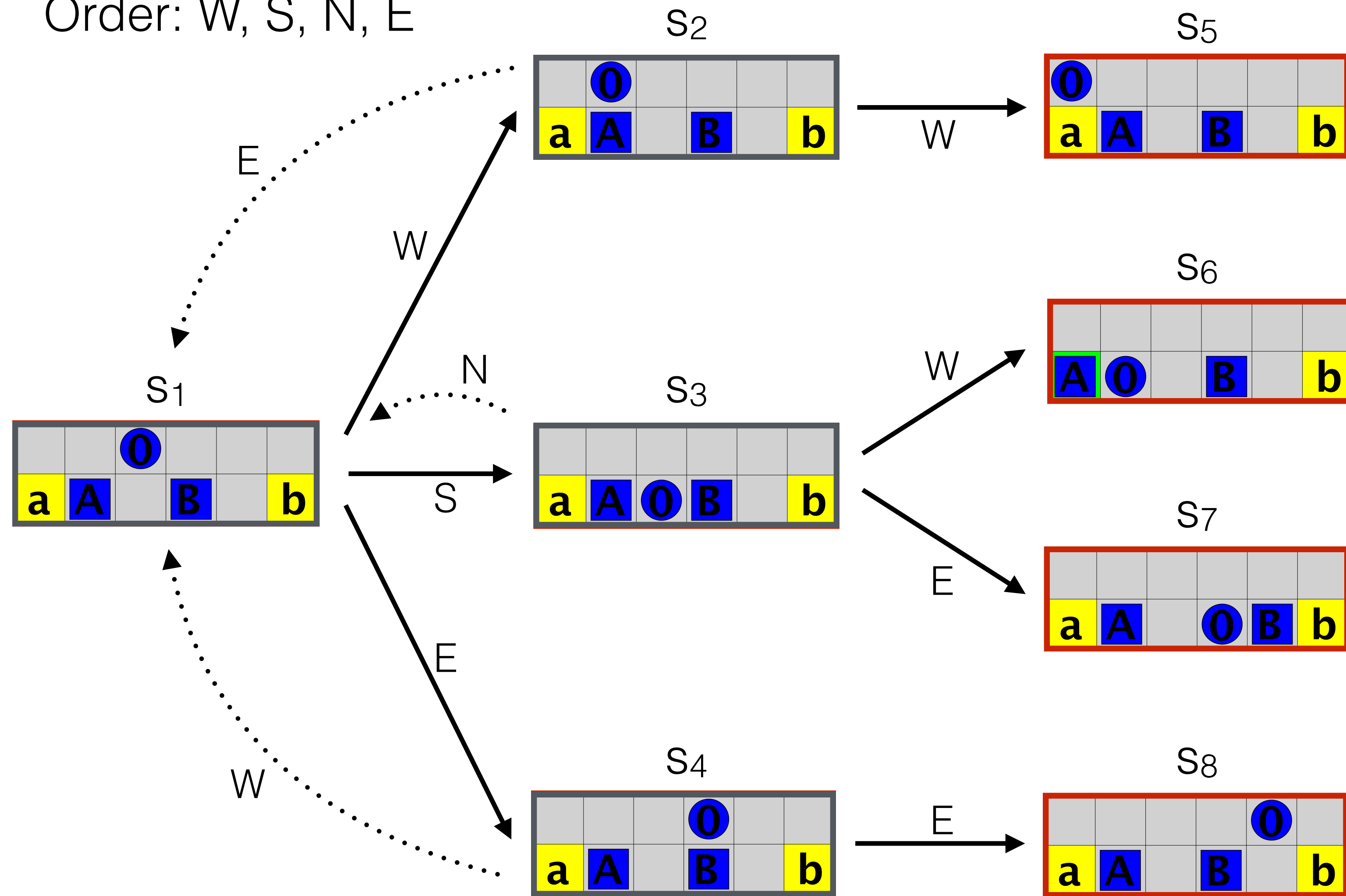
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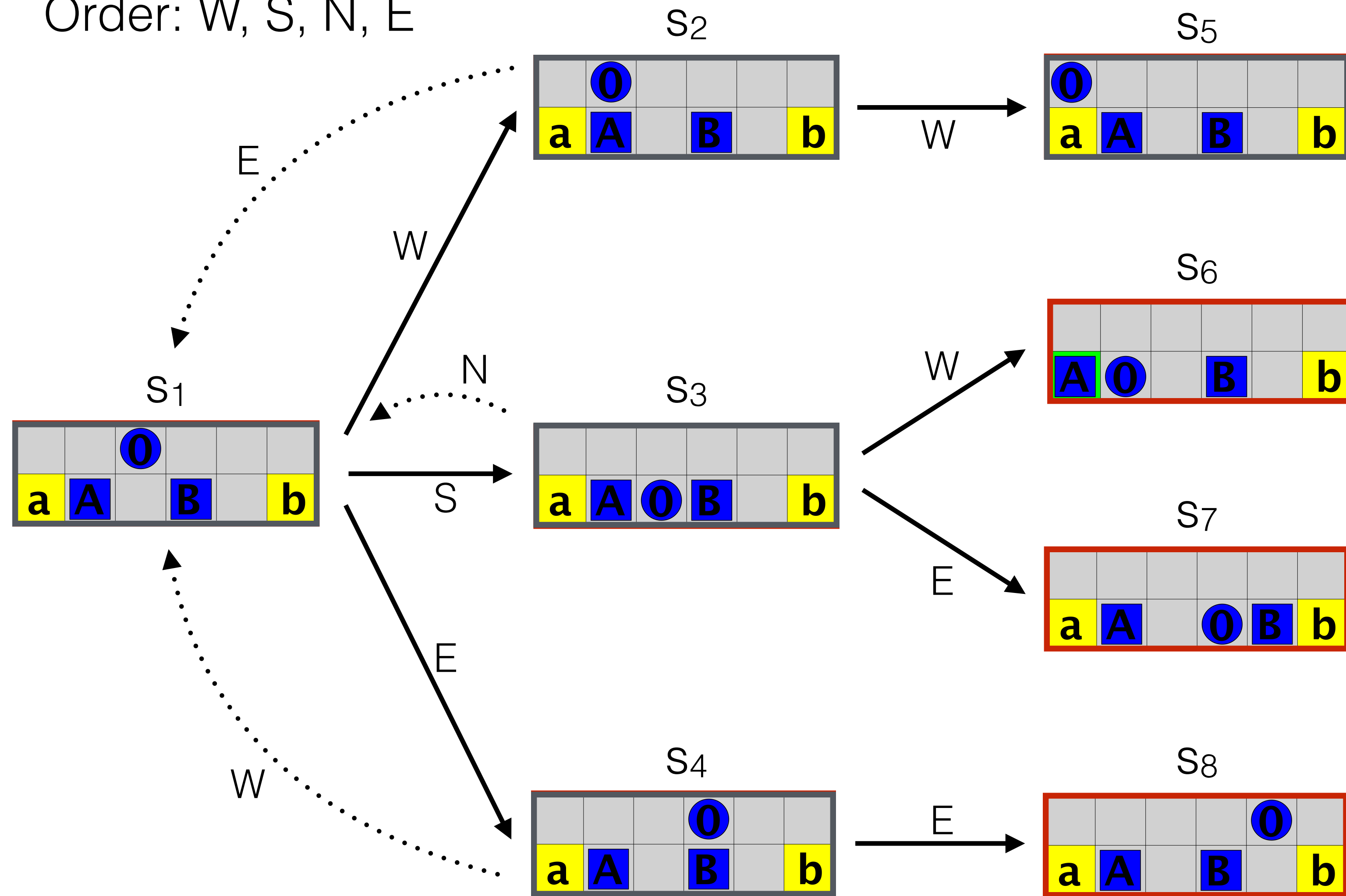
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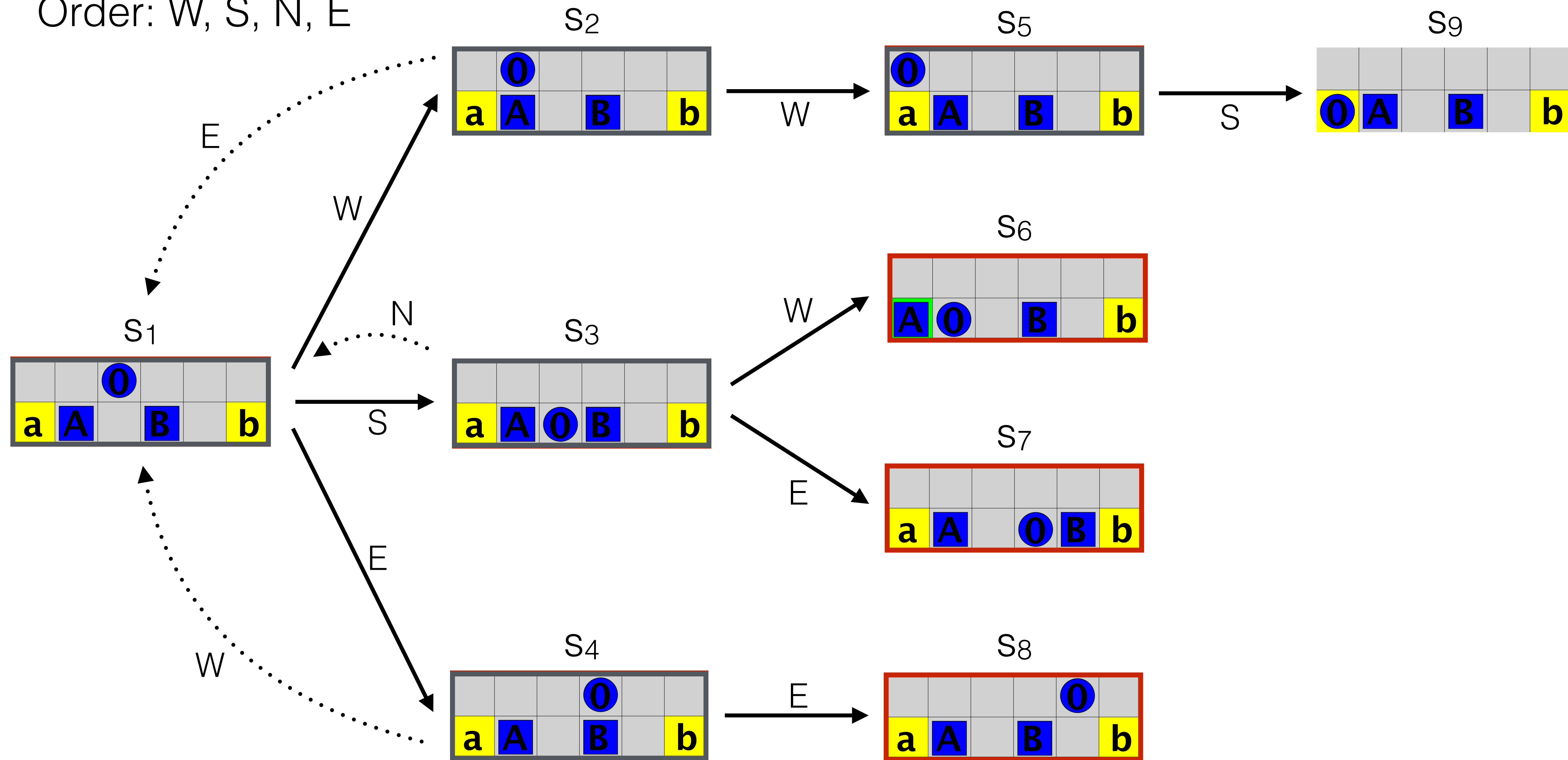
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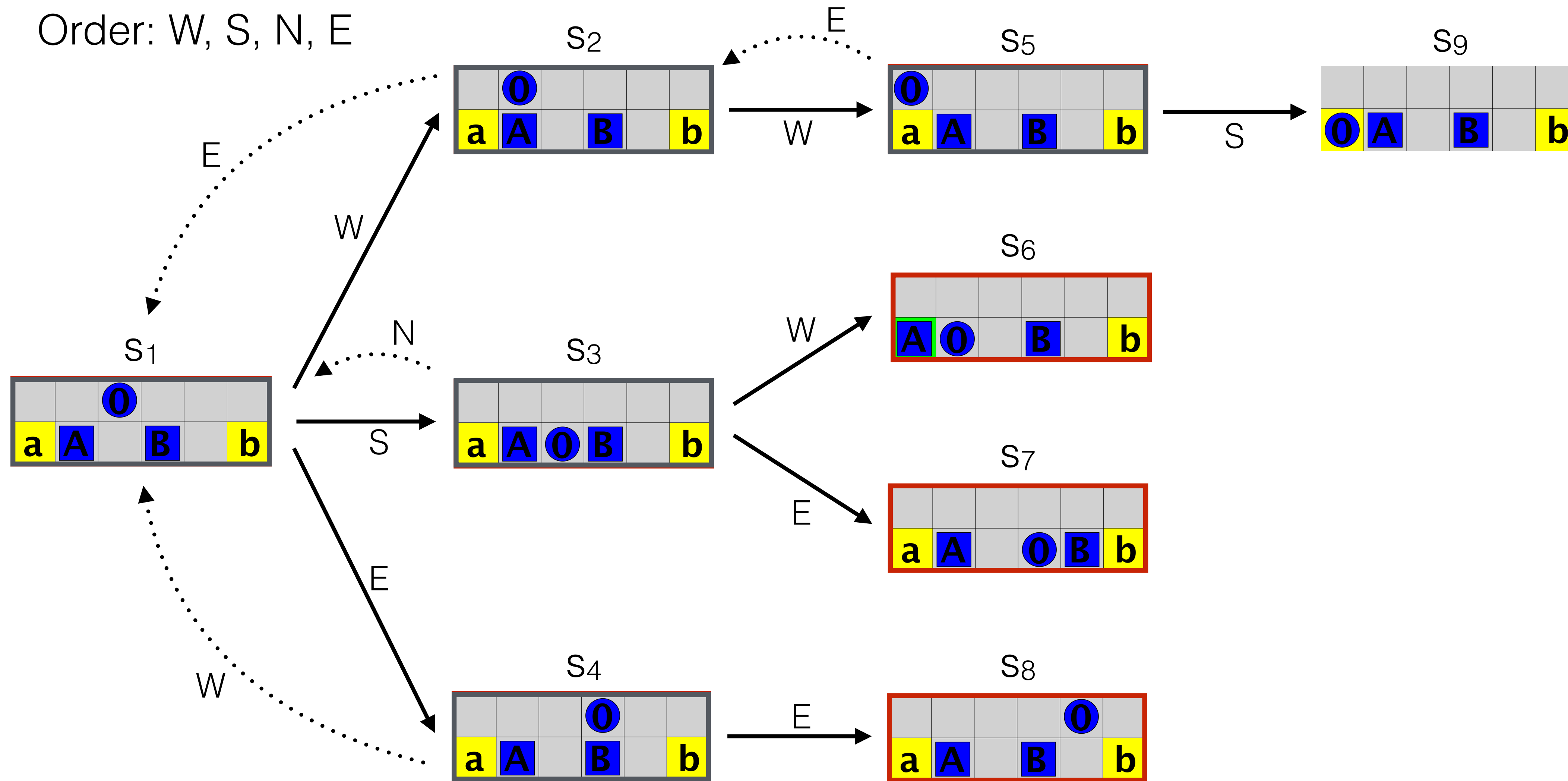
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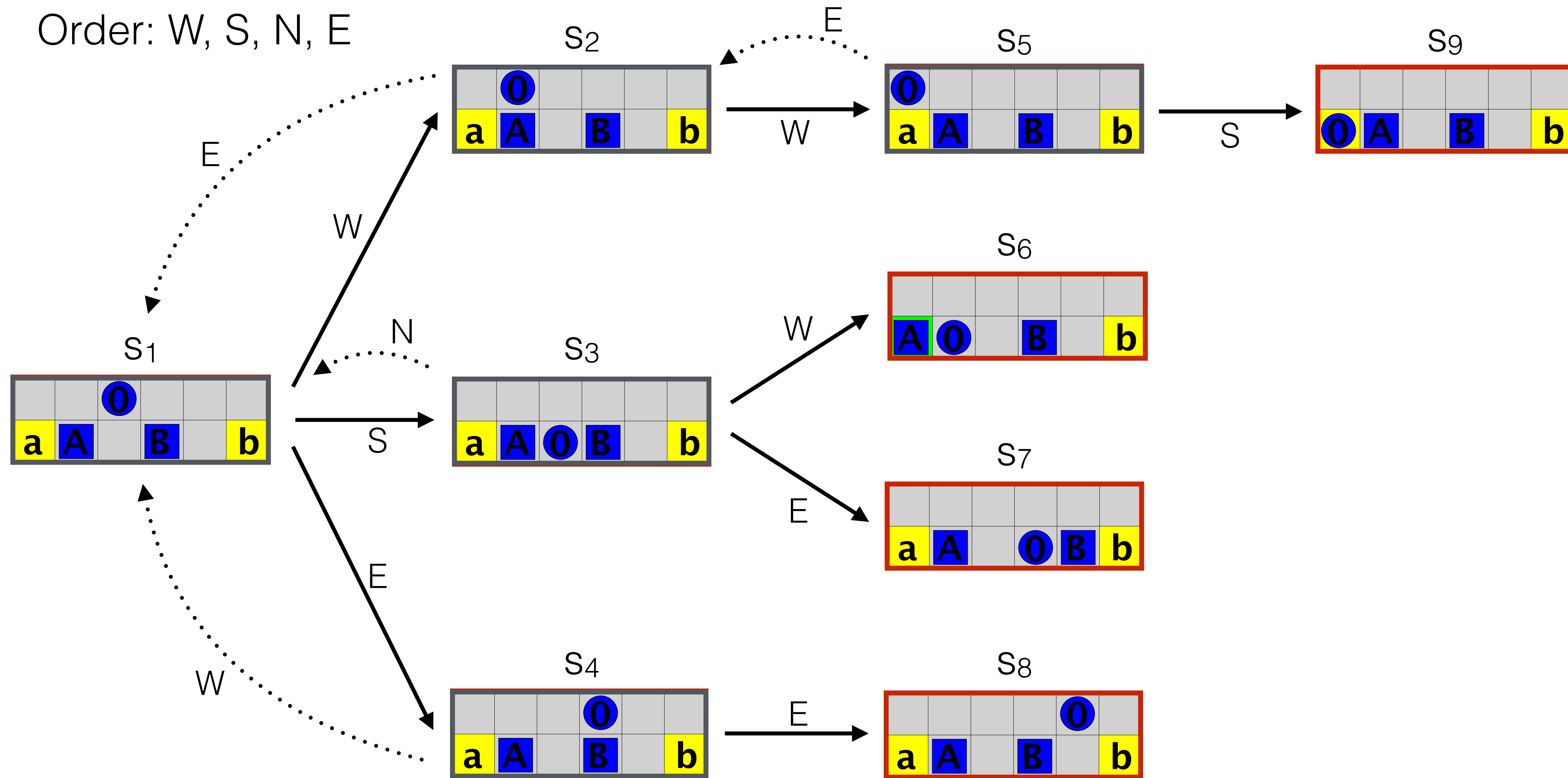
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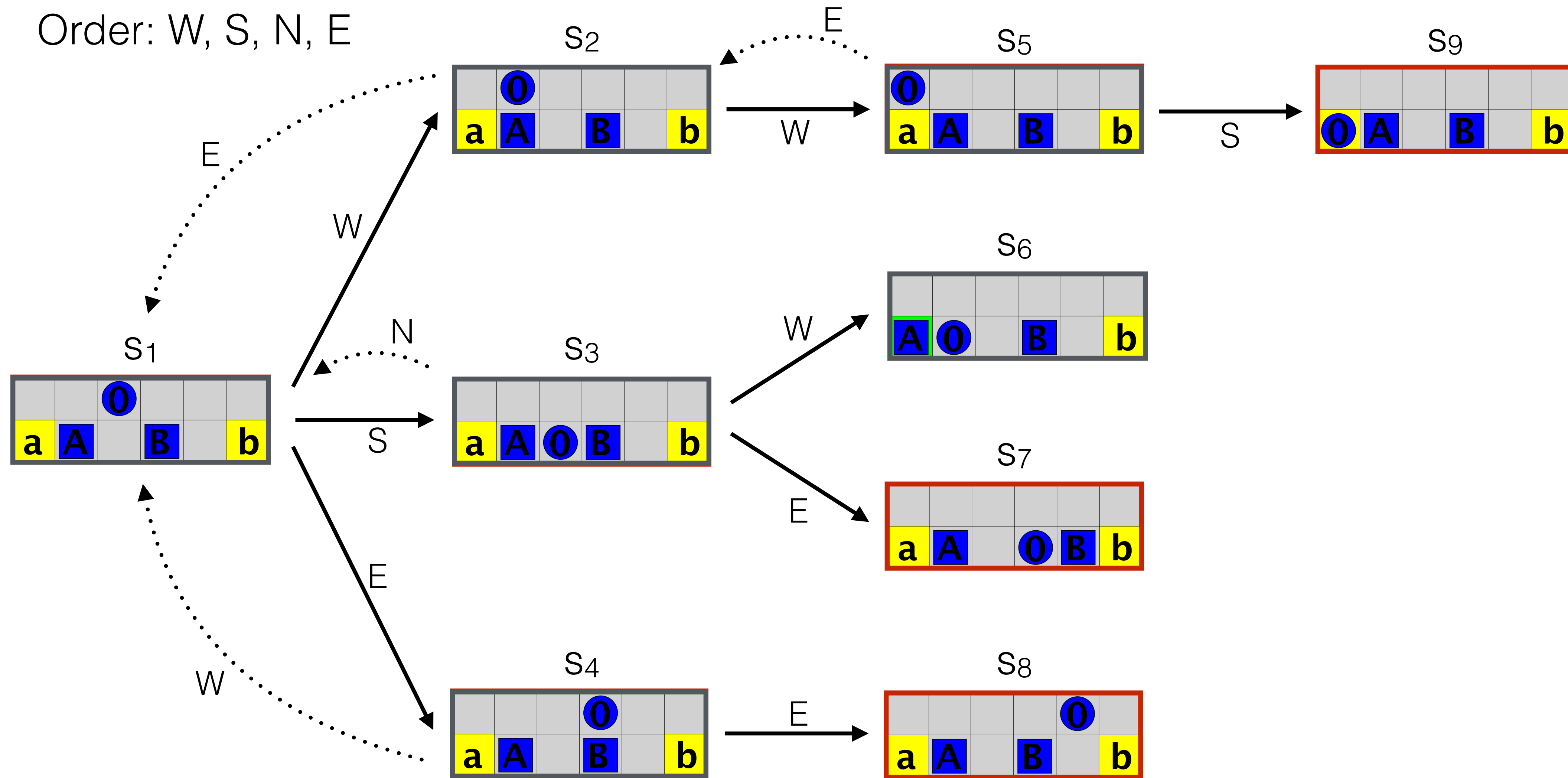
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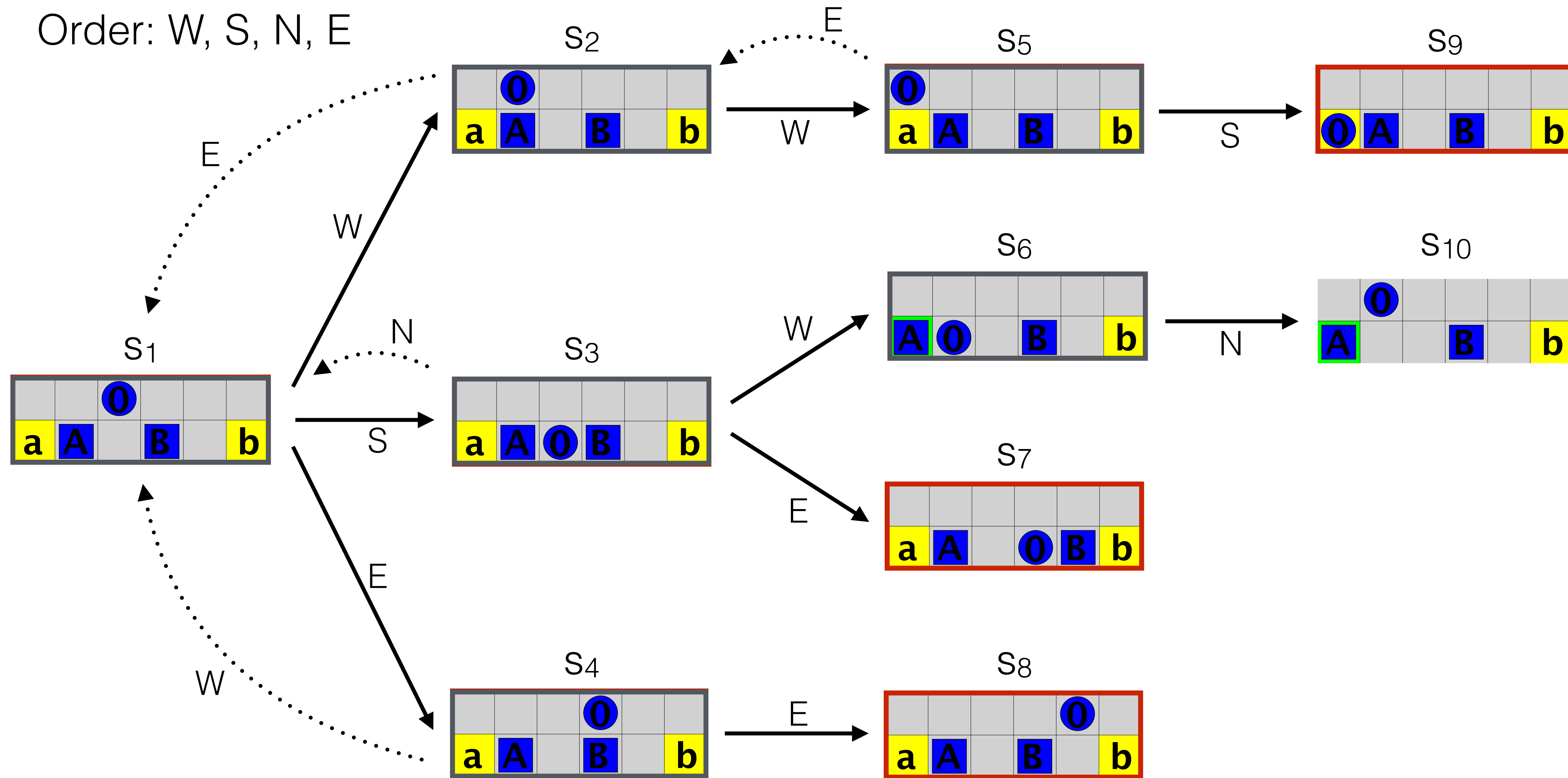
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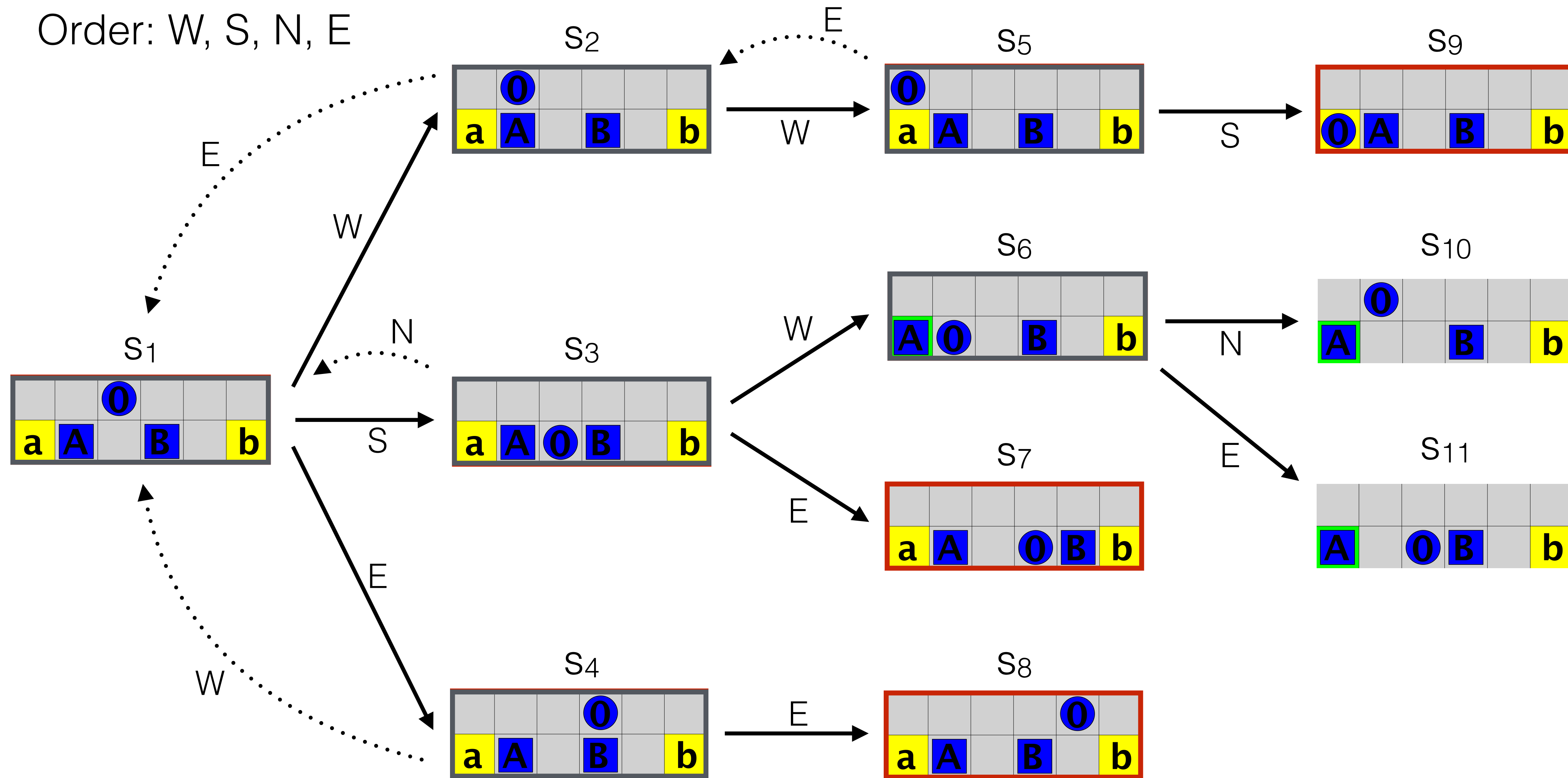
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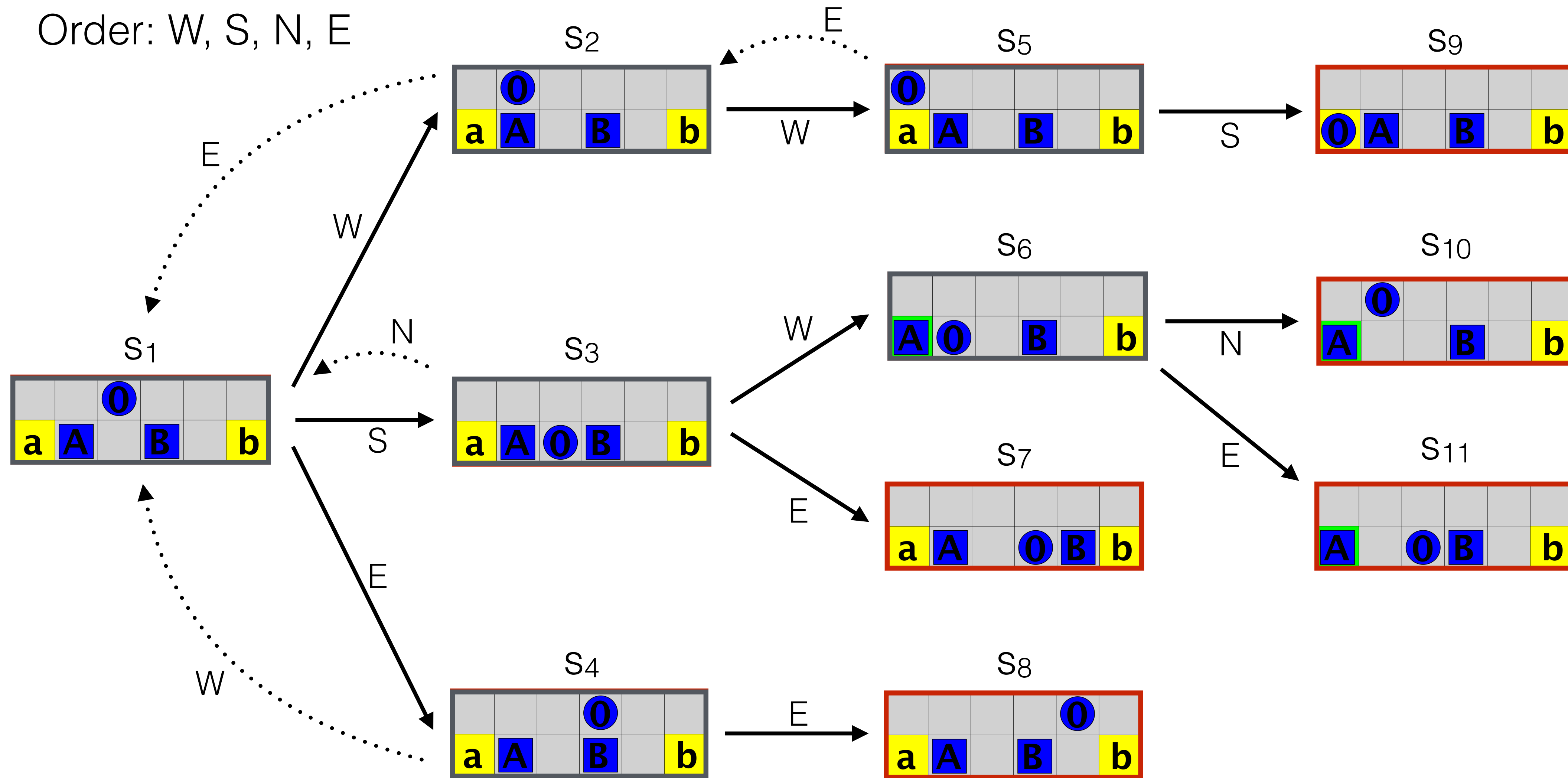
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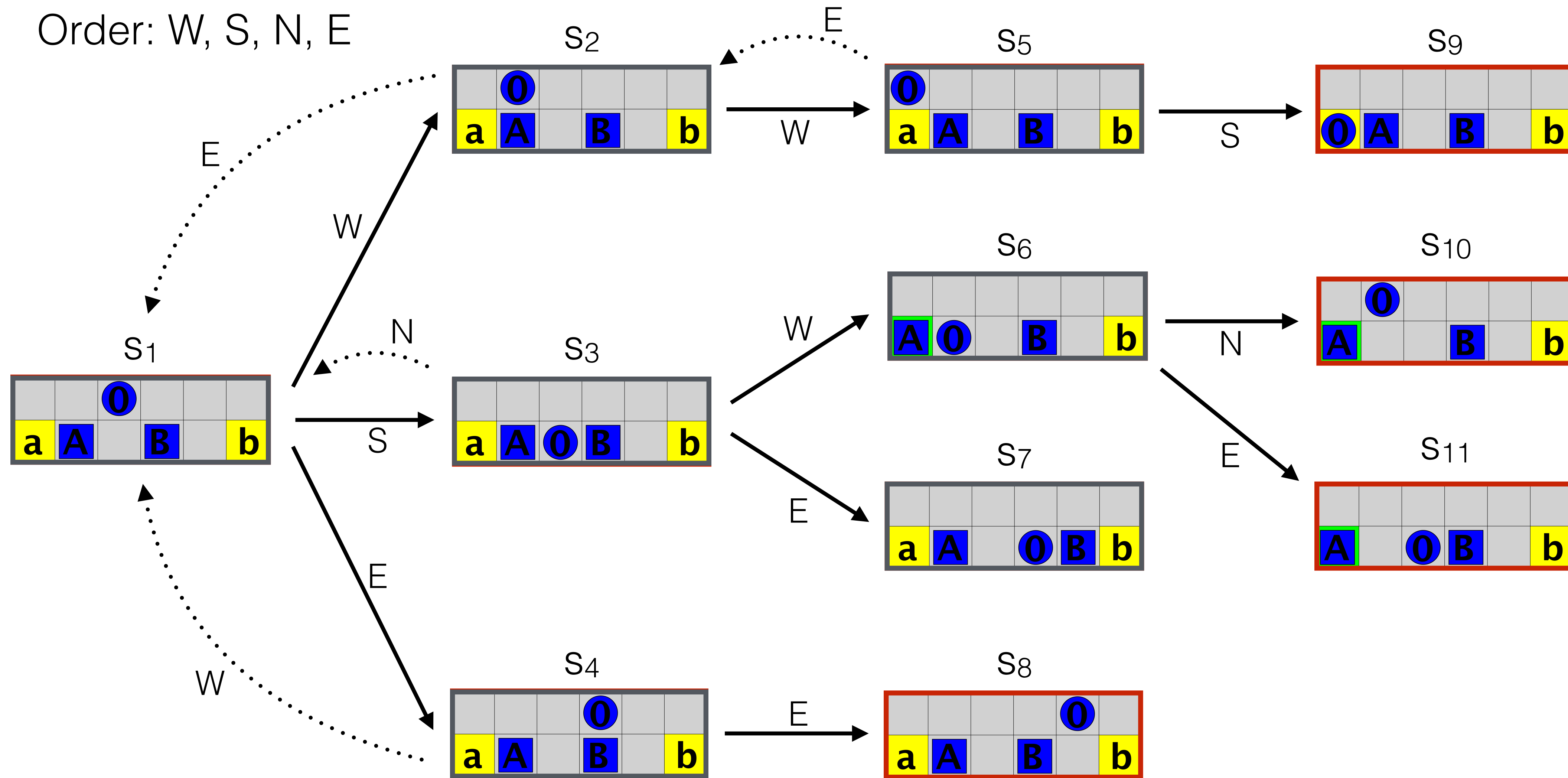
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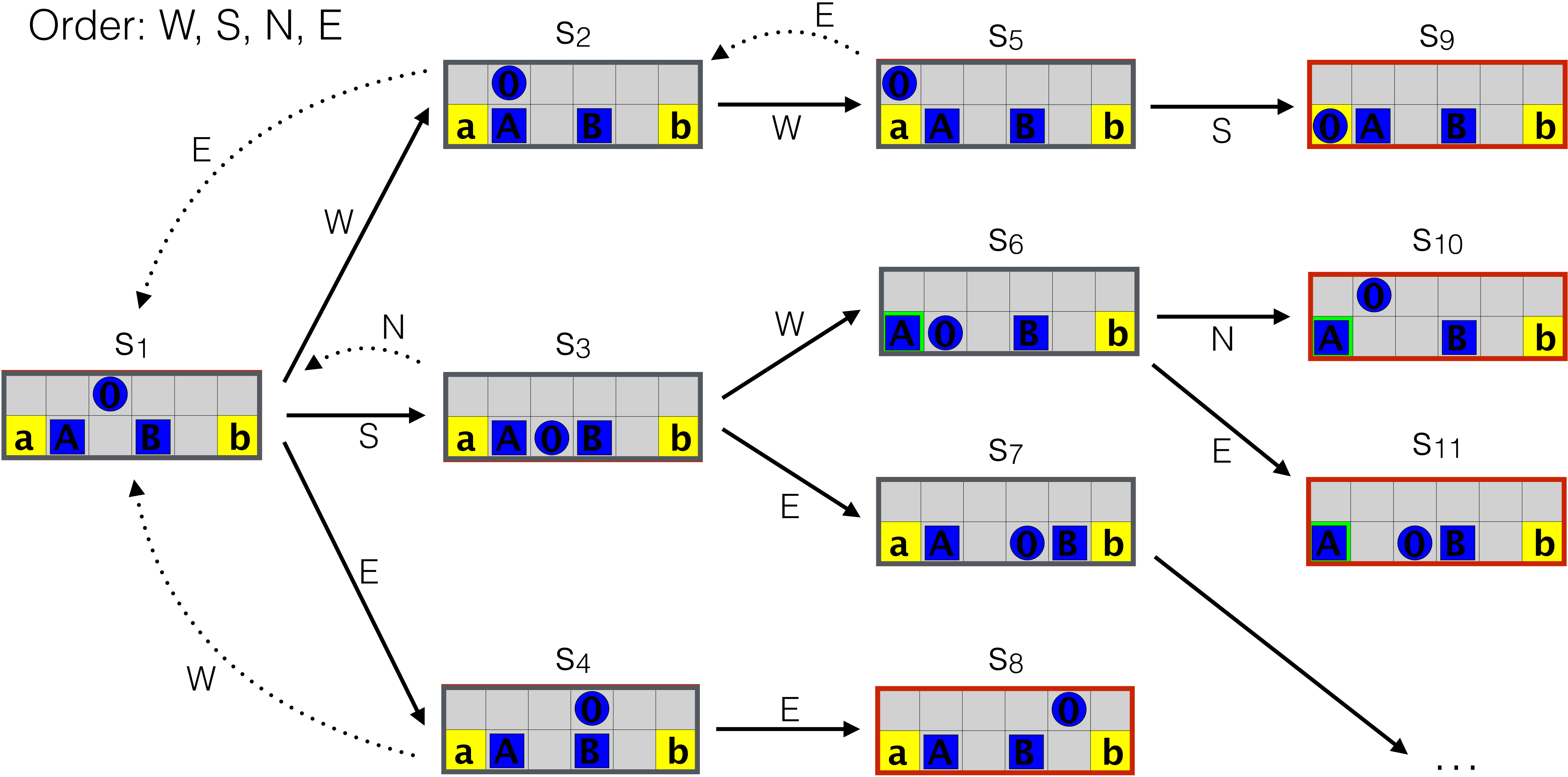
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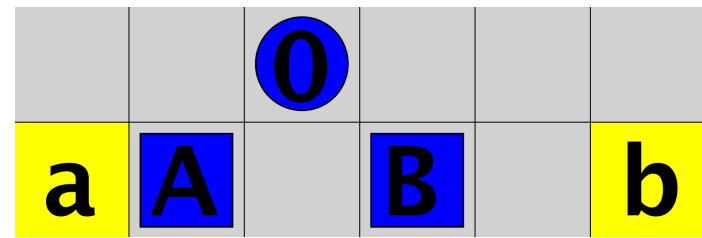


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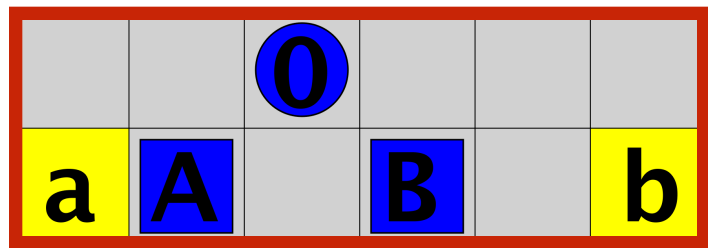


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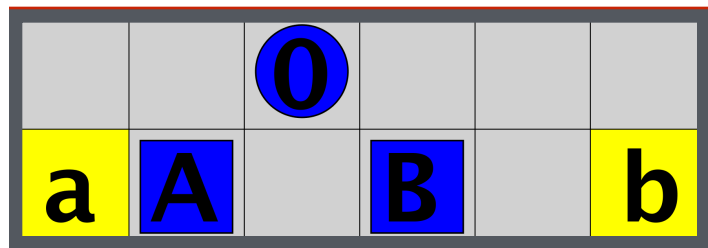


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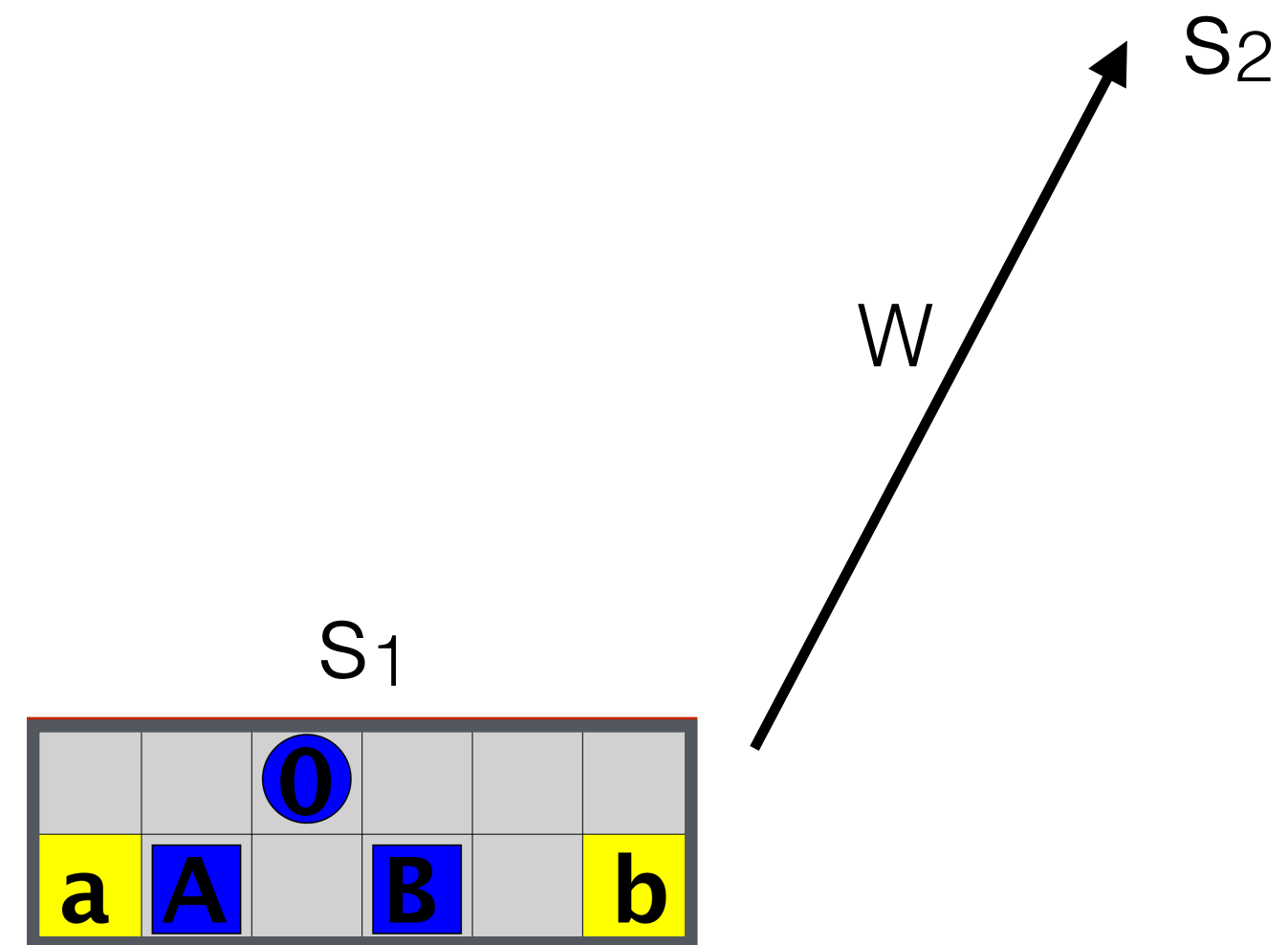
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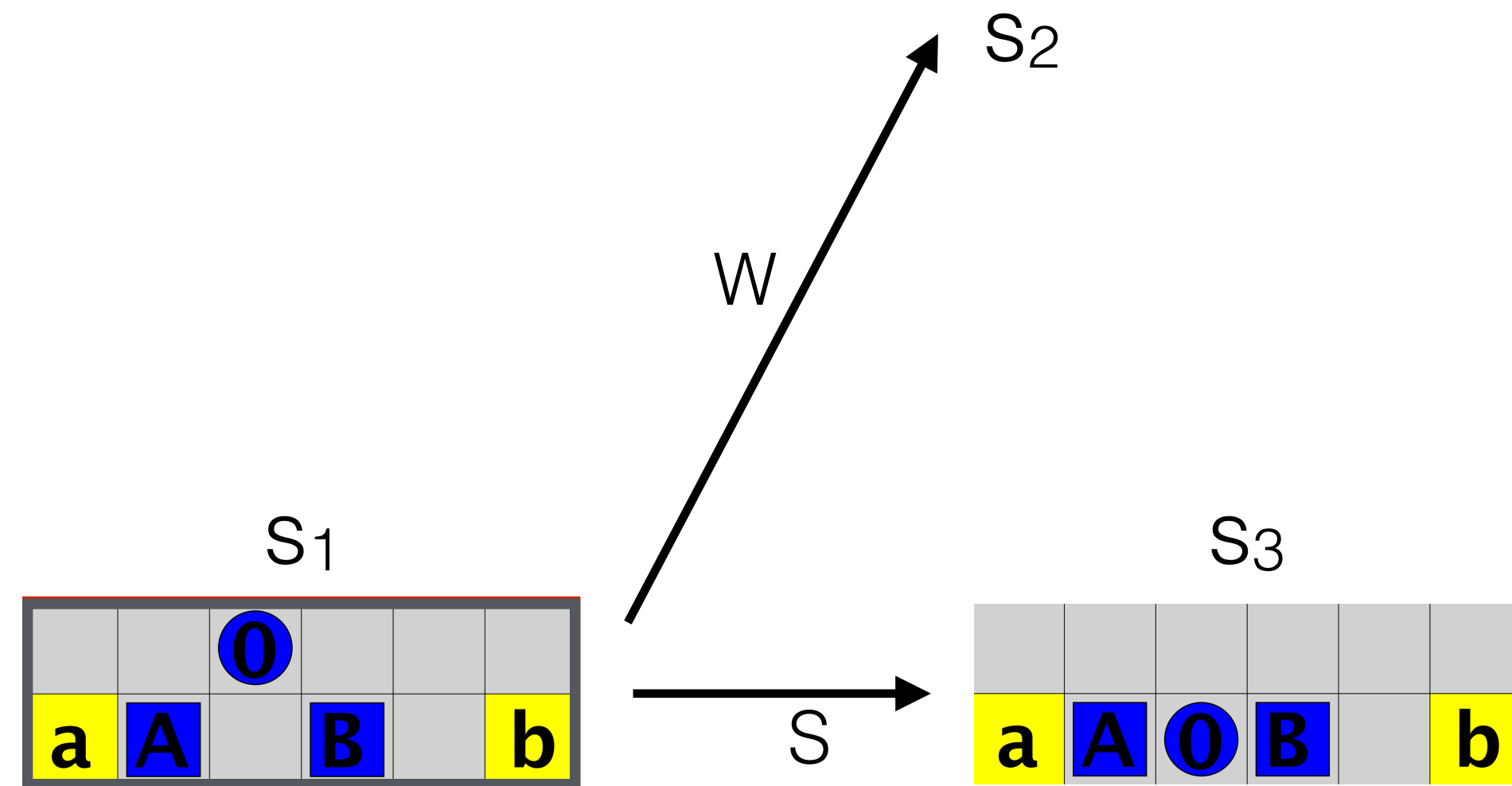
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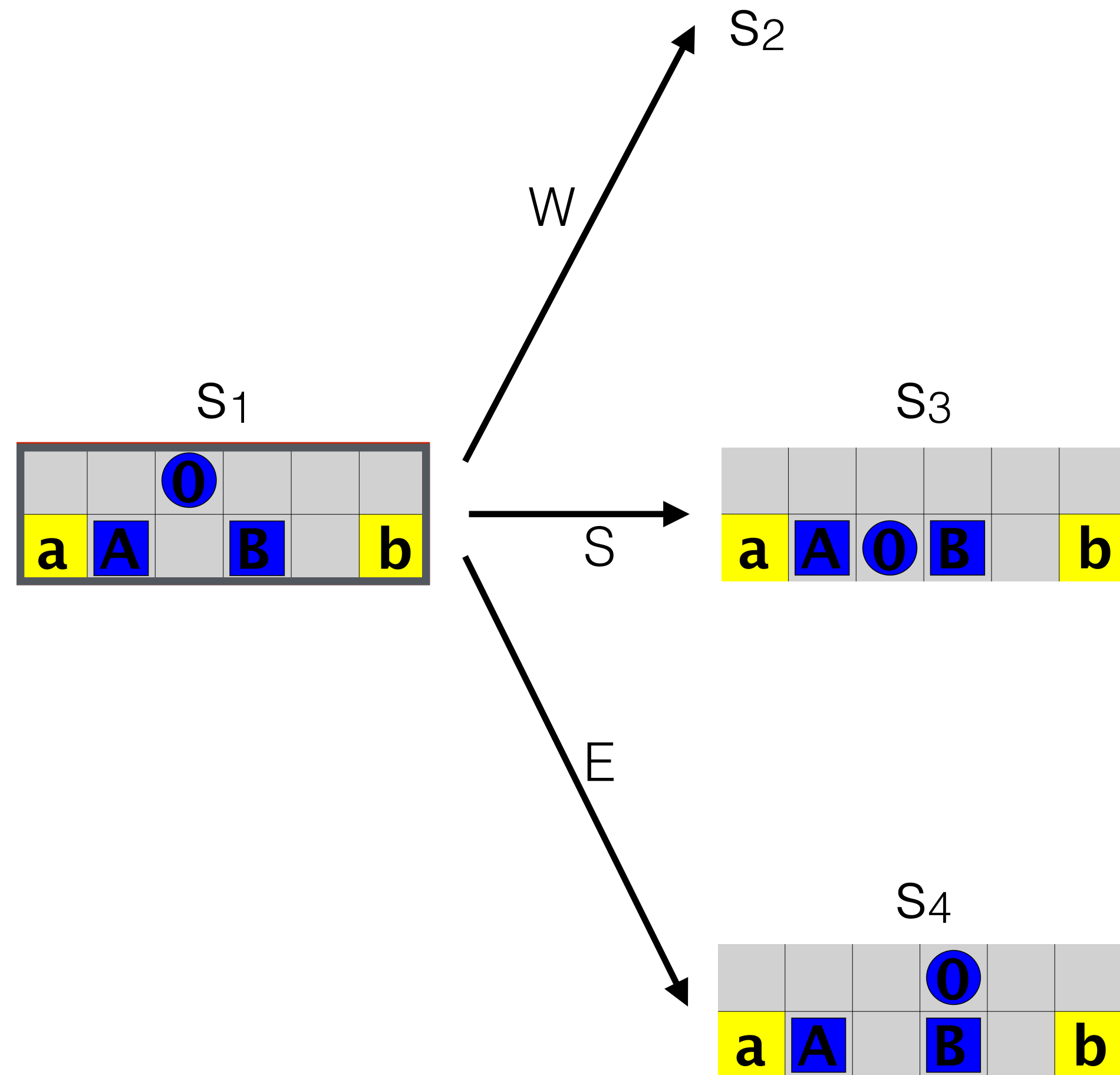
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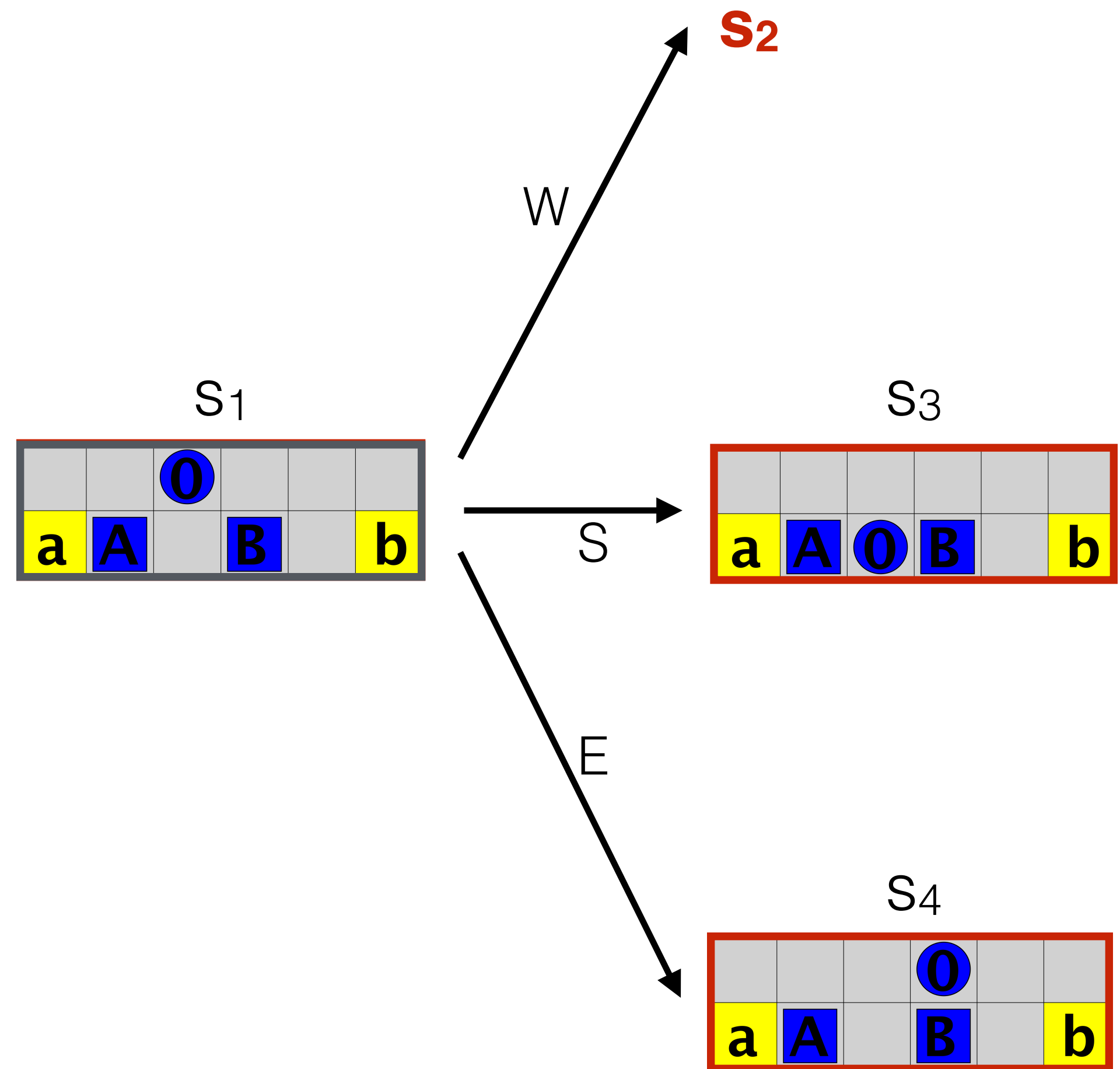
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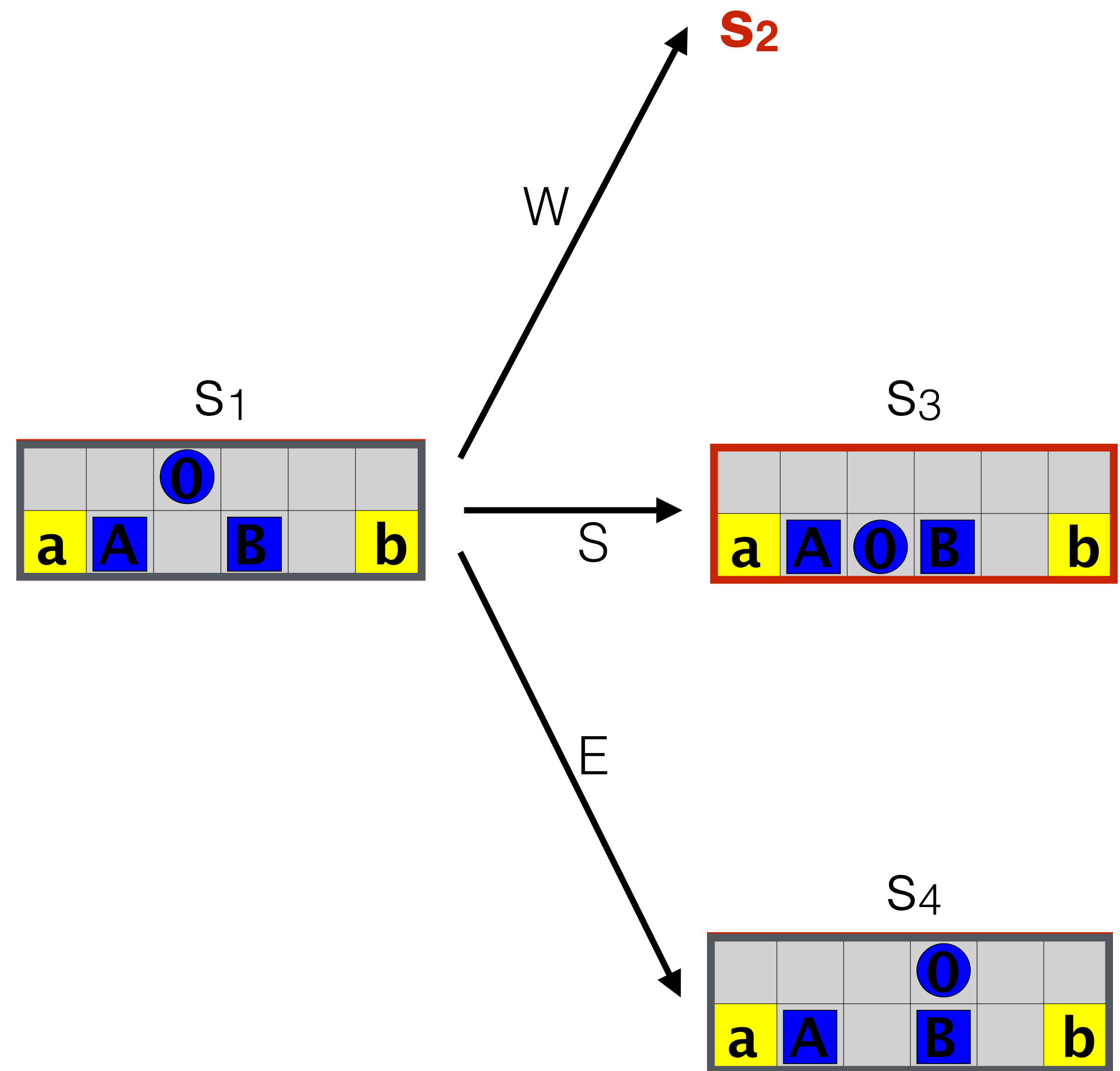
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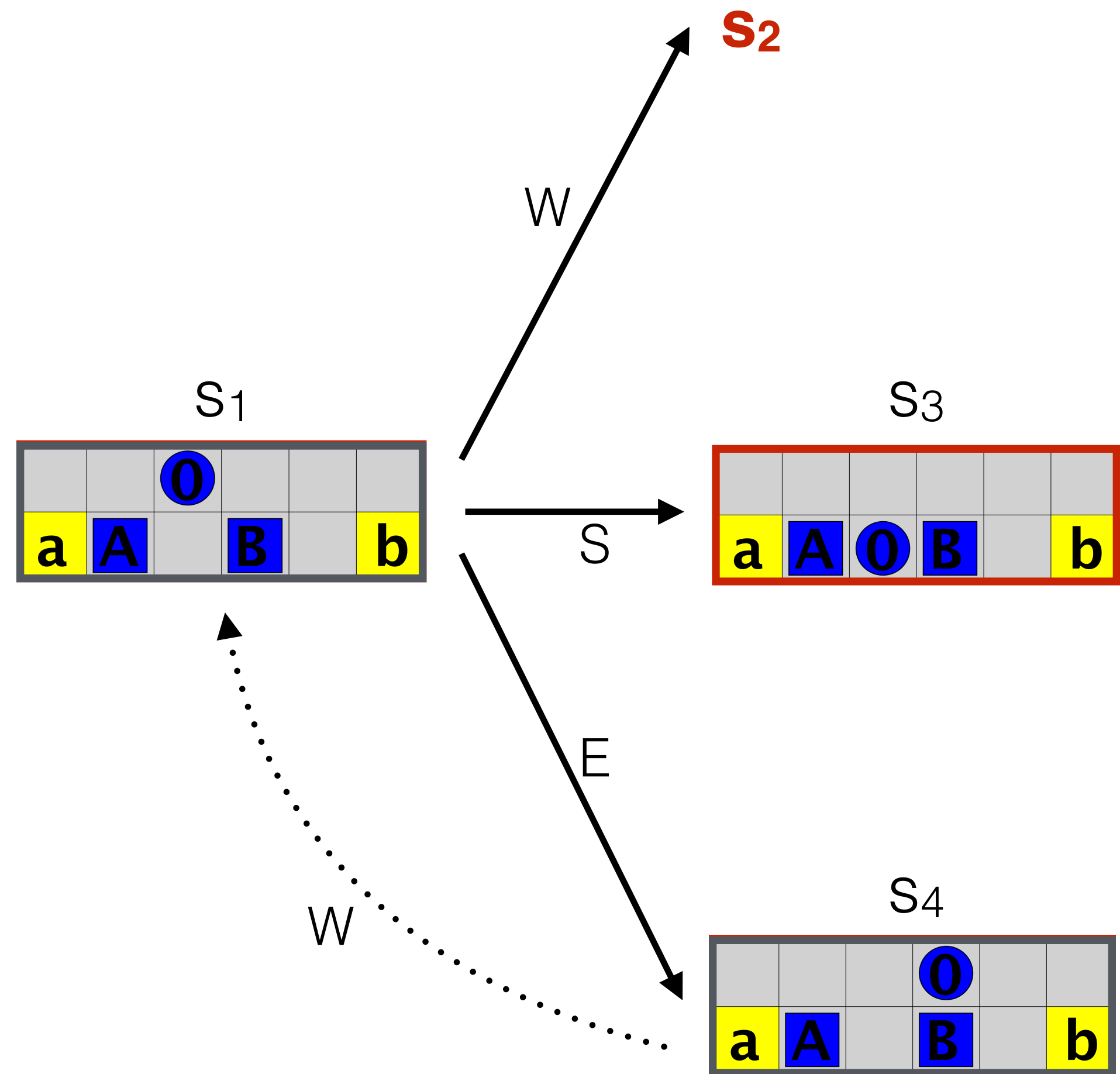
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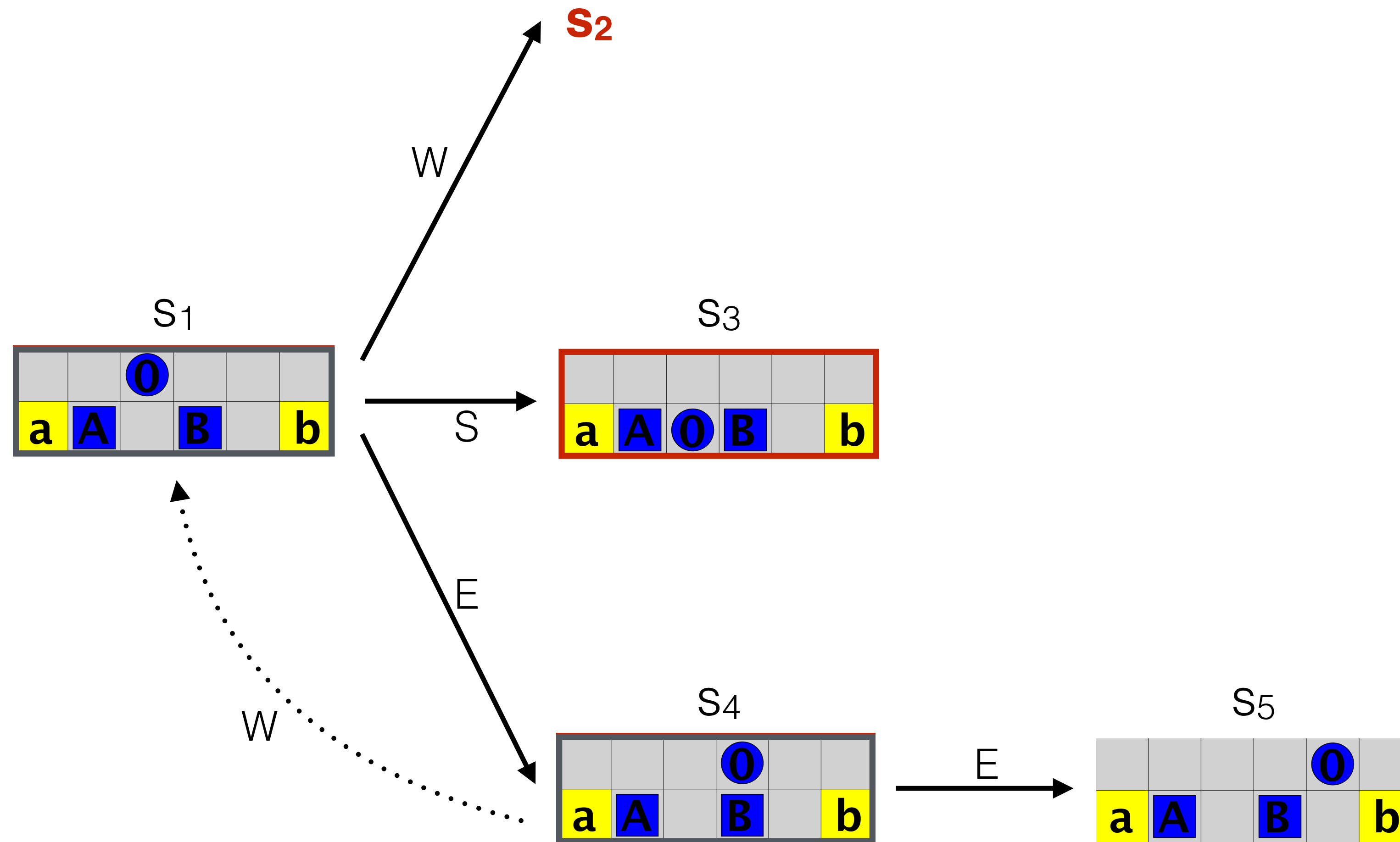
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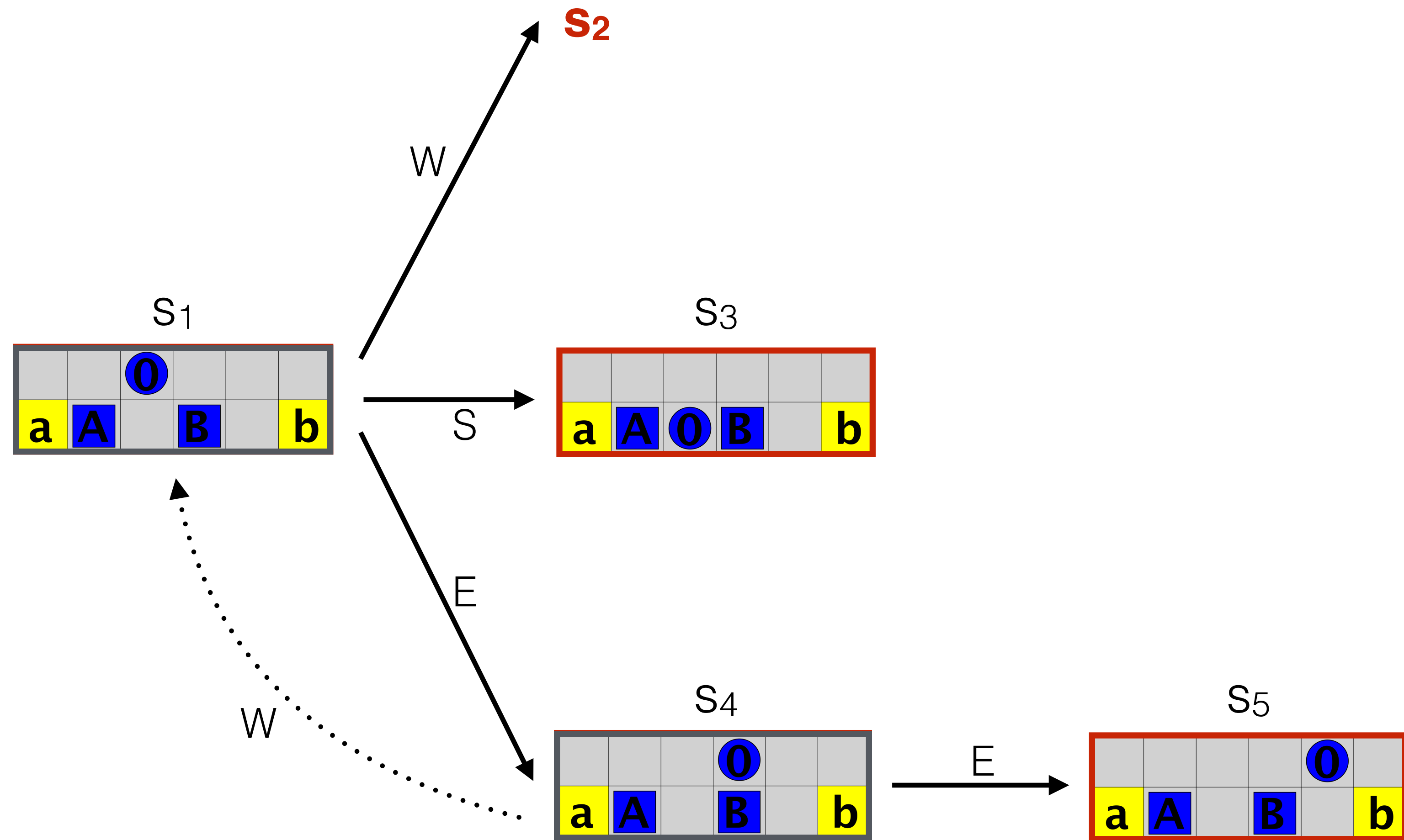
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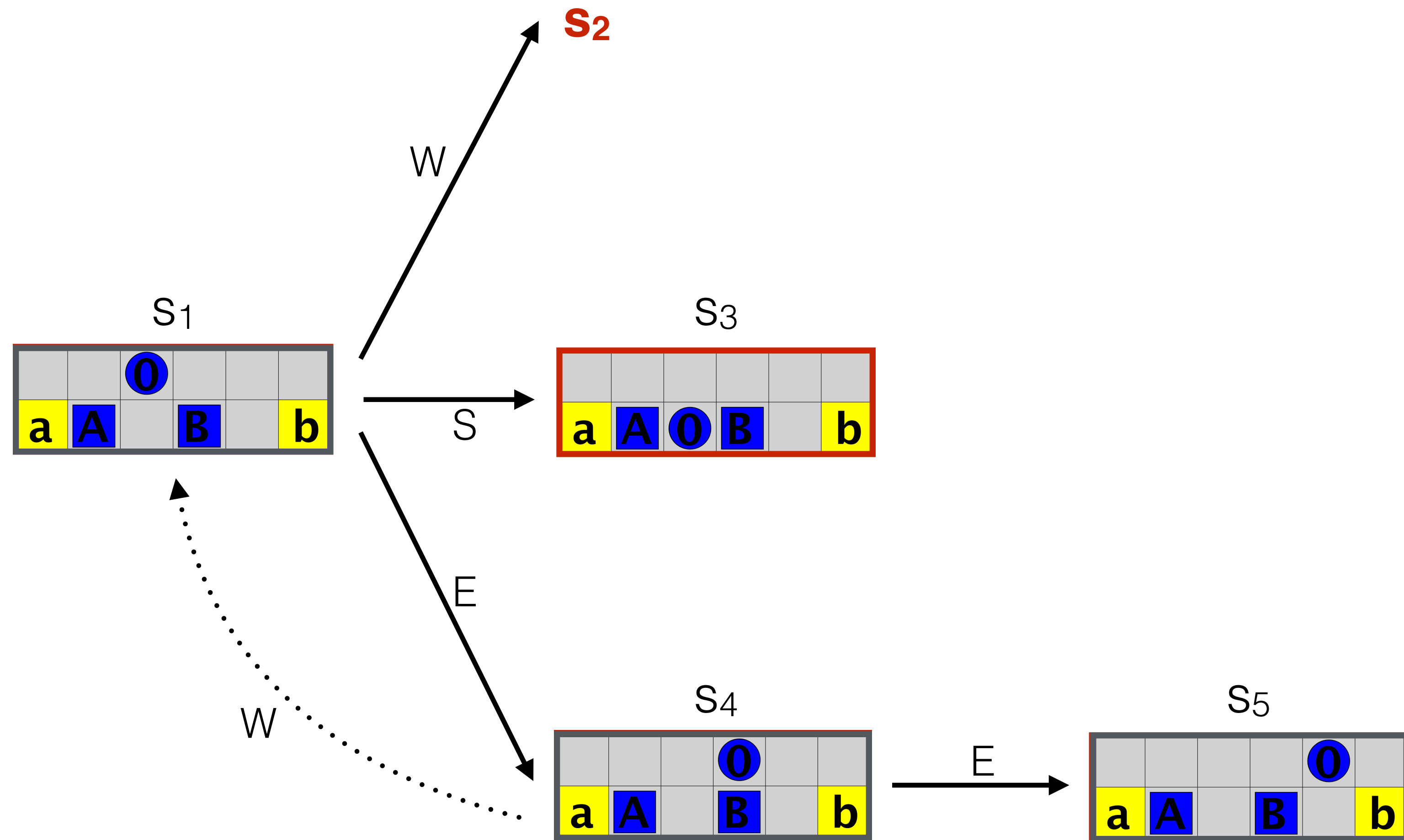
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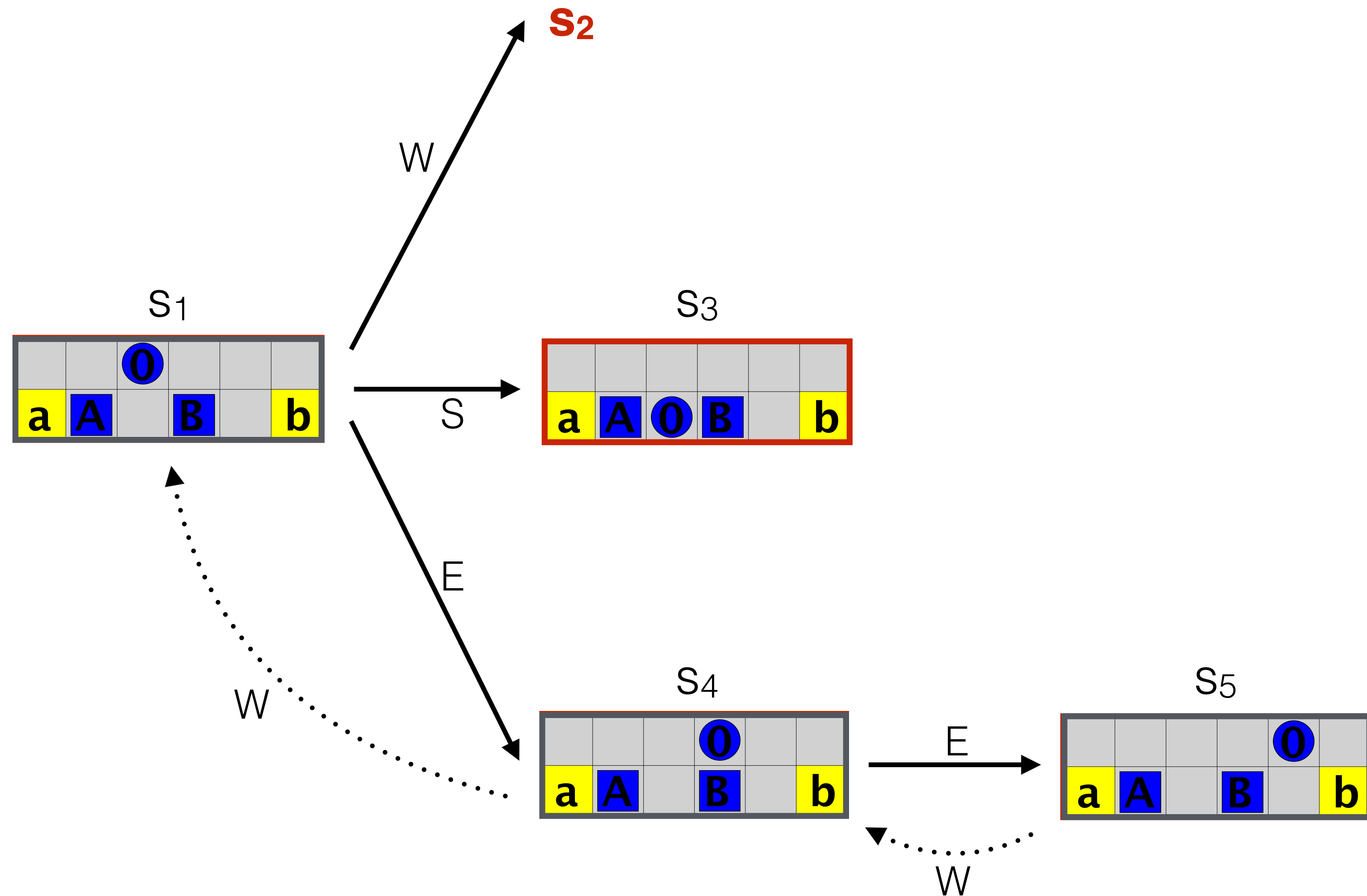
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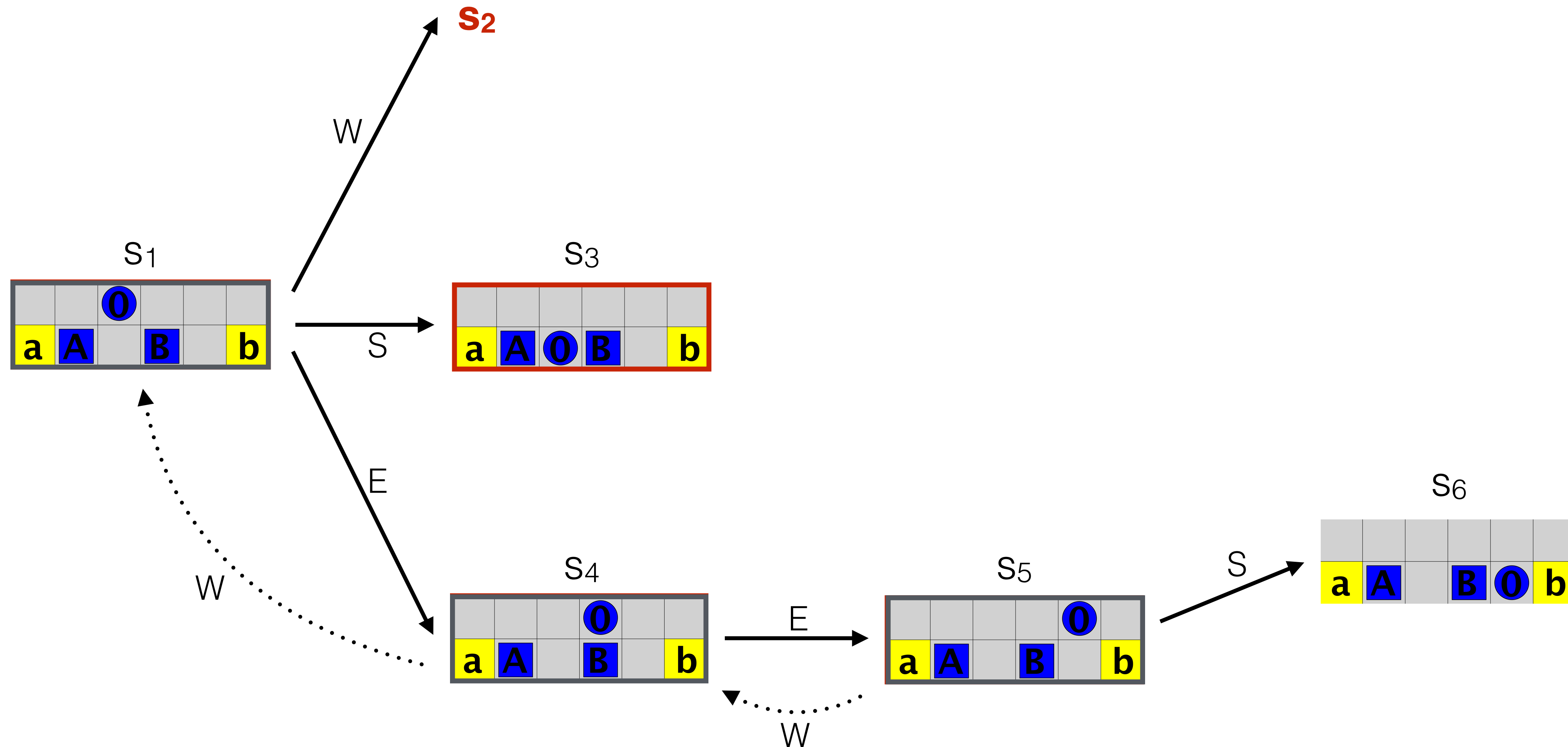
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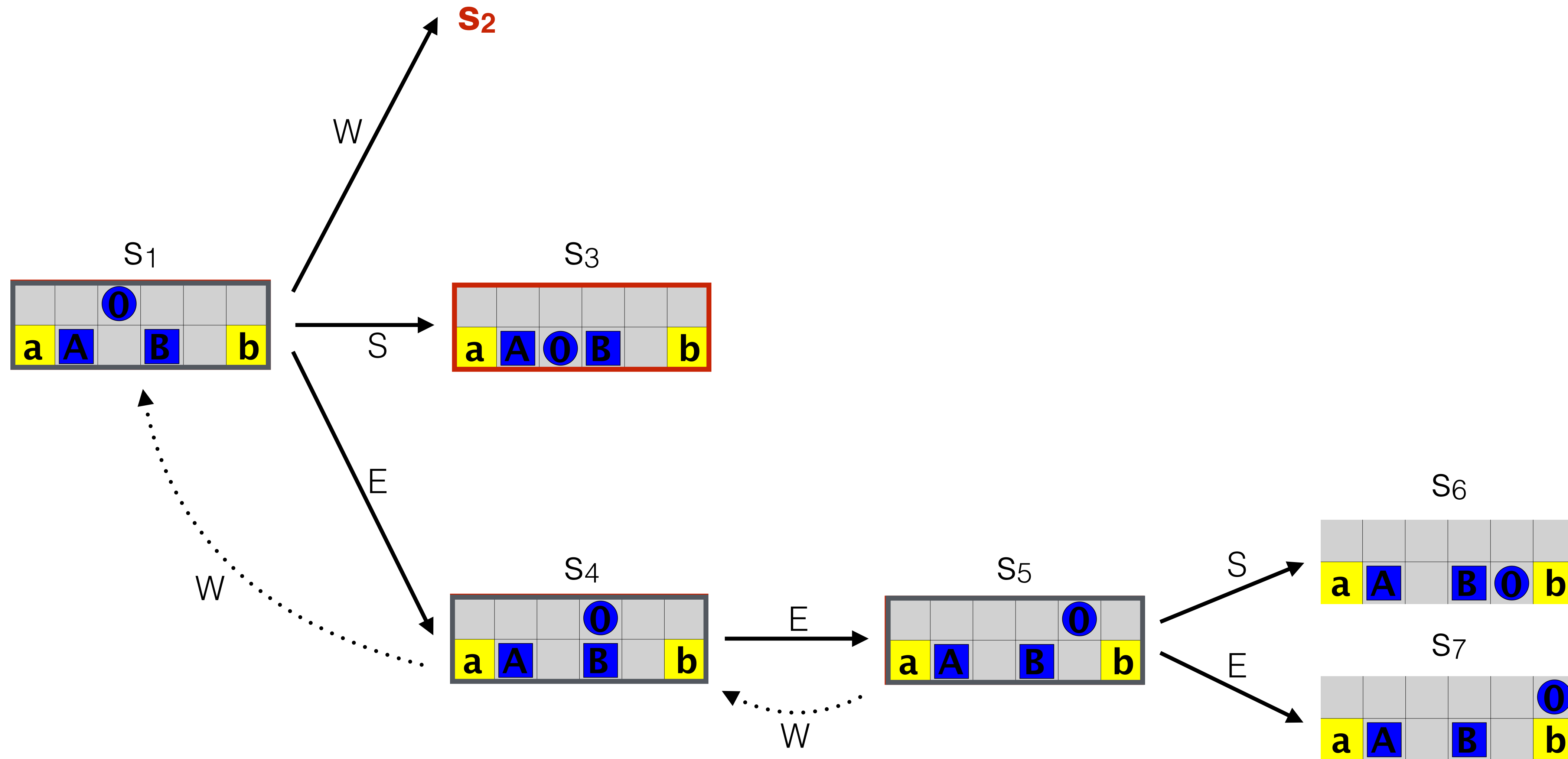
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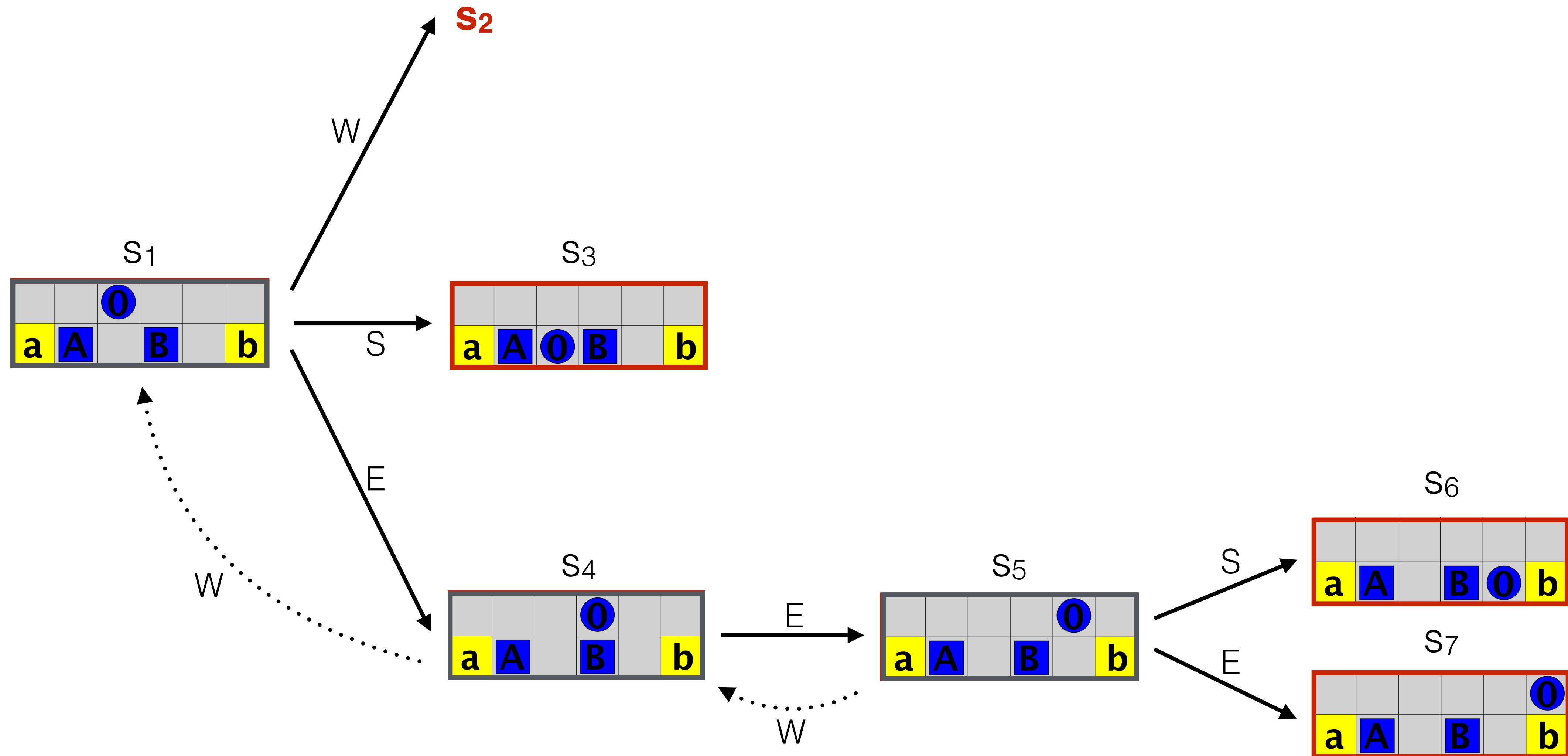
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DFS example (Sokoban rules = only pushing)

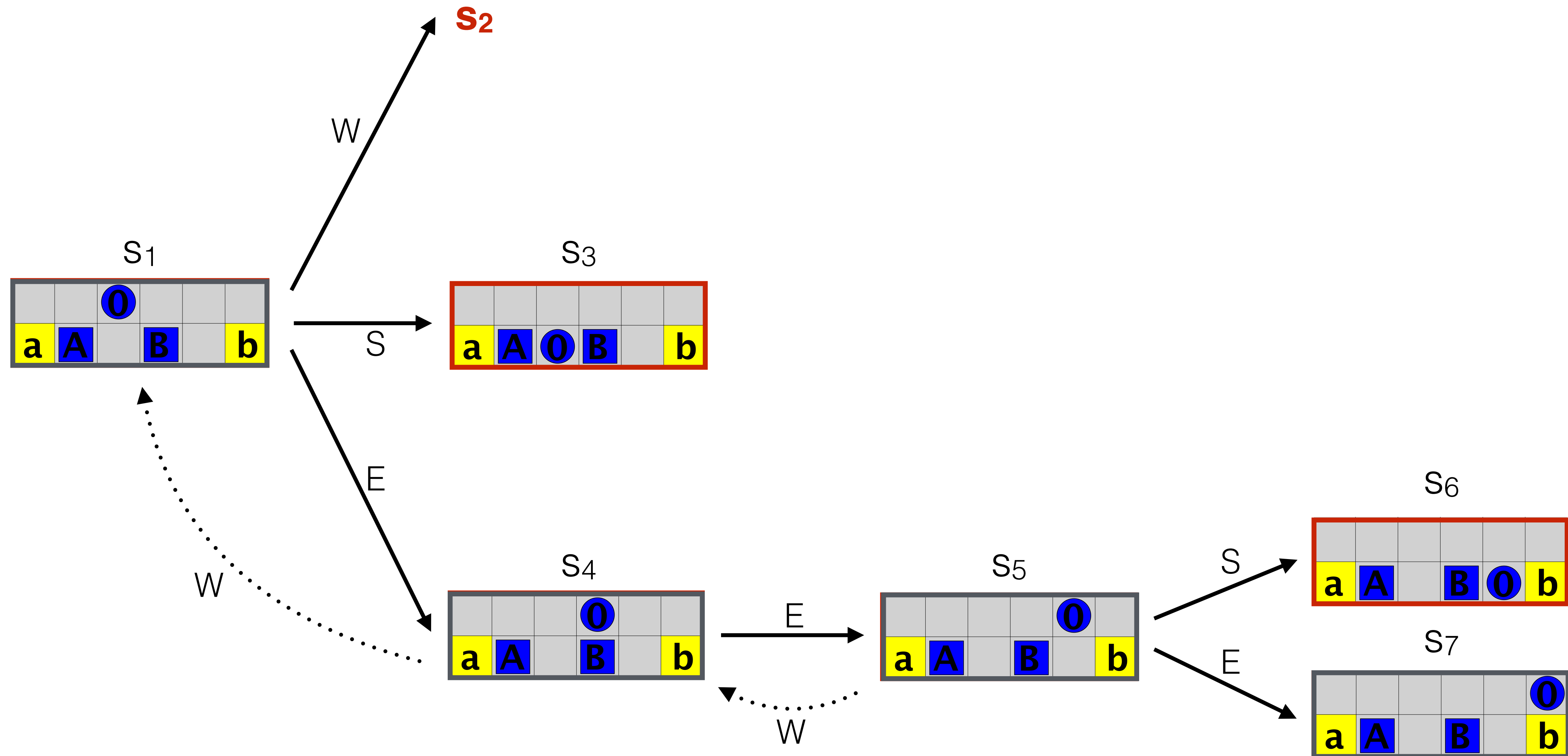
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

DFS example (Sokoban rules = only pushing)

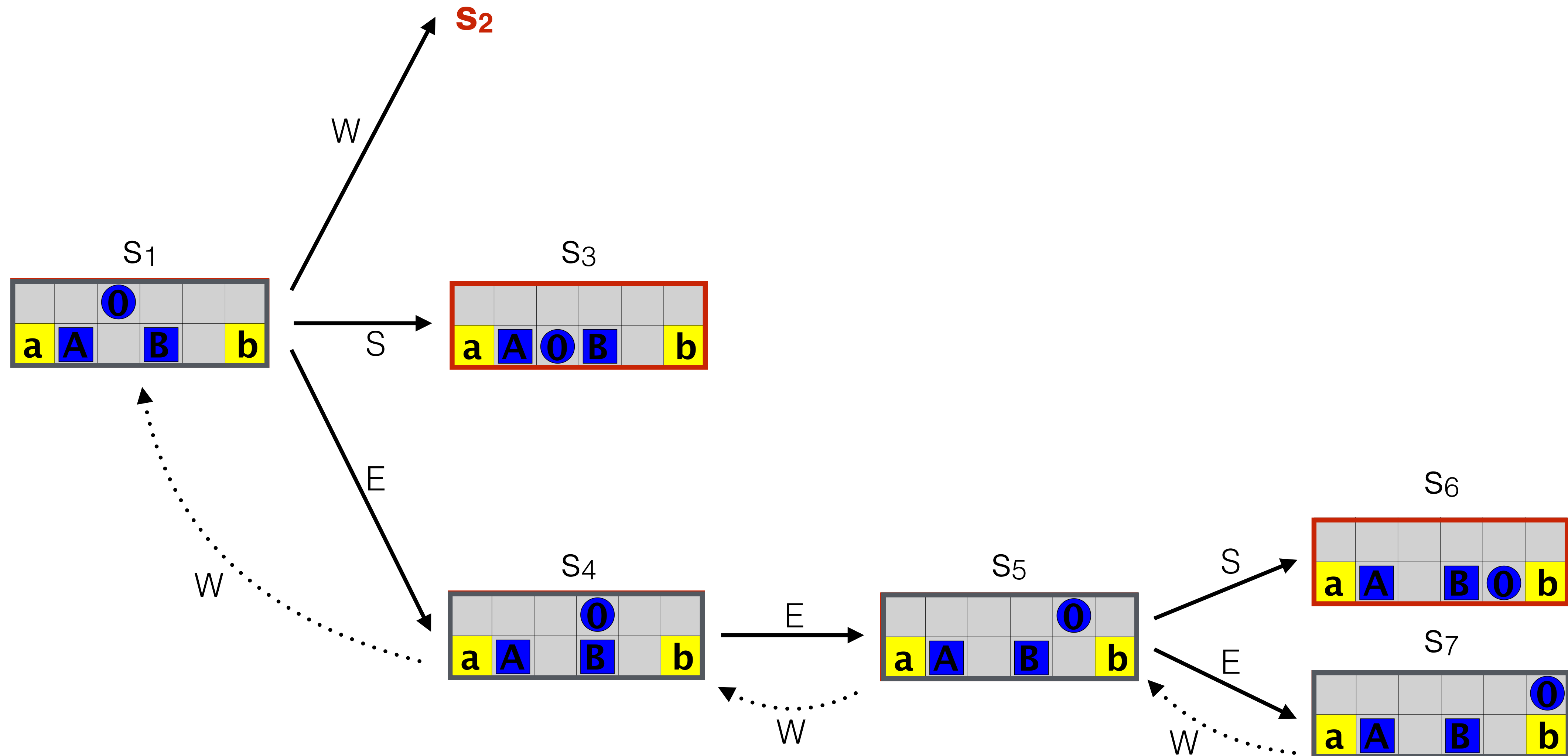
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

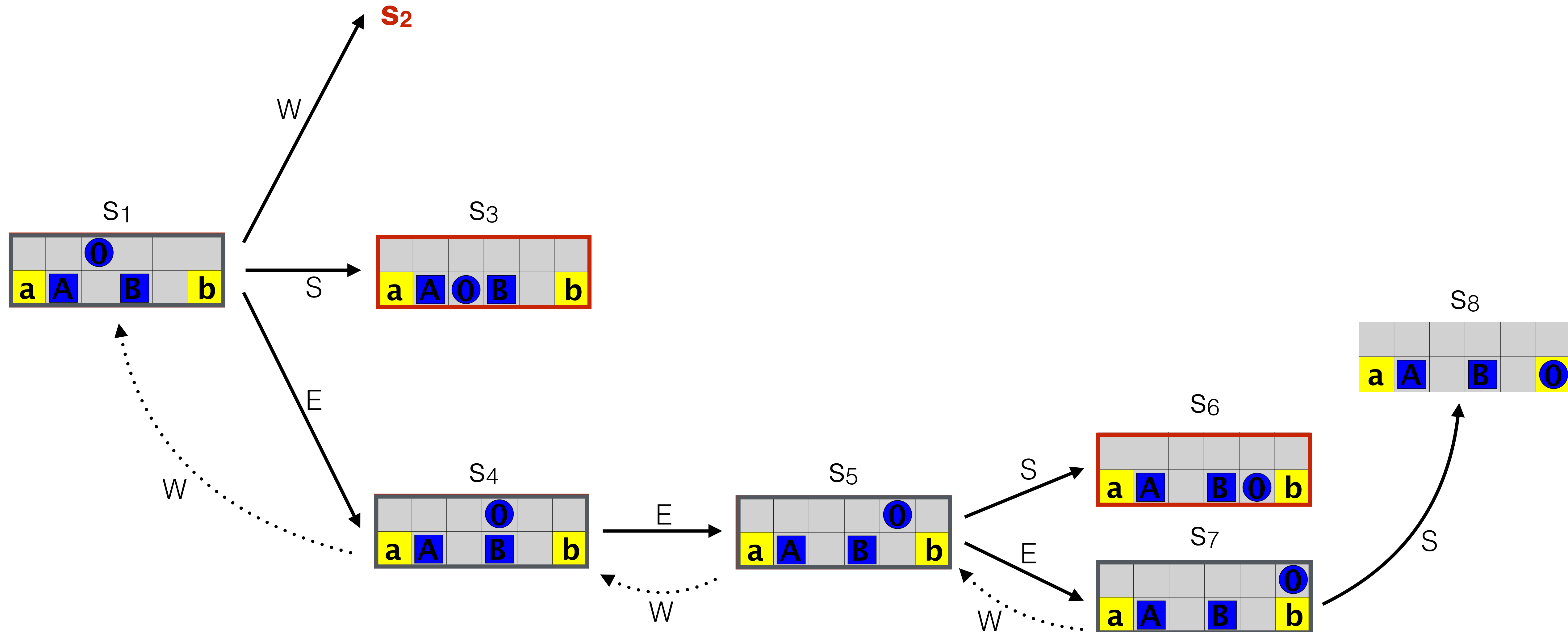
DFS example (Sokoban rules = only pushing)

Order: W, S, N, E



DFS example (Sokoban rules = only pushing)

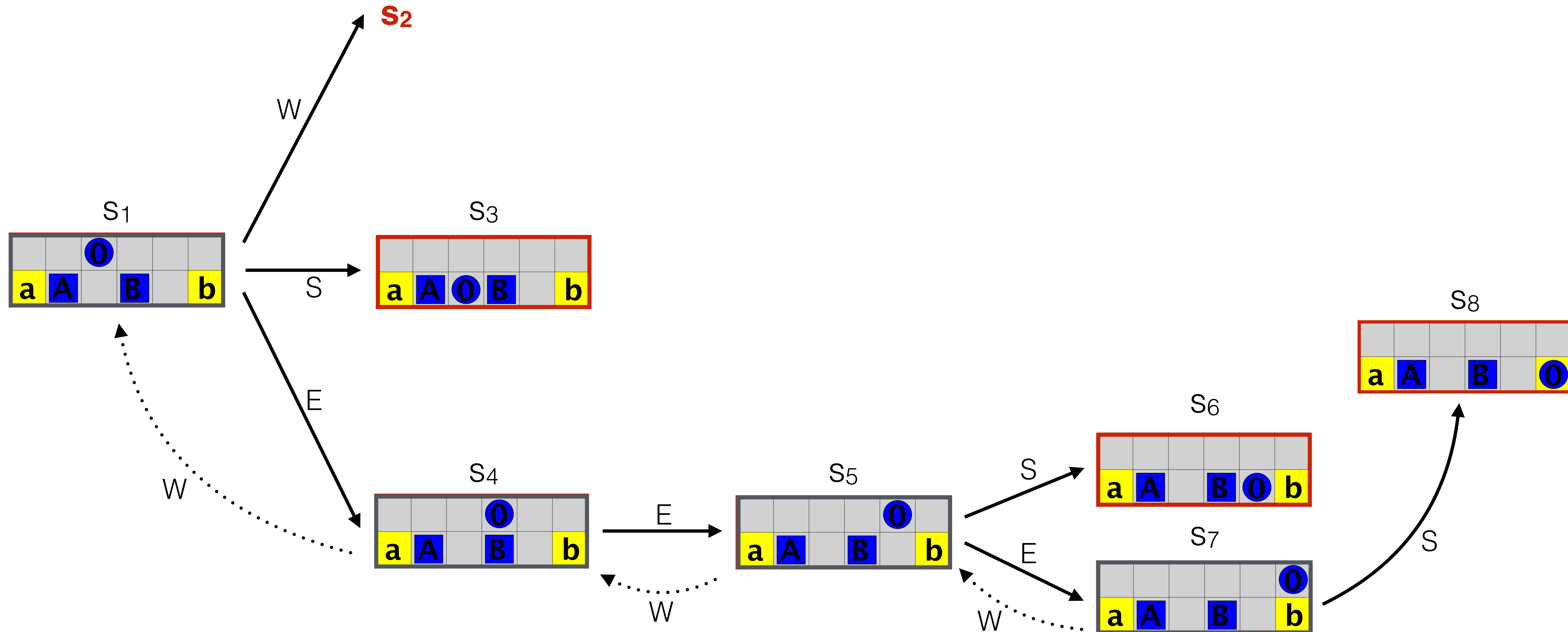
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

DFS example (Sokoban rules = only pushing)

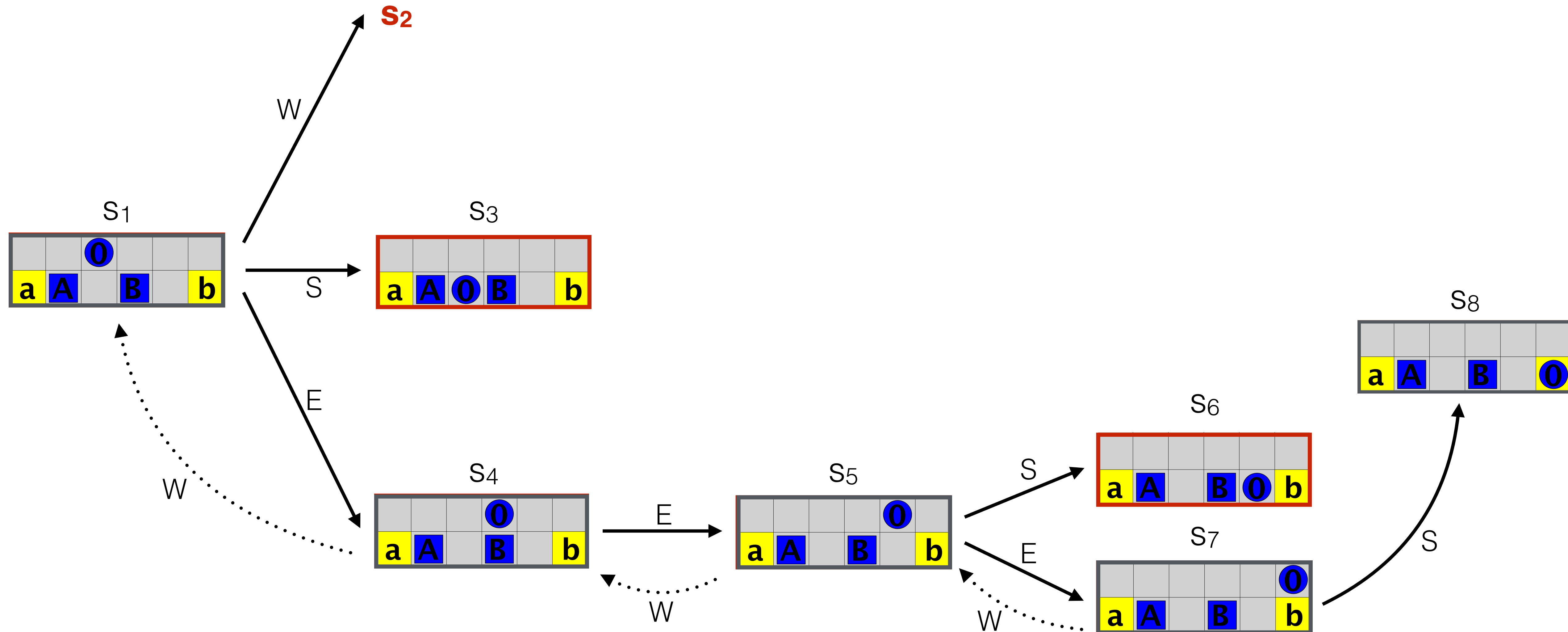
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

DFS example (Sokoban rules = only pushing)

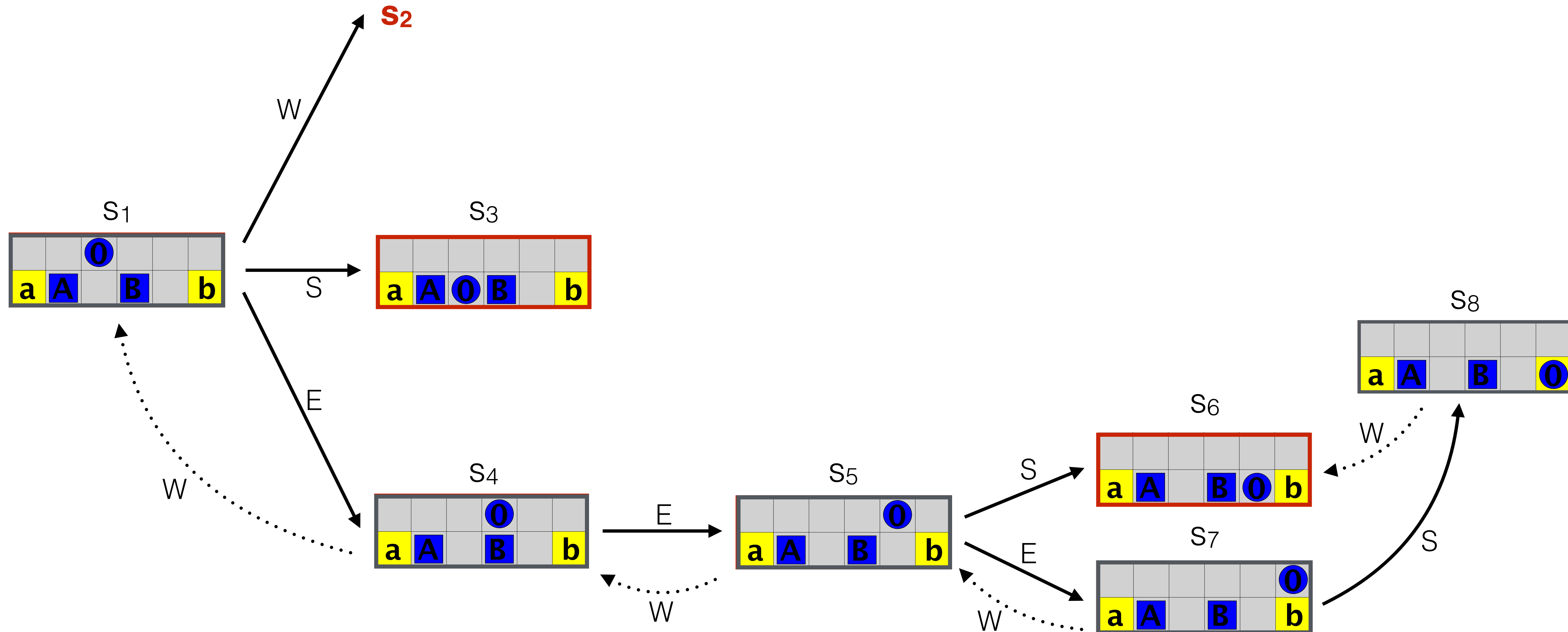
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

DFS example (Sokoban rules = only pushing)

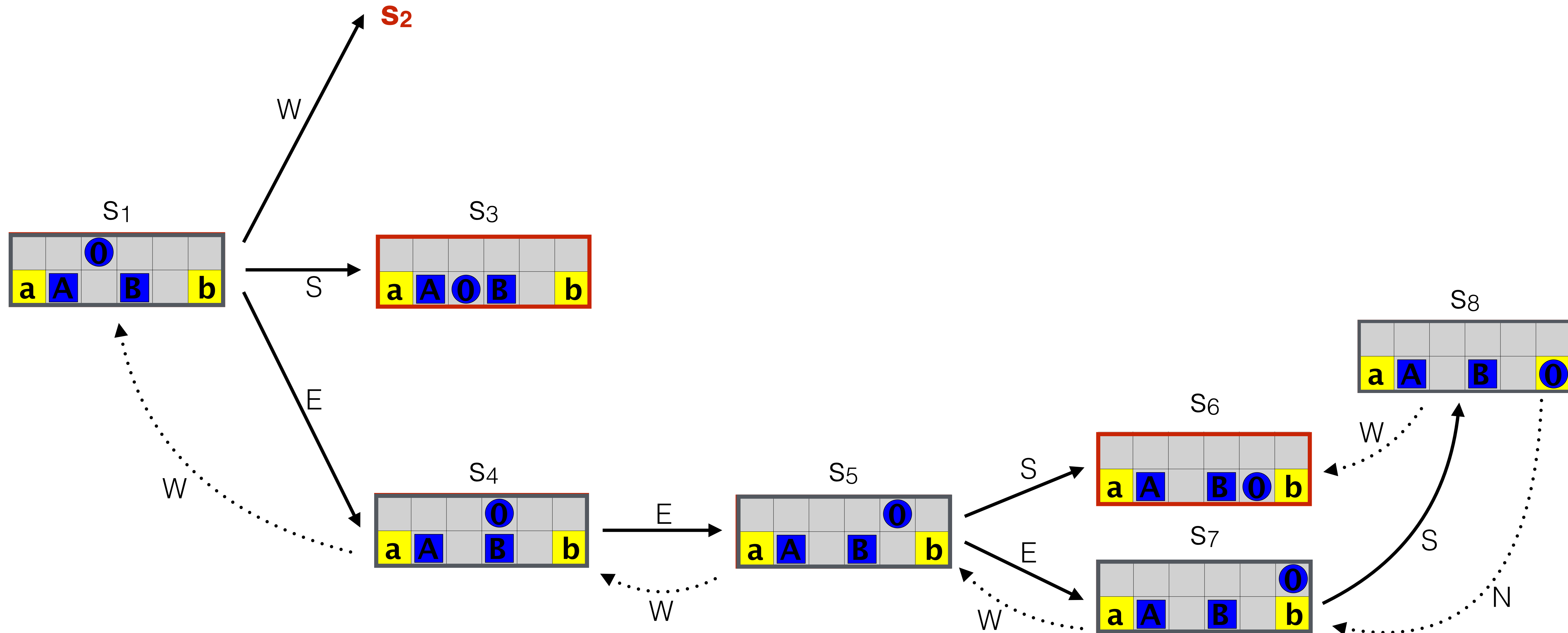
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

DFS example (Sokoban rules = only pushing)

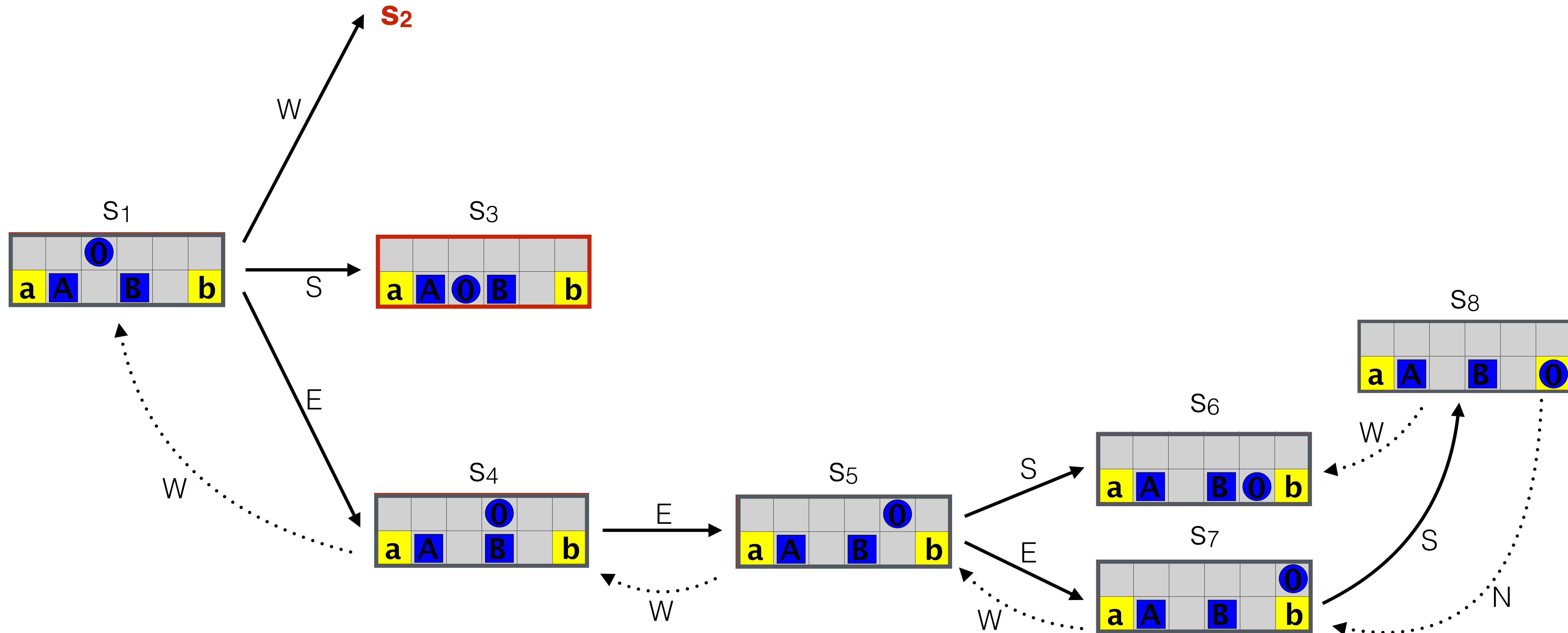
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

DFS example (Sokoban rules = only pushing)

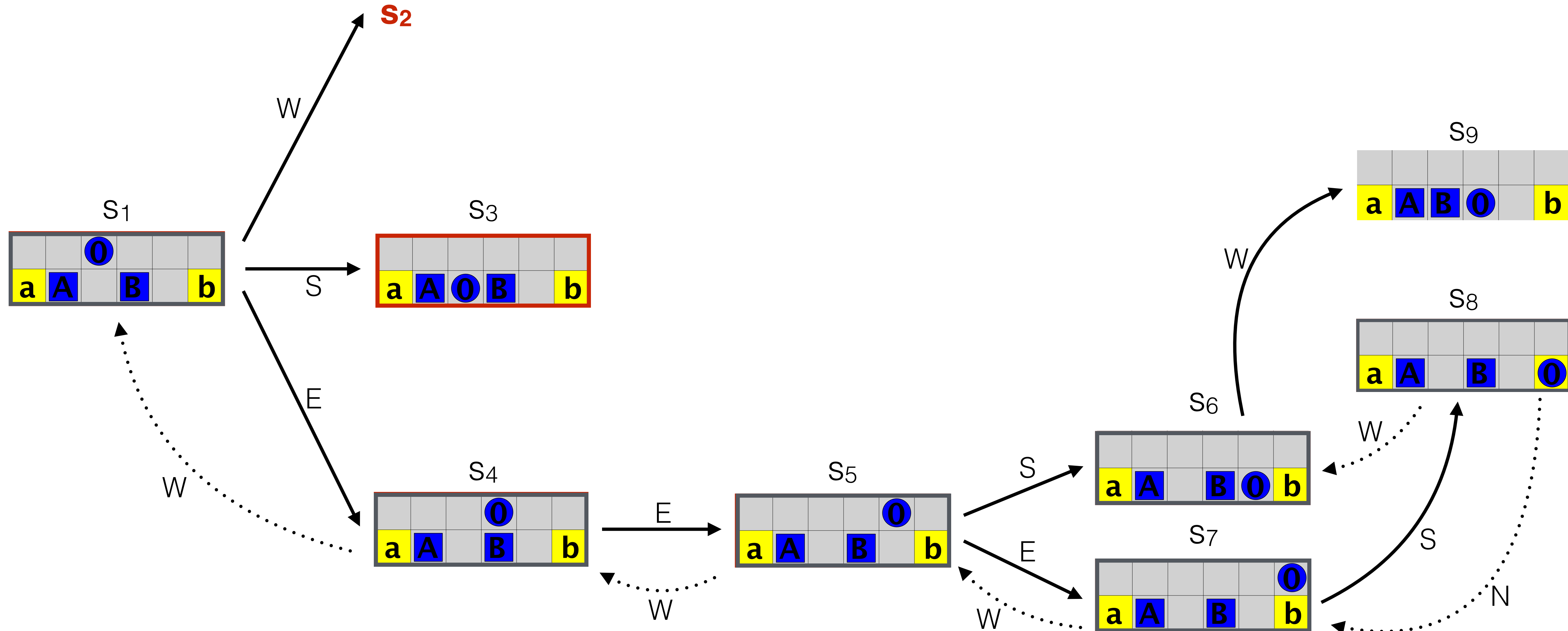
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

DFS example (Sokoban rules = only pushing)

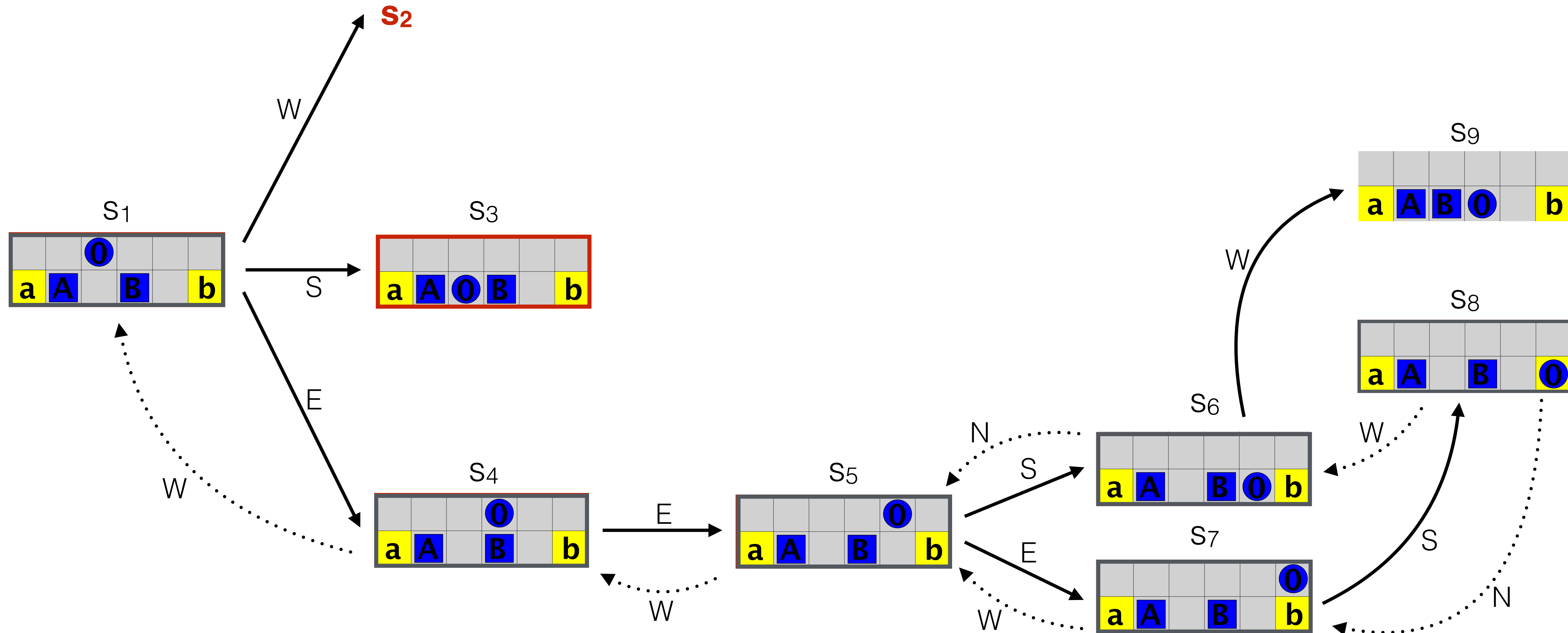
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

DFS example (Sokoban rules = only pushing)

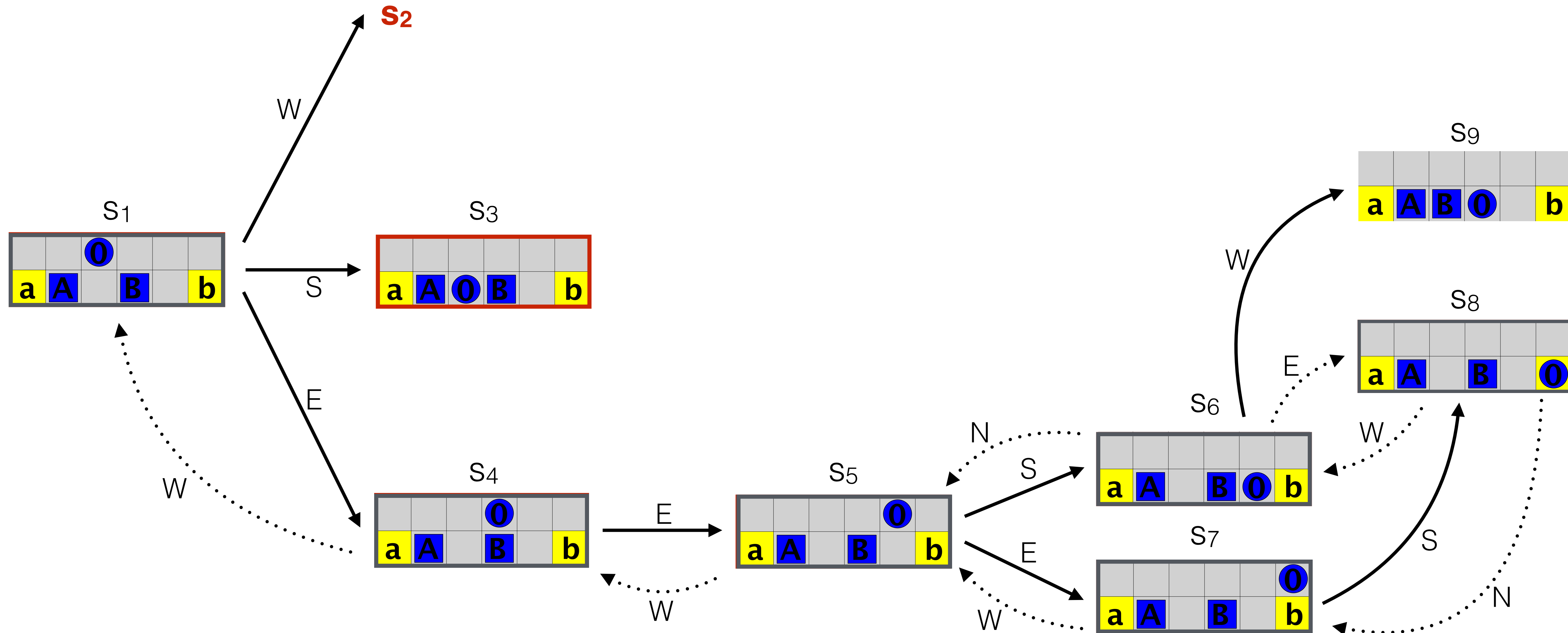
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

DFS example (Sokoban rules = only pushing)

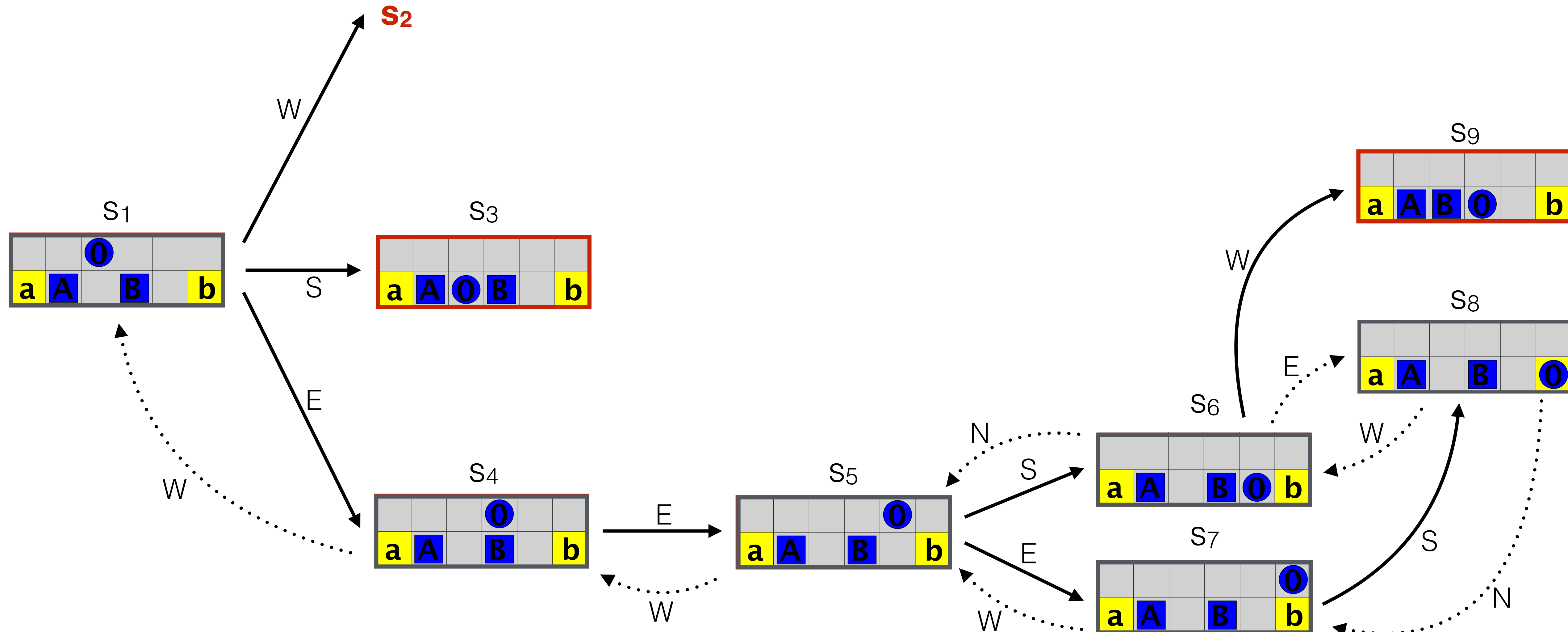
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

DFS example (Sokoban rules = only pushing)

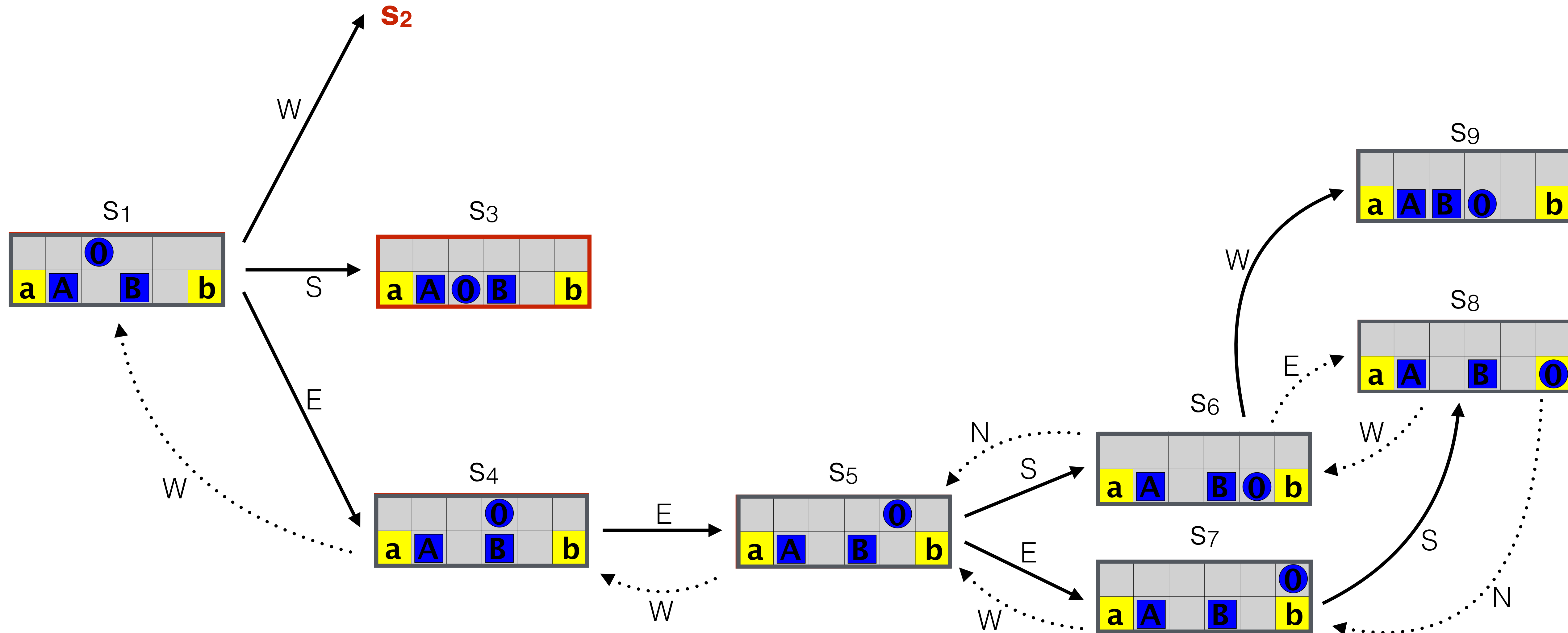
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

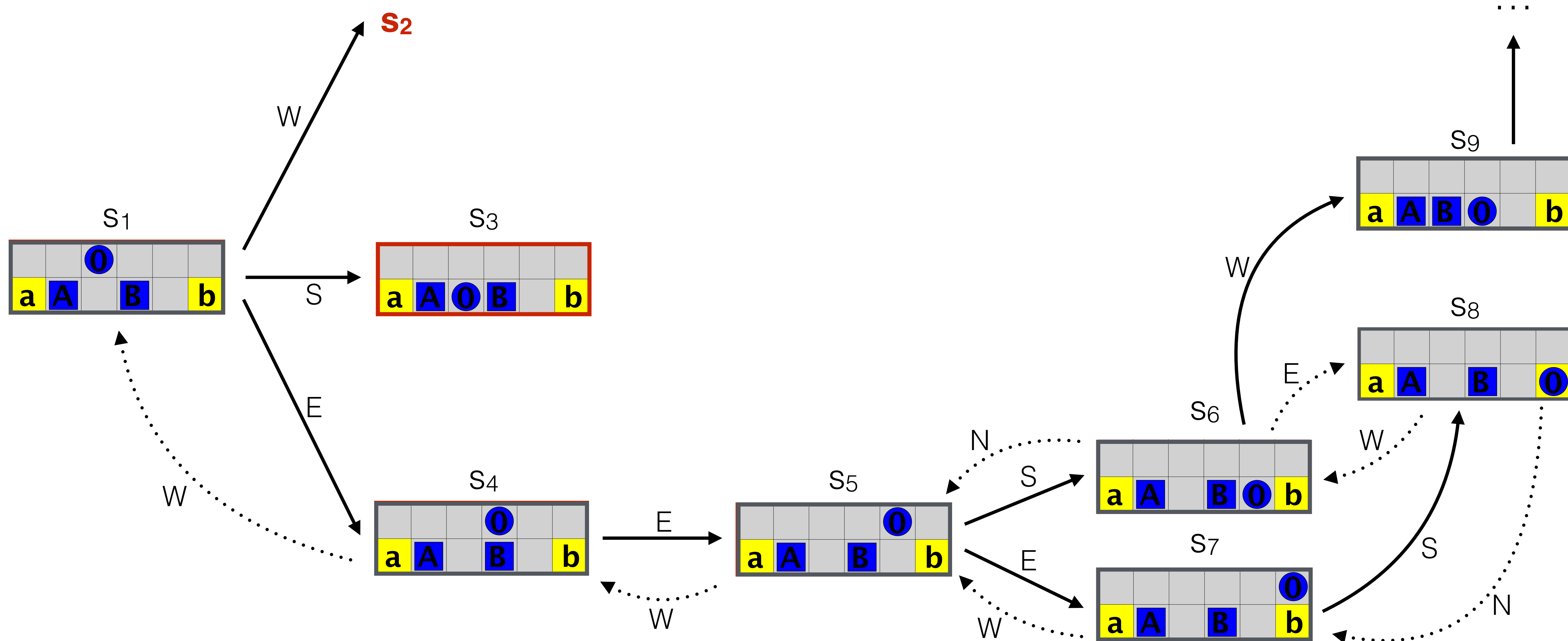
DFS example (Sokoban rules = only pushing)

Order: W, S, N, E



DFS example (Sokoban rules = only pushing)

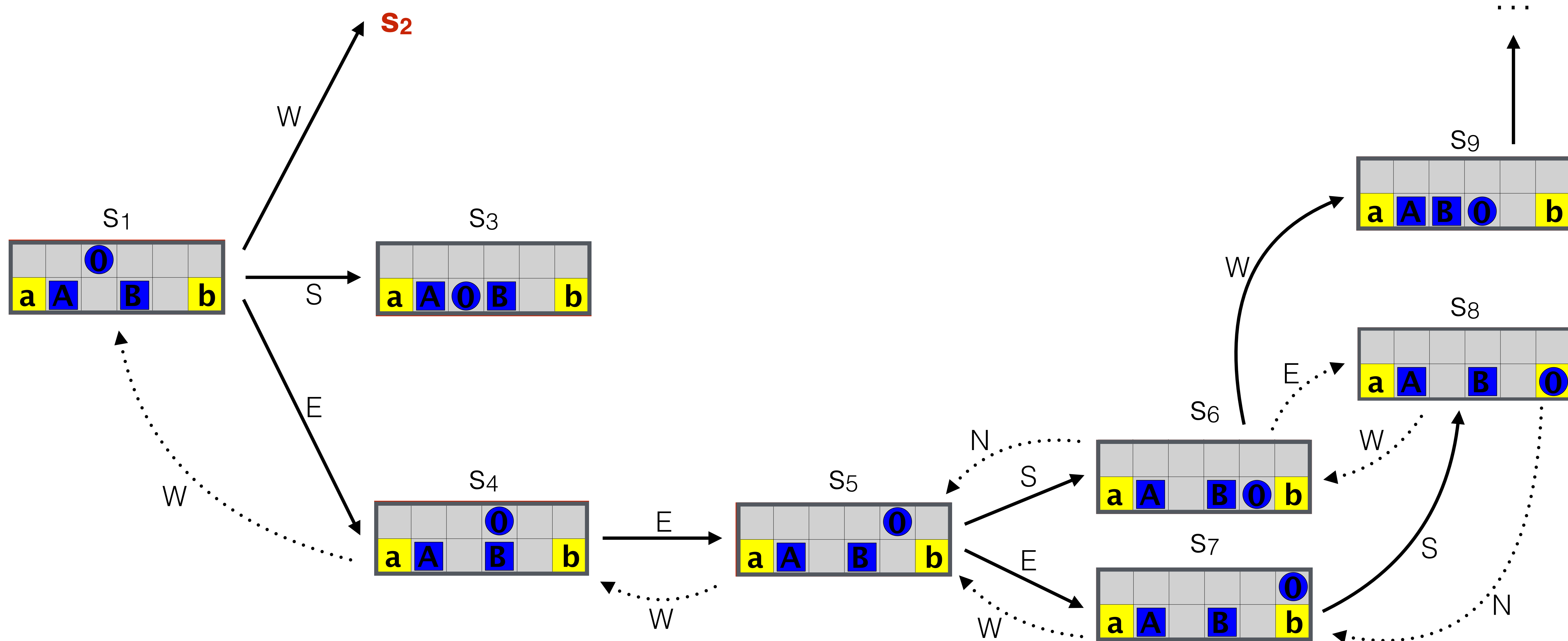
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

DFS example (Sokoban rules = only pushing)

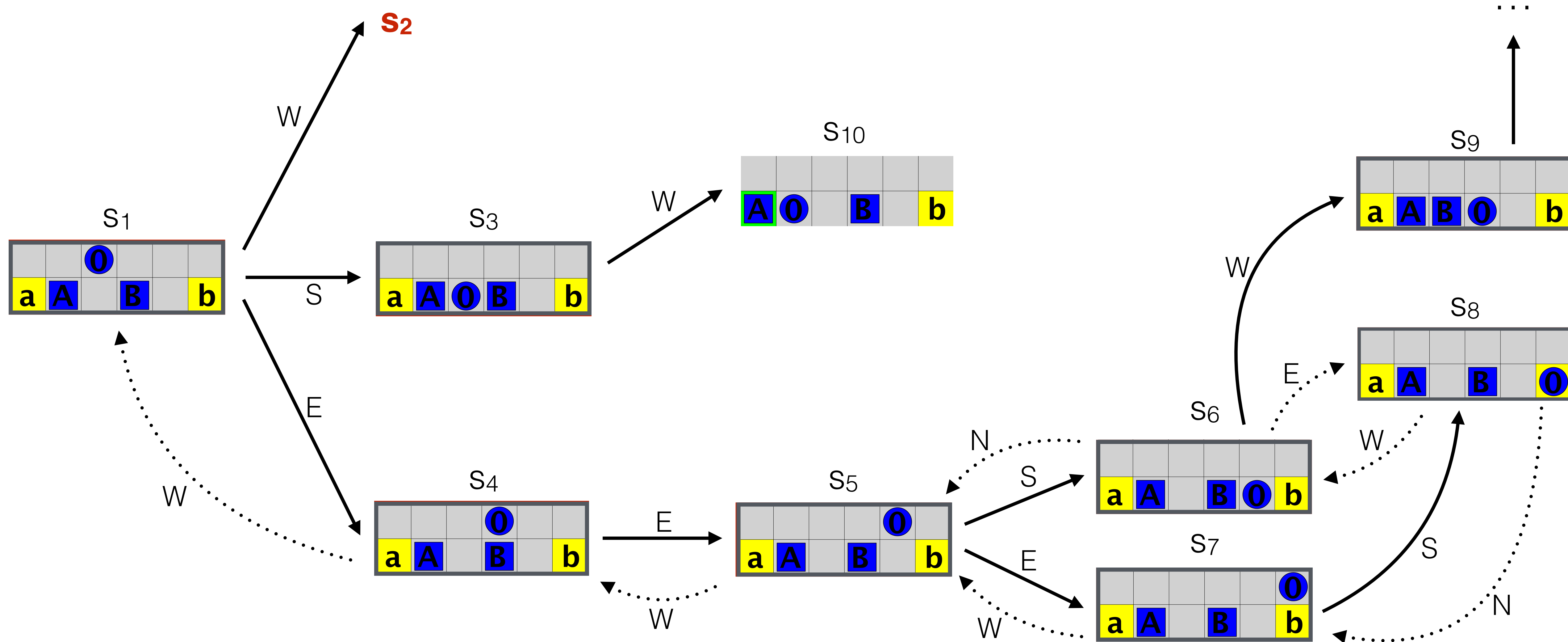
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

DFS example (Sokoban rules = only pushing)

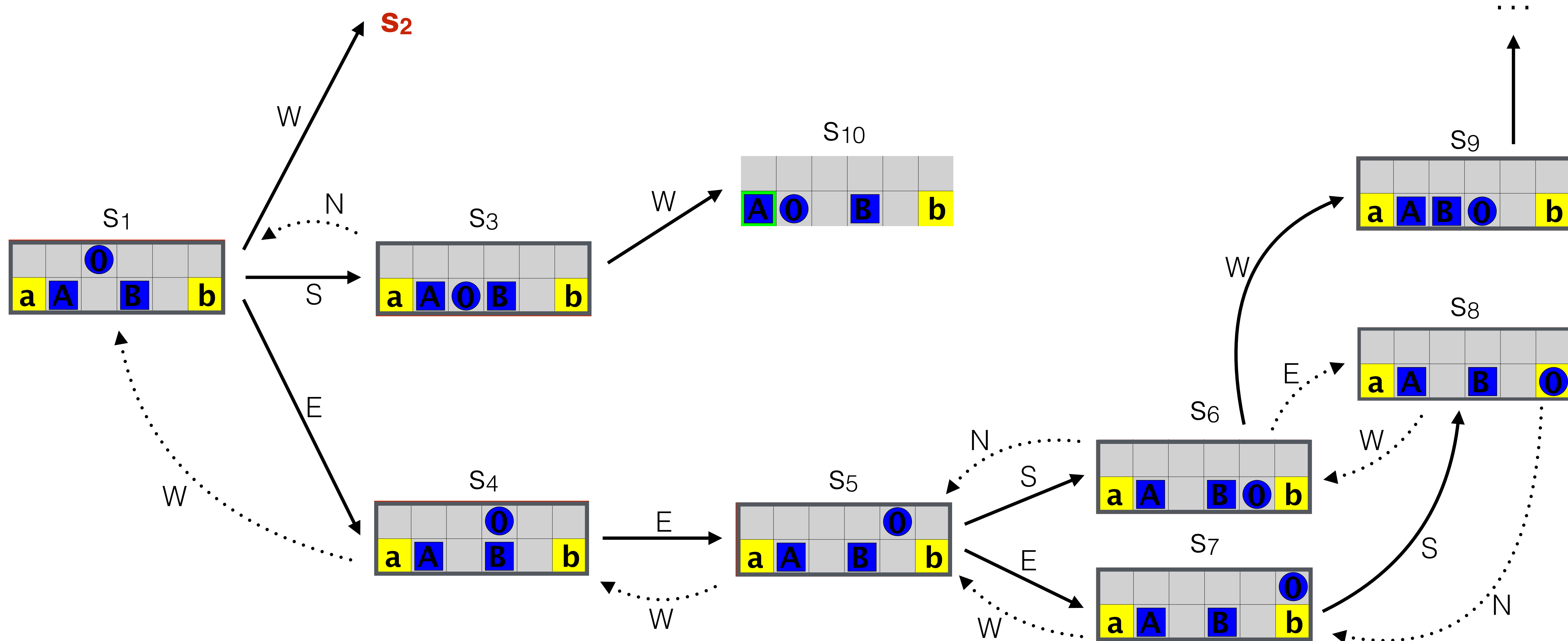
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

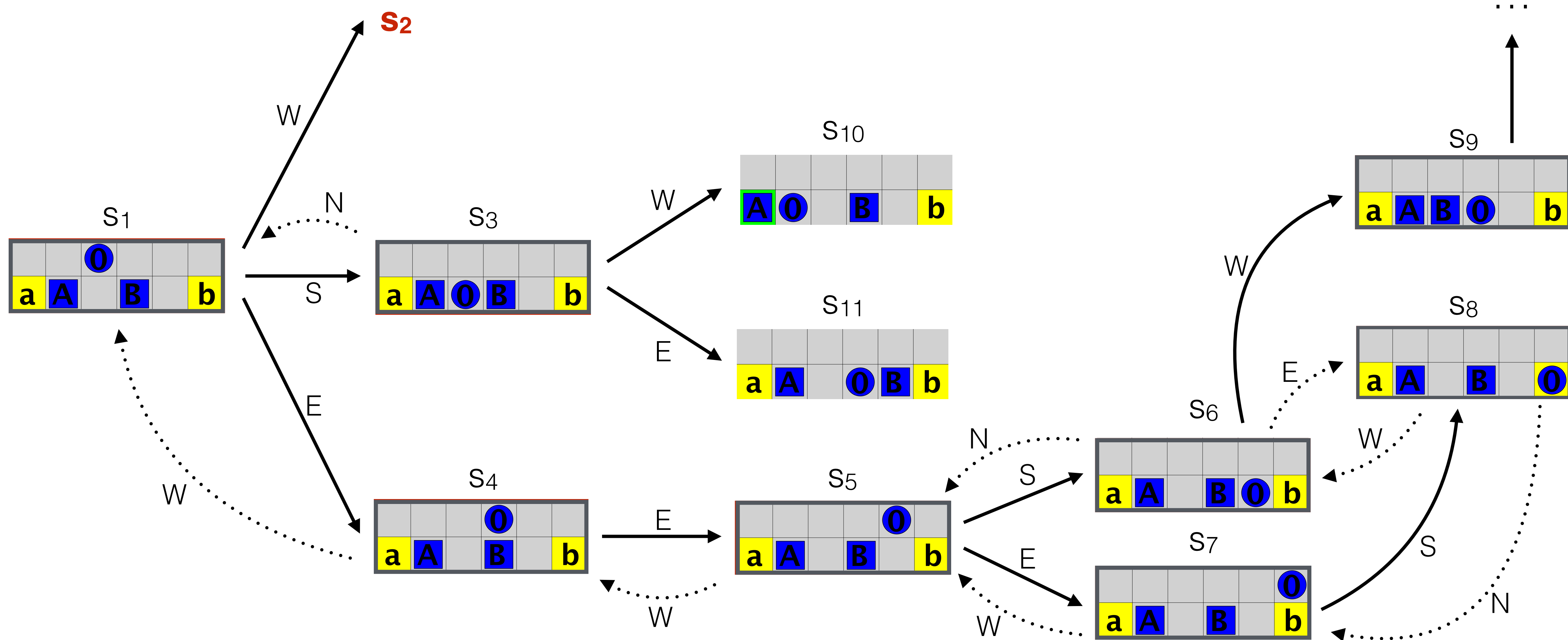
DFS example (Sokoban rules = only pushing)

Order: W, S, N, E



DFS example (Sokoban rules = only pushing)

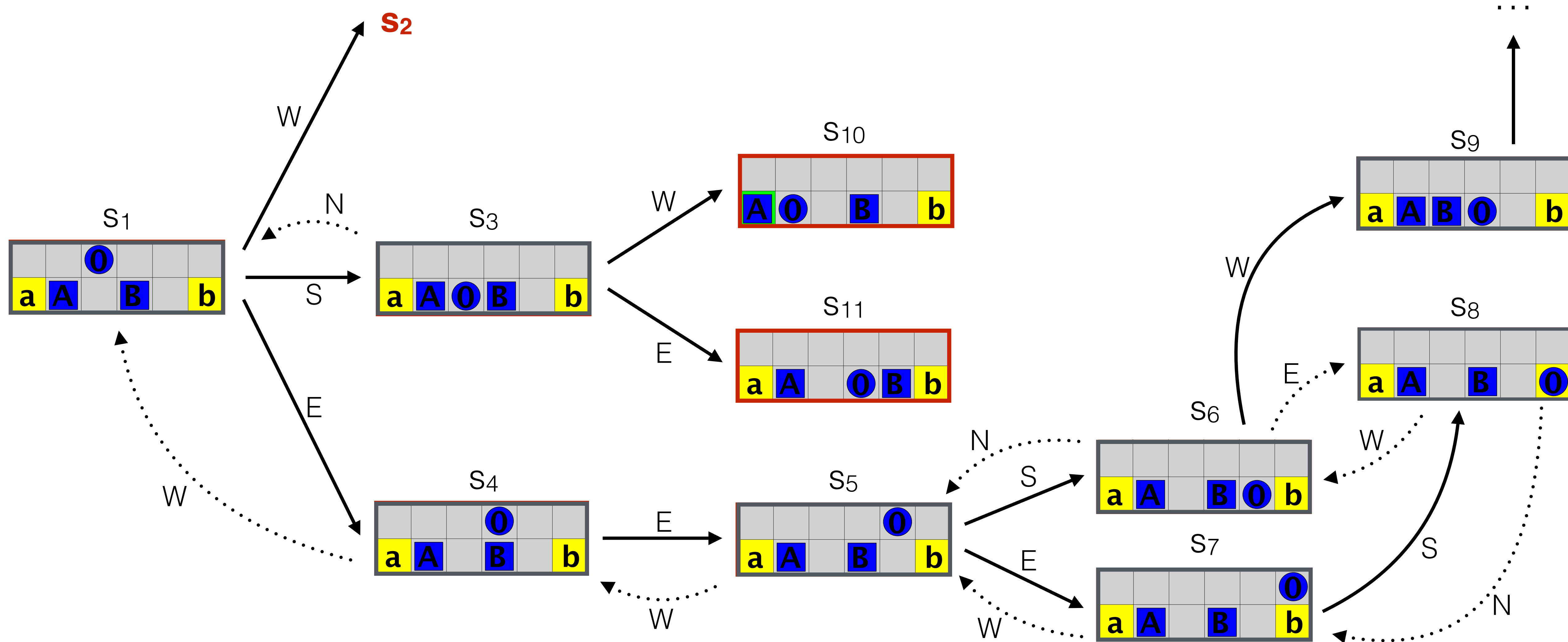
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

DFS example (Sokoban rules = only pushing)

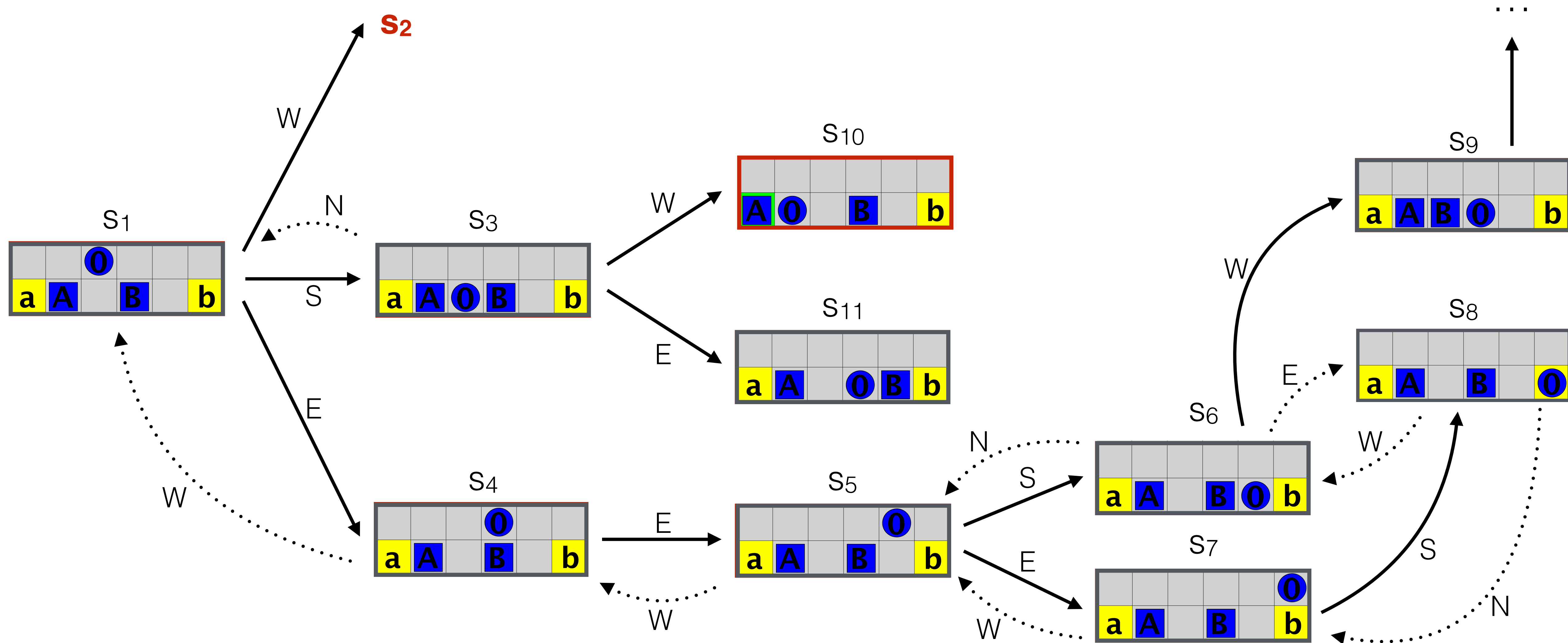
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

DFS example (Sokoban rules = only pushing)

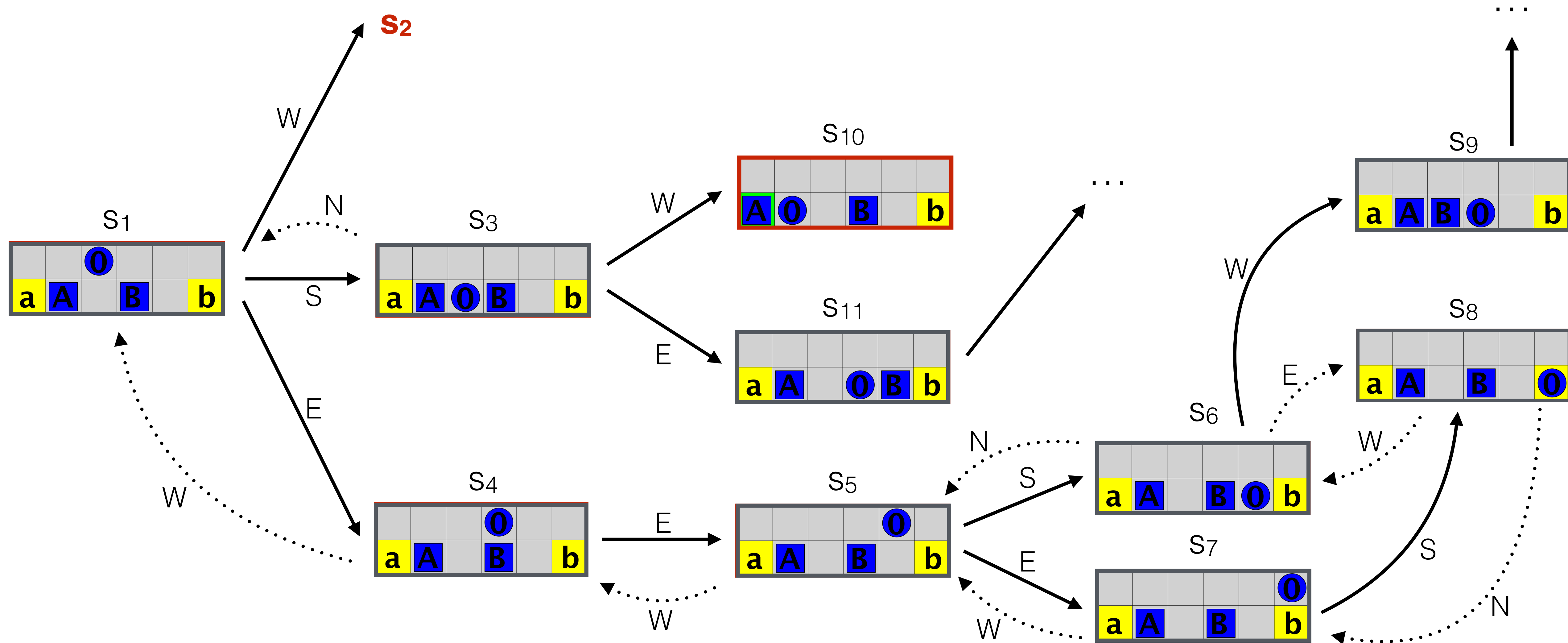
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

DFS example (Sokoban rules = only pushing)

Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

Informed search strategies with GRAPH-SEARCH

- **Best-First Search:**
 - Frontier is a **priority queue** where the key of a node n is denoted $f(n)$.
 - **Choose leaf node:** extract minimal node from priority queue (that is, a node n with minimal $f(n)$).
 - **Add child to frontier:** insert node into priority queue.
- Let $g(n)$ denote the distance of a node n from the initial state (length of shortest path from init state to n). Let $h(n)$ denote a **heuristic function** ($h(n)$ gives an estimate of the distance from n to the goal).
- Different versions of best-first search depending on how the key $f(n)$ of a node n is calculated:
 - **A***: $f(n) = g(n) + h(n)$.
 - **WA***: $f(n) = g(n) + W h(n)$, for some constant $W > 1$.
 - **Greedy best first search**: $f(n) = h(n)$.
 - Which algorithm do you get when letting $f(n) = g(n)$?

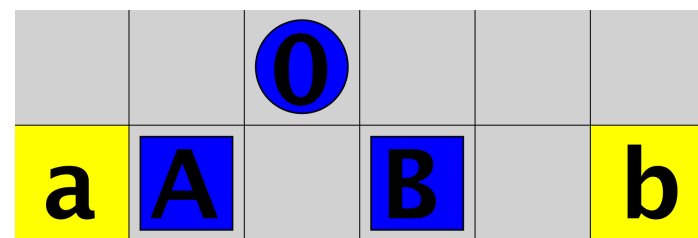
Designing heuristic functions

- Designing good heuristic functions $h(n)$ is a great art form.
- Repetition from 02180 (R&N Ch. 3): What properties should a good heuristic function have?
- You will work with designing heuristic functions both in Assignment 1 and 3.
- A simple example for the Sokoban domain assuming unique goals for each box:
 $h(n)$ = the sum of the distances of boxes to their goals.
- See example using this heuristics on the next page.

Greedy best-first search example

Order: W, S, N, E

S₁

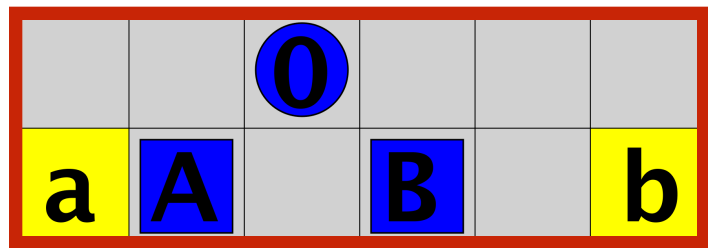


Red border: in frontier. **Grey border:** in exploredNodes.

Greedy best-first search example

Order: W, S, N, E

S₁

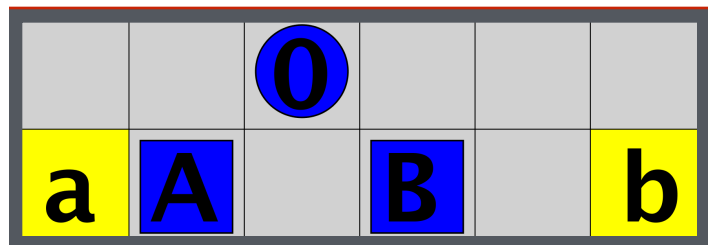


Red border: in frontier. **Grey border:** in exploredNodes.

Greedy best-first search example

Order: W, S, N, E

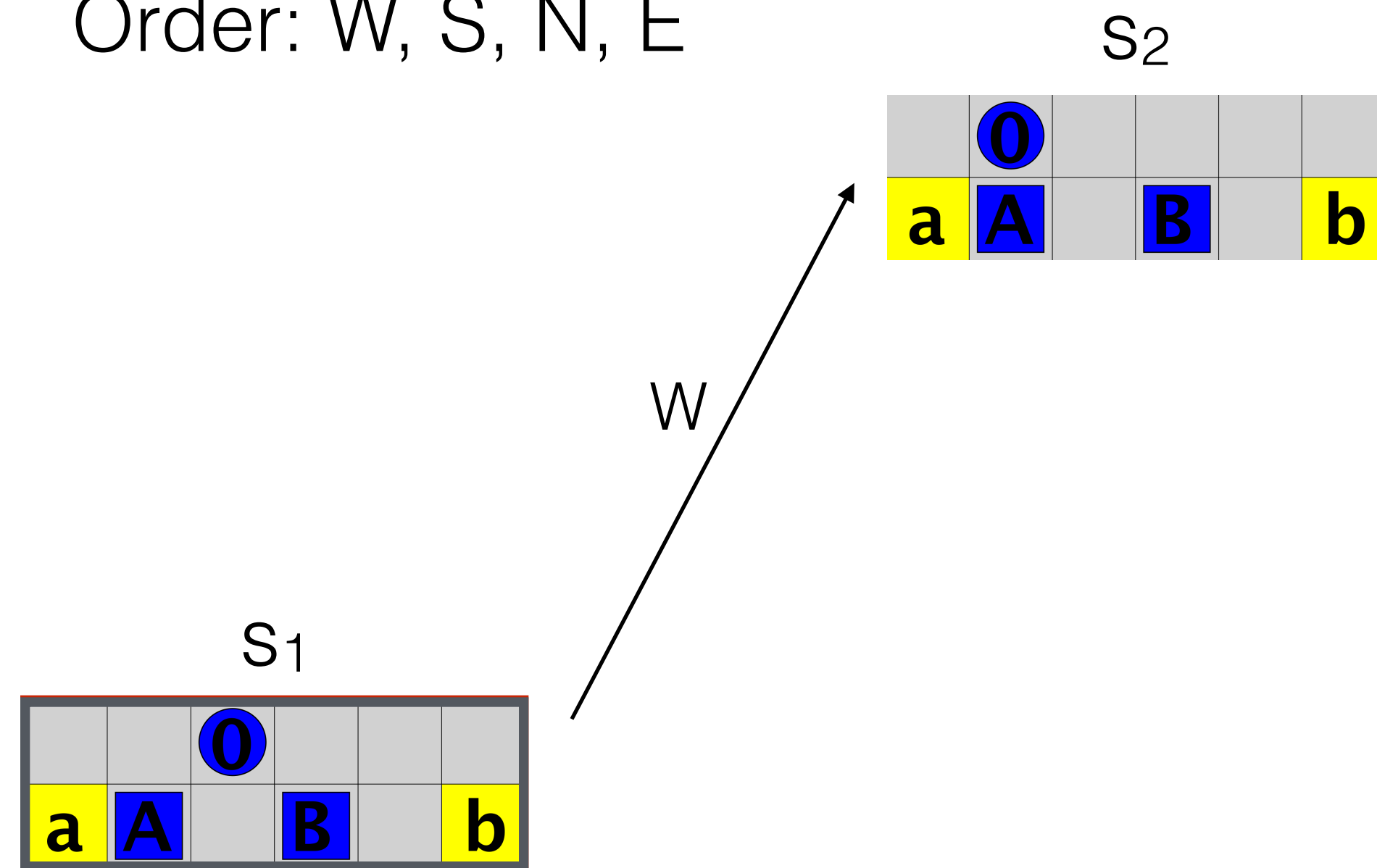
S₁



Red border: in frontier. **Grey border:** in exploredNodes.

Greedy best-first search example

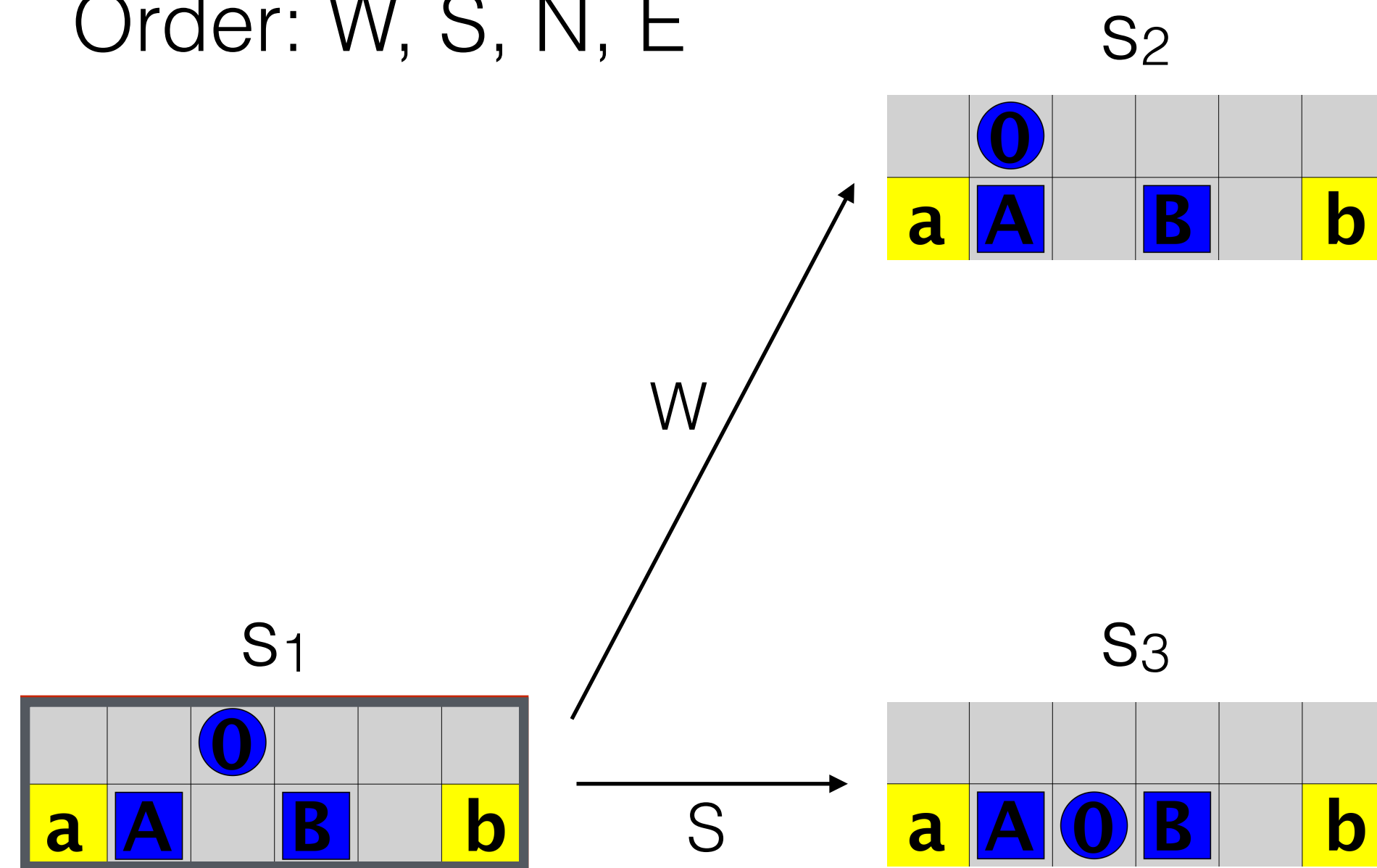
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

Greedy best-first search example

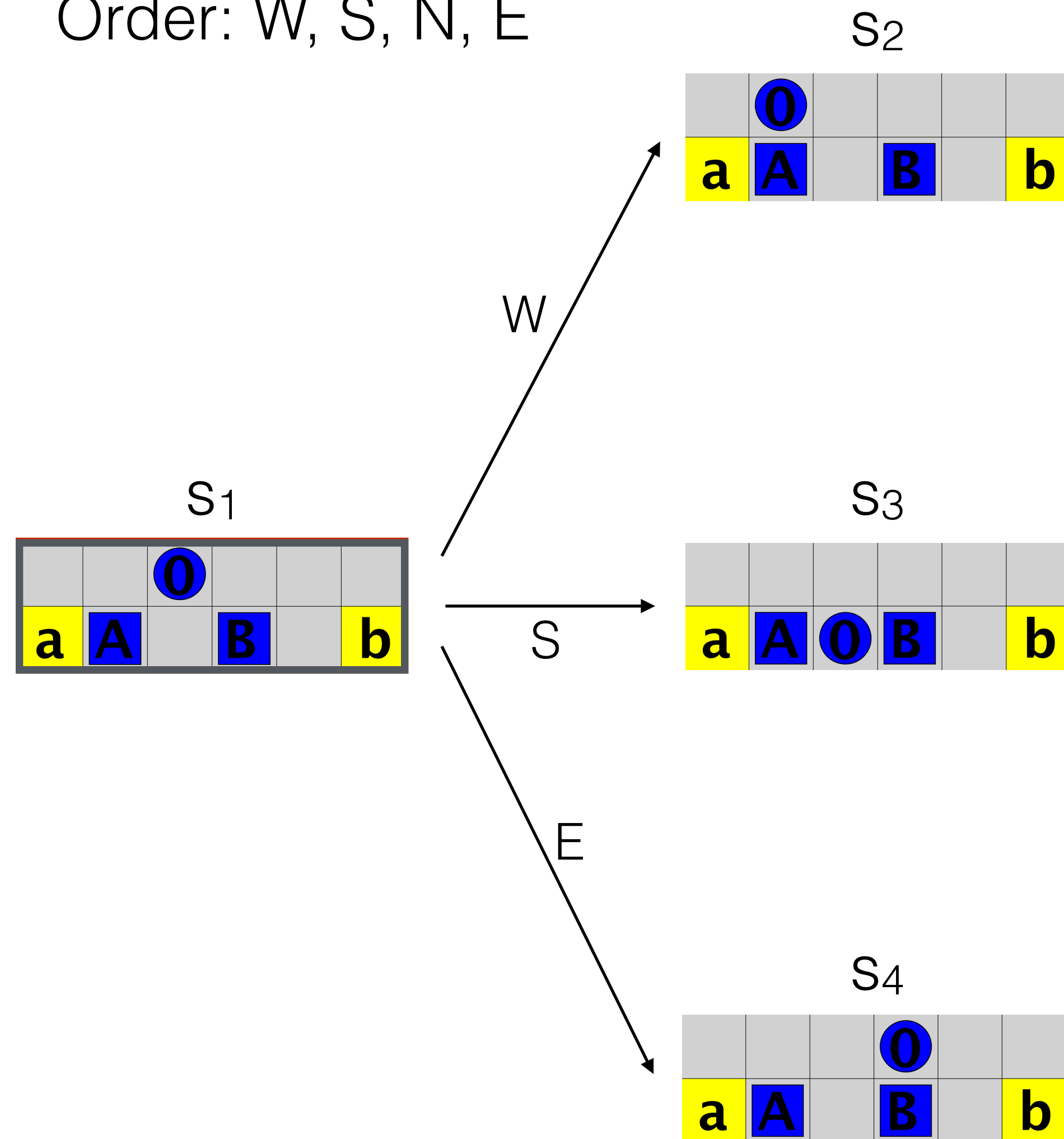
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

Greedy best-first search example

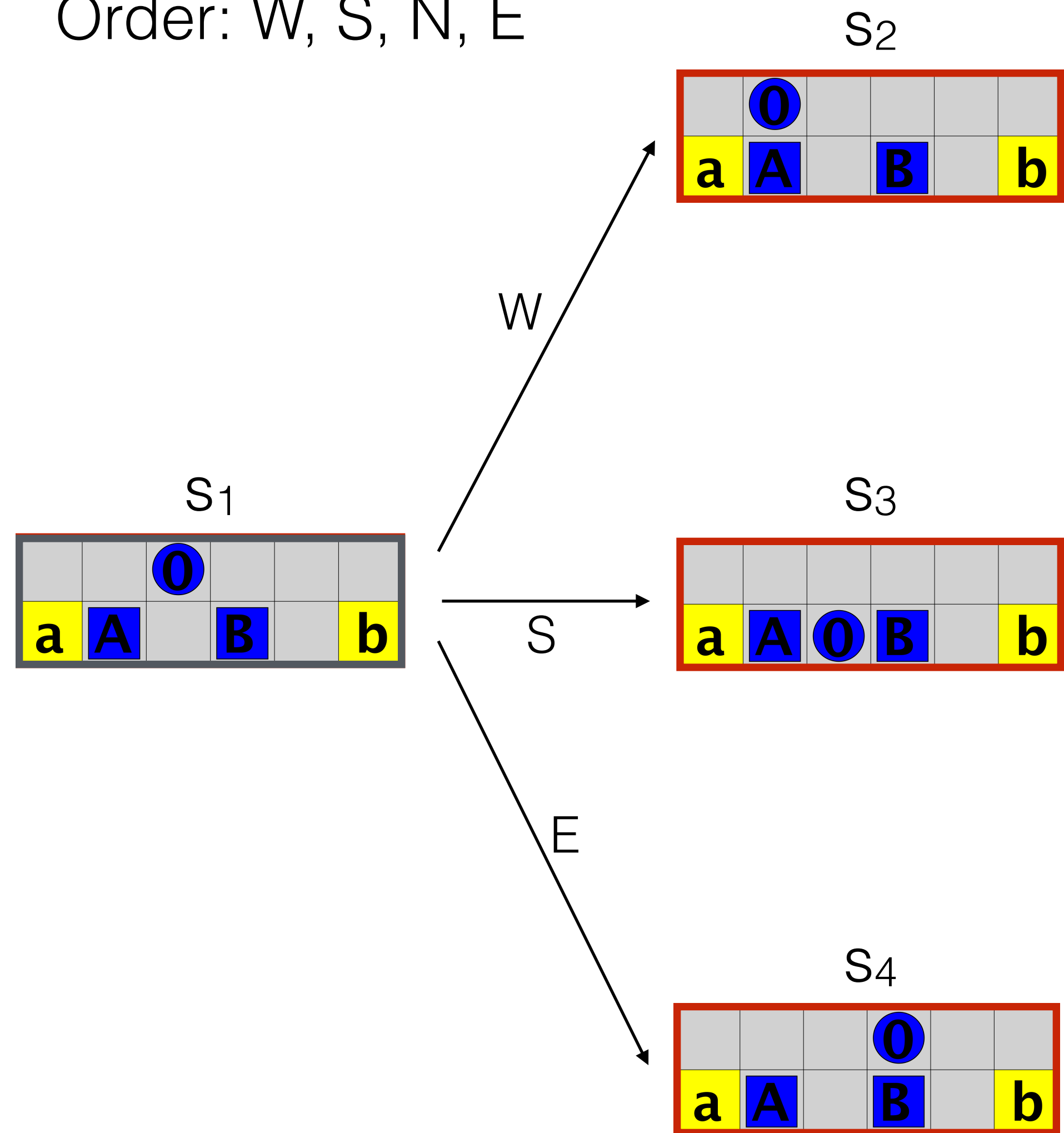
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

Greedy best-first search example

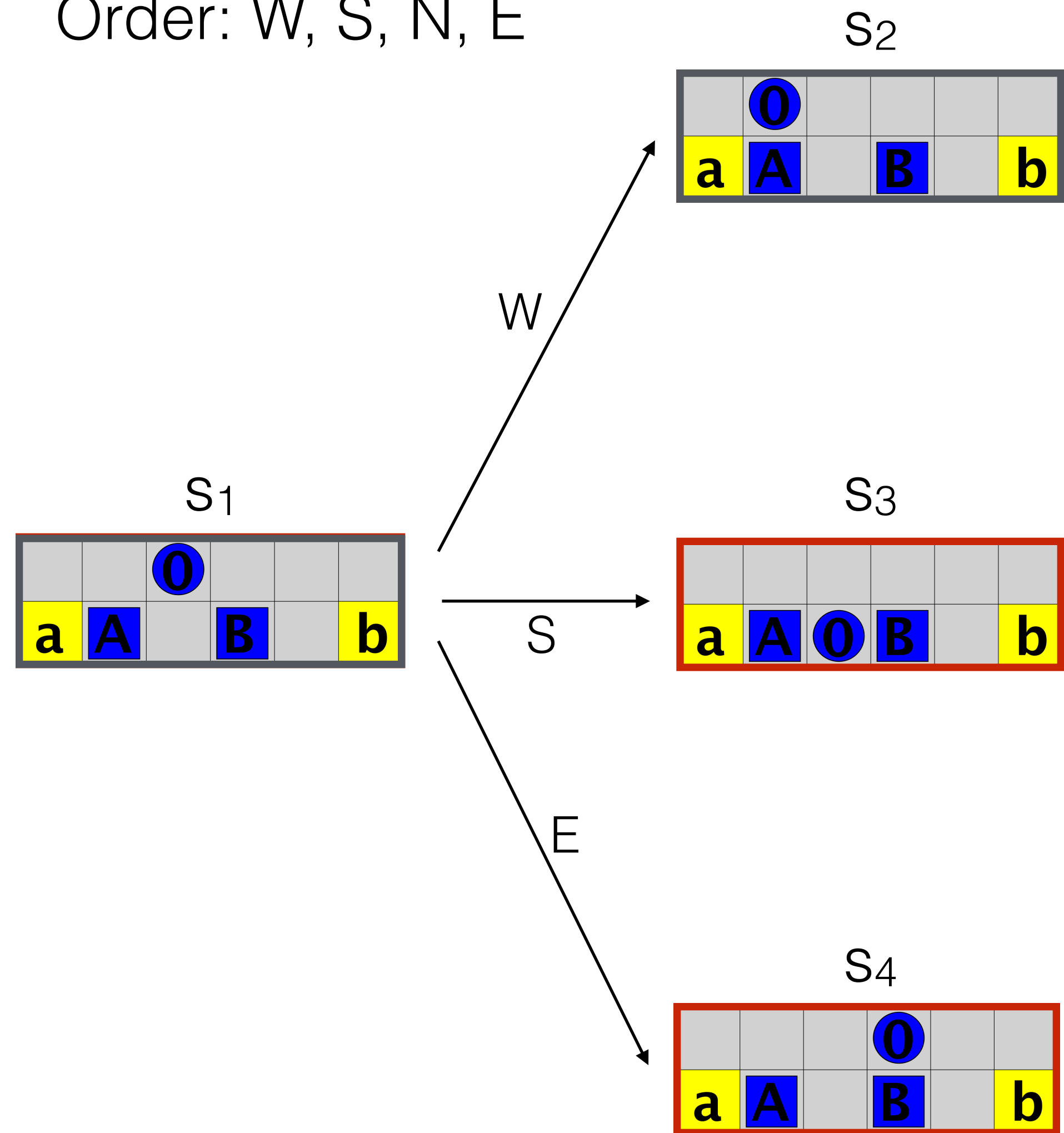
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

Greedy best-first search example

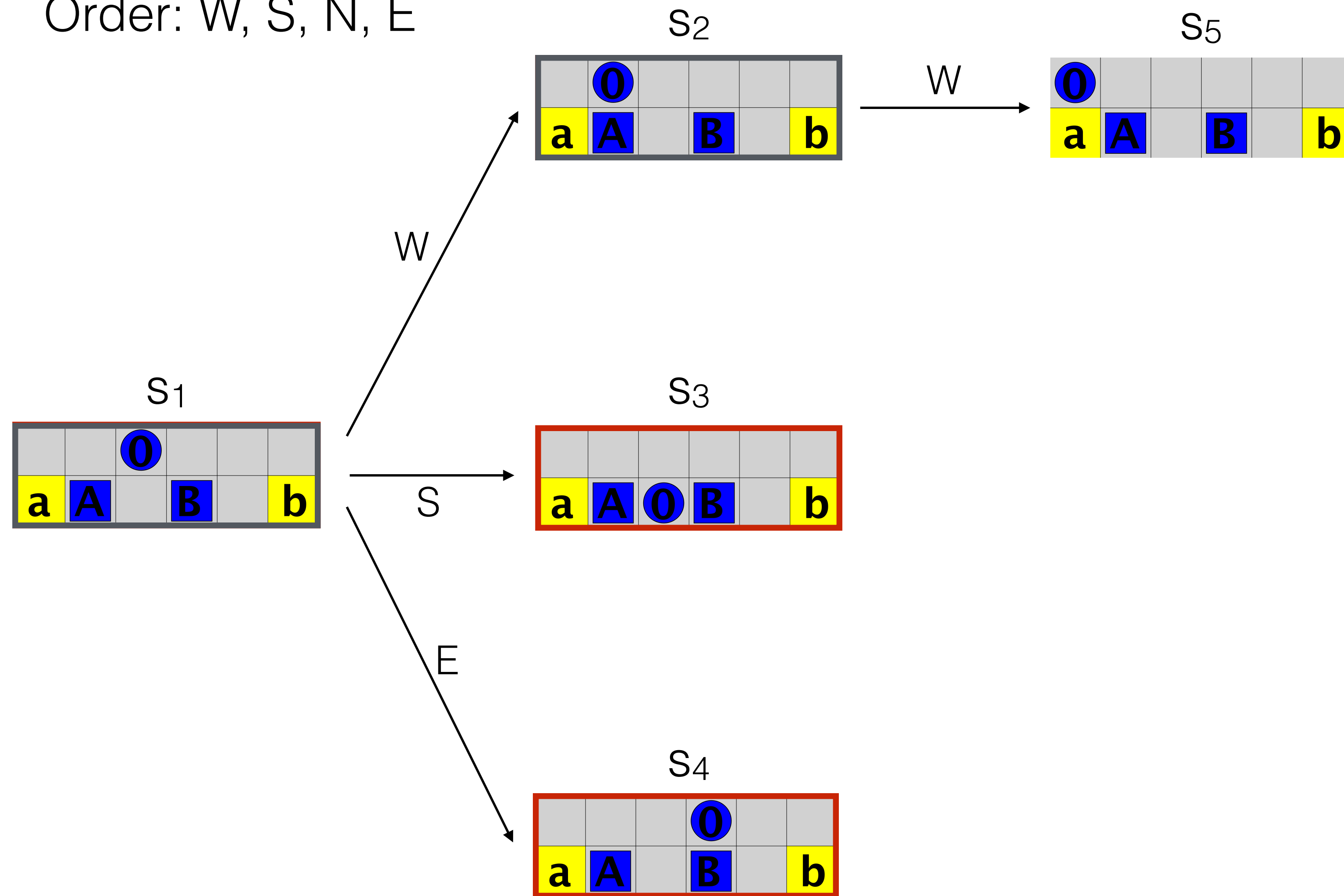
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

Greedy best-first search example

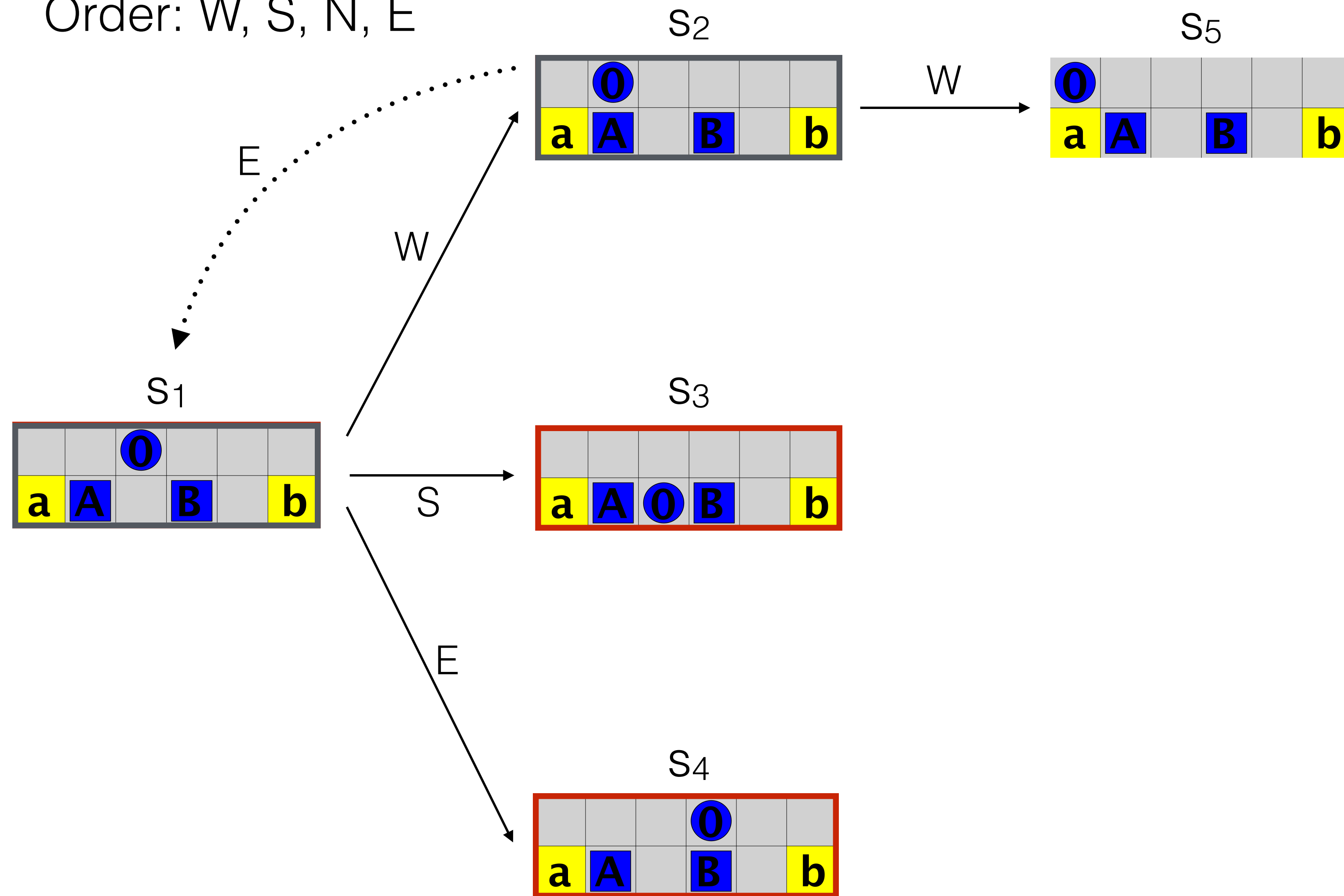
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

Greedy best-first search example

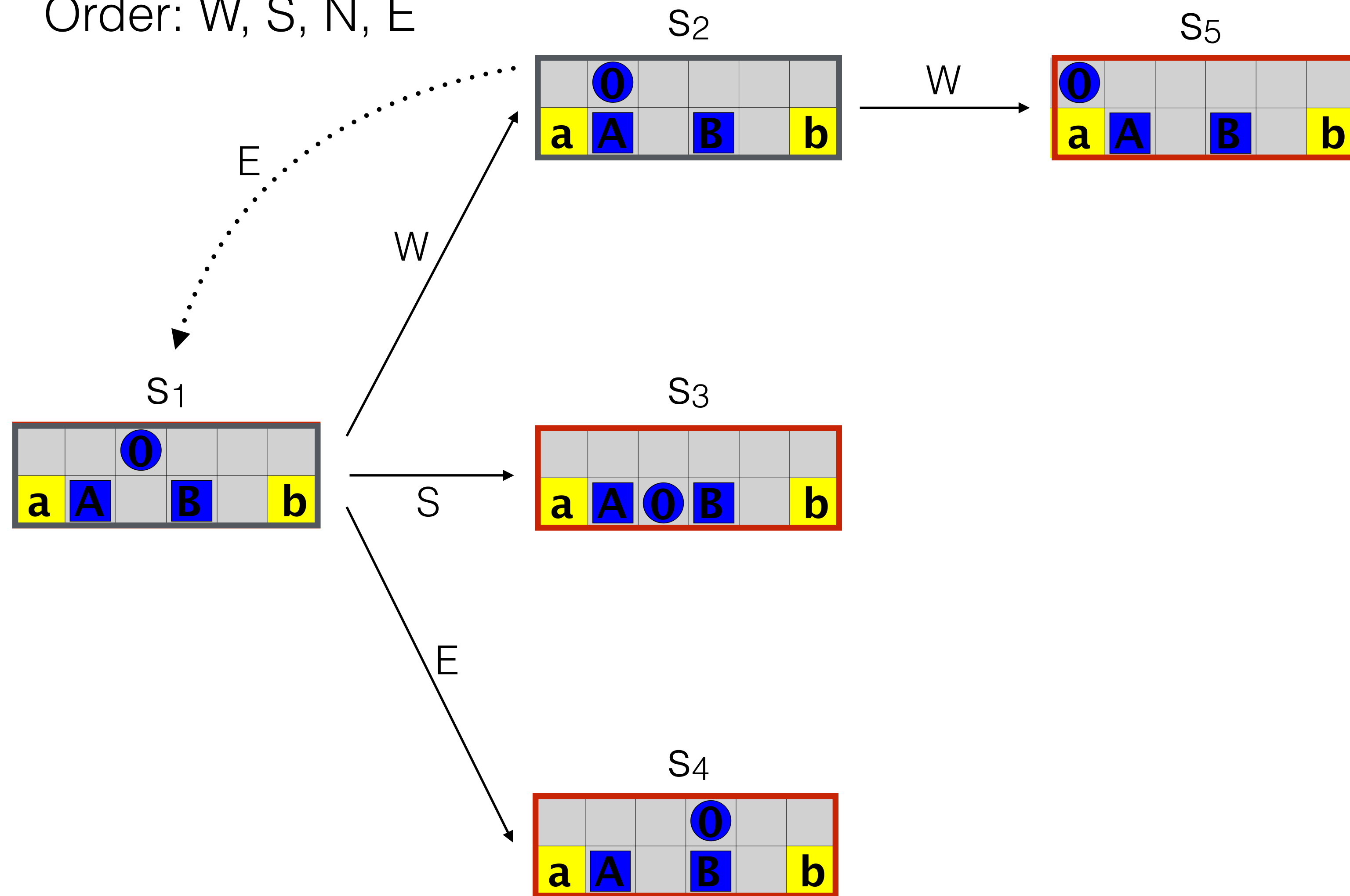
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

Greedy best-first search example

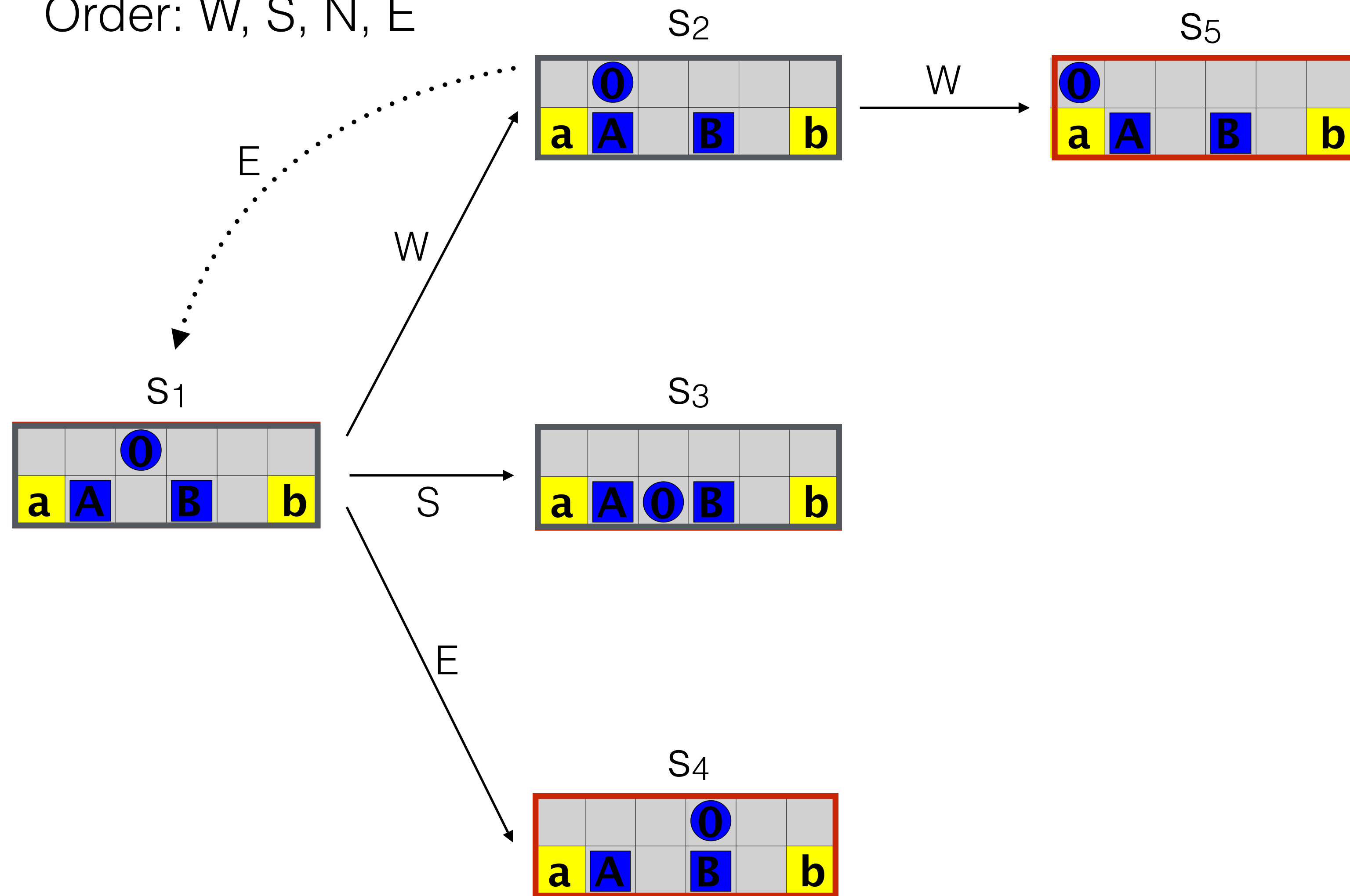
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

Greedy best-first search example

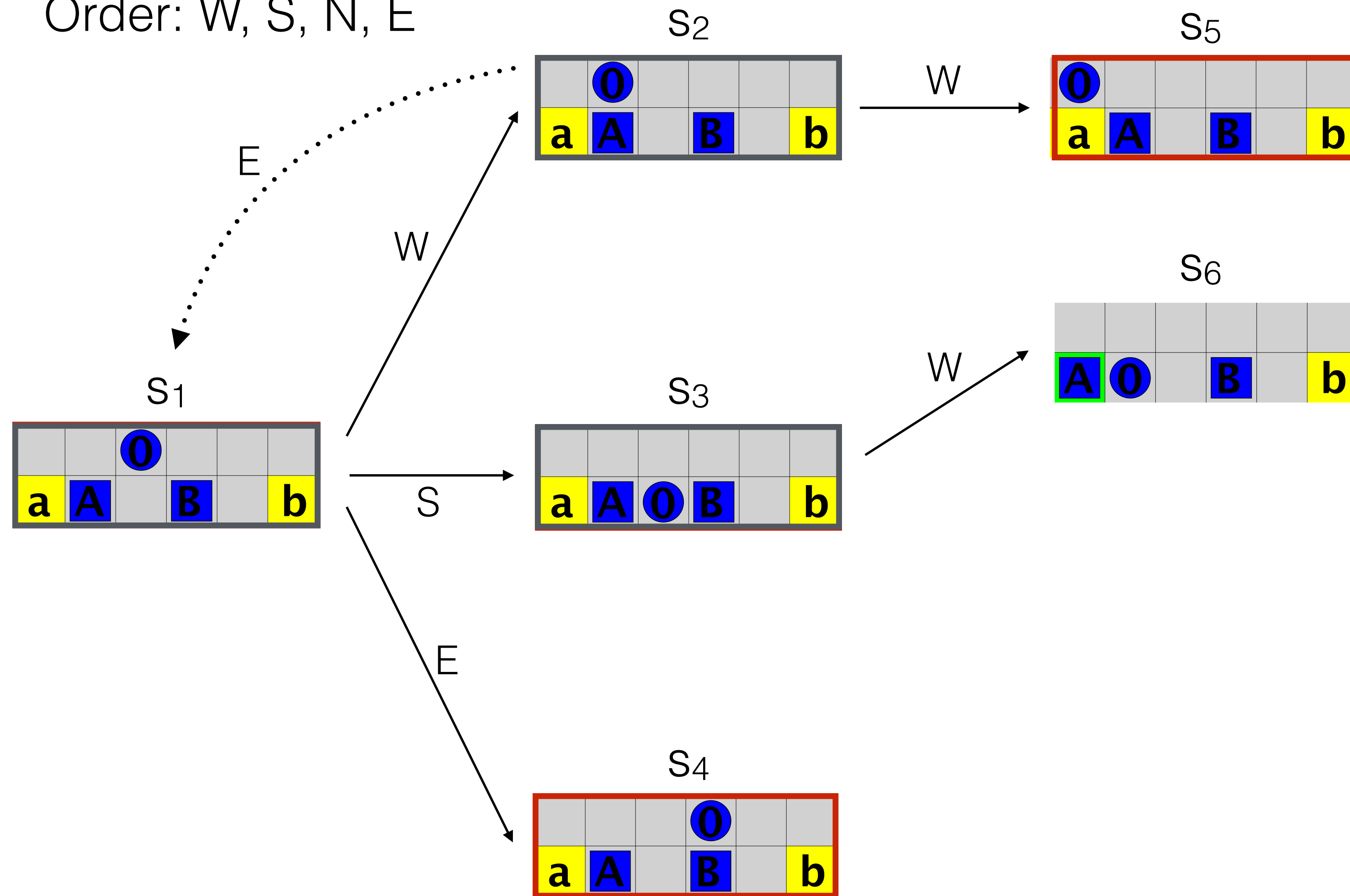
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

Greedy best-first search example

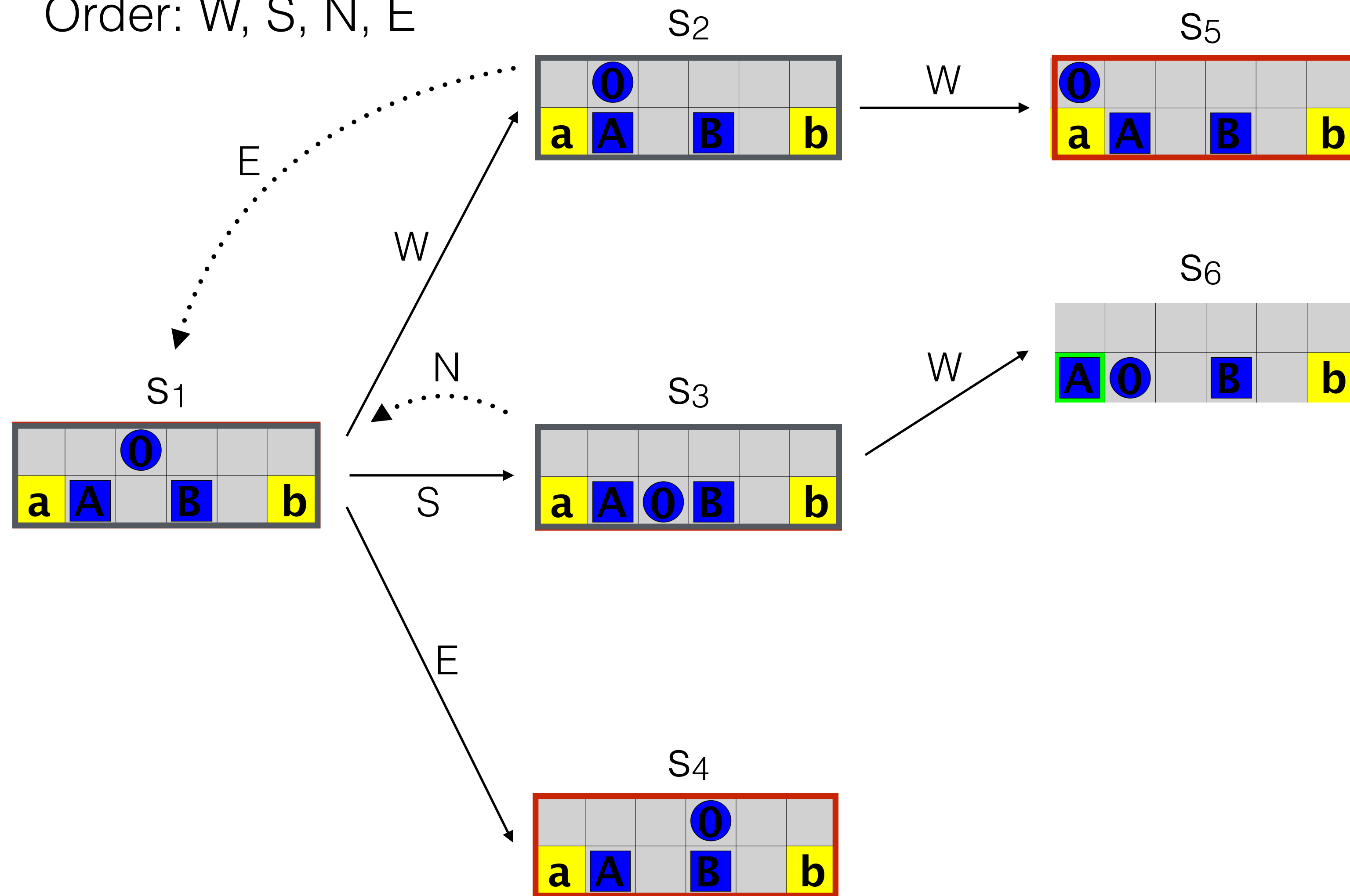
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

Greedy best-first search example

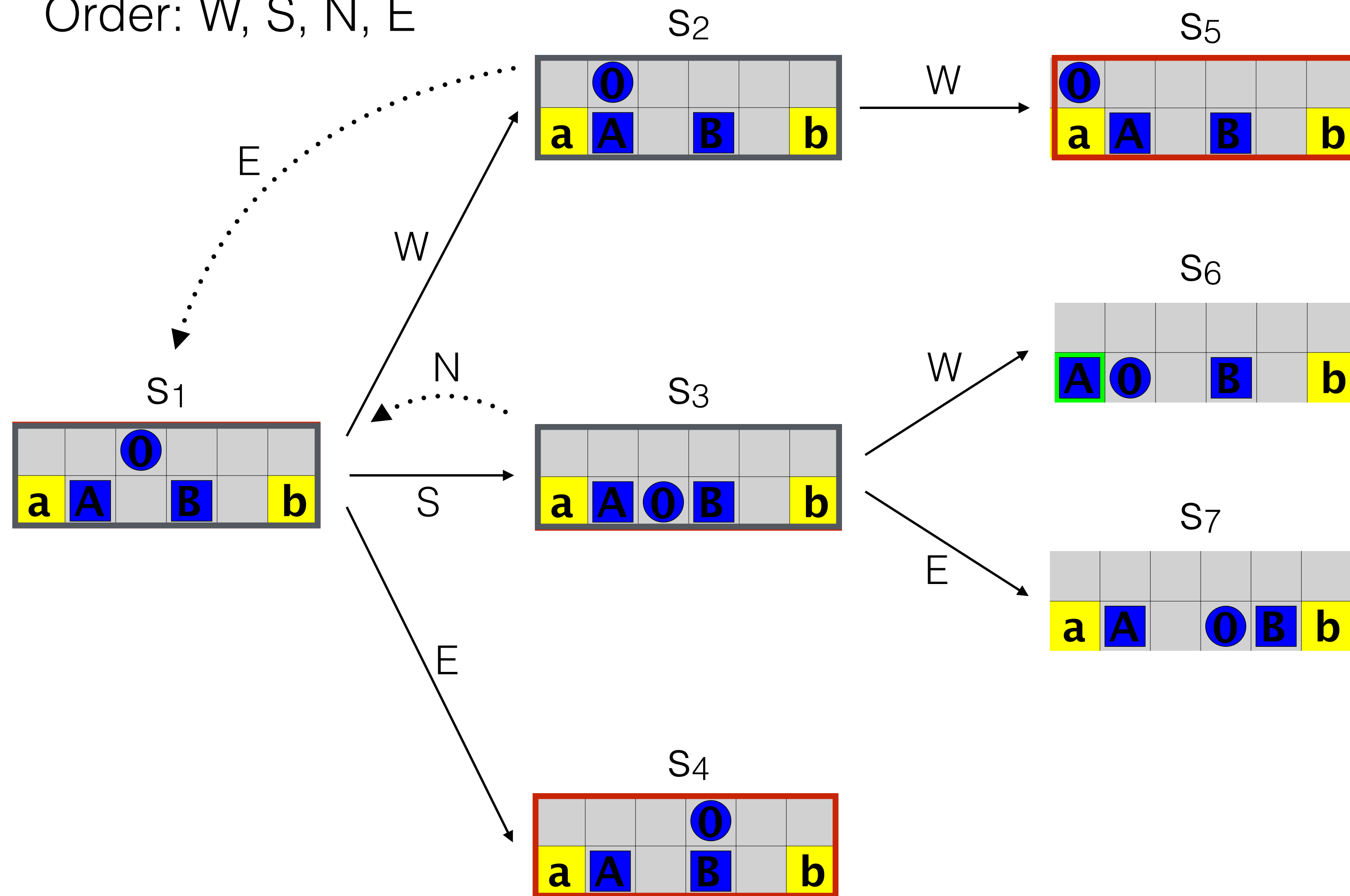
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

Greedy best-first search example

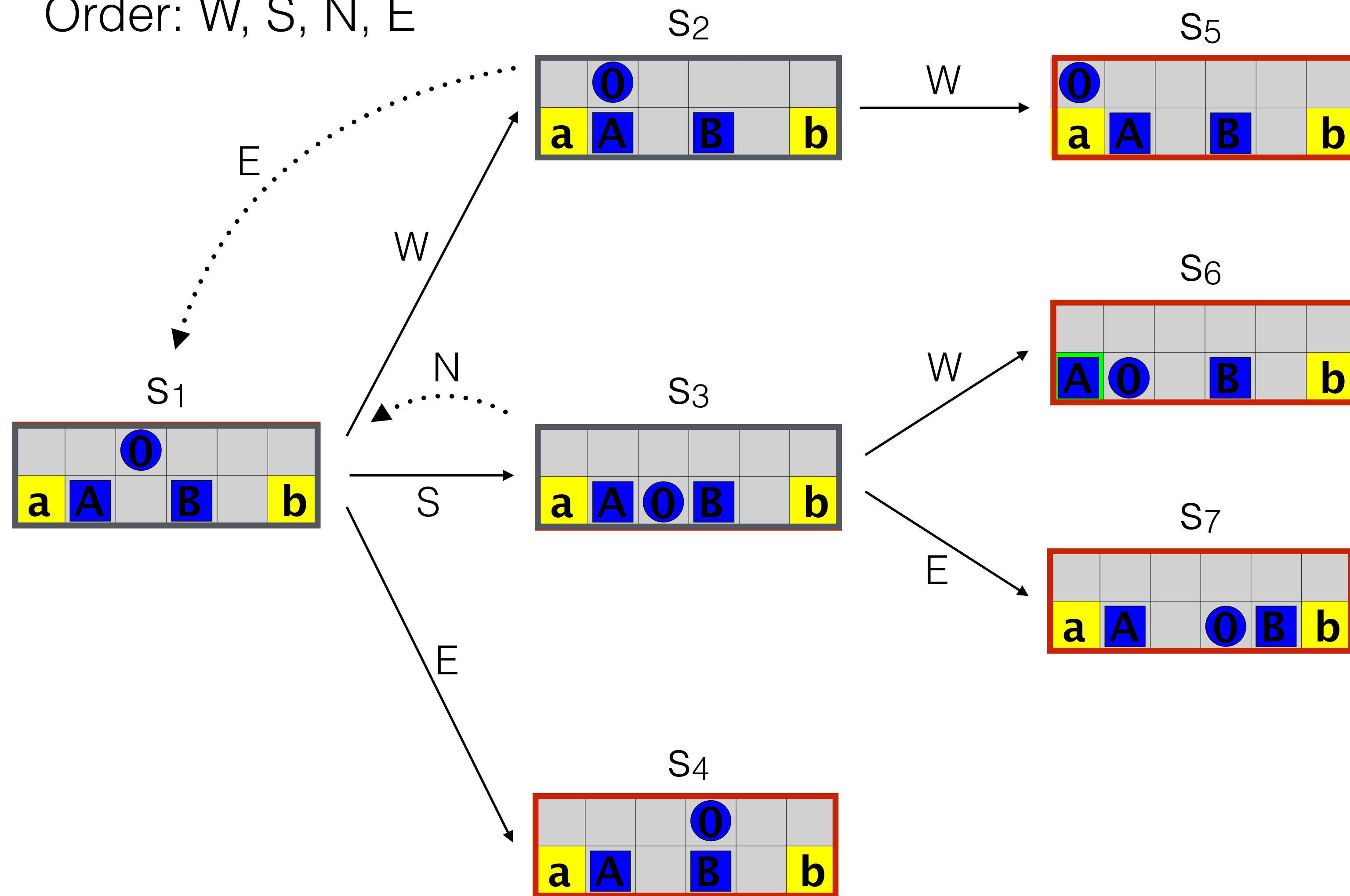
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

Greedy best-first search example

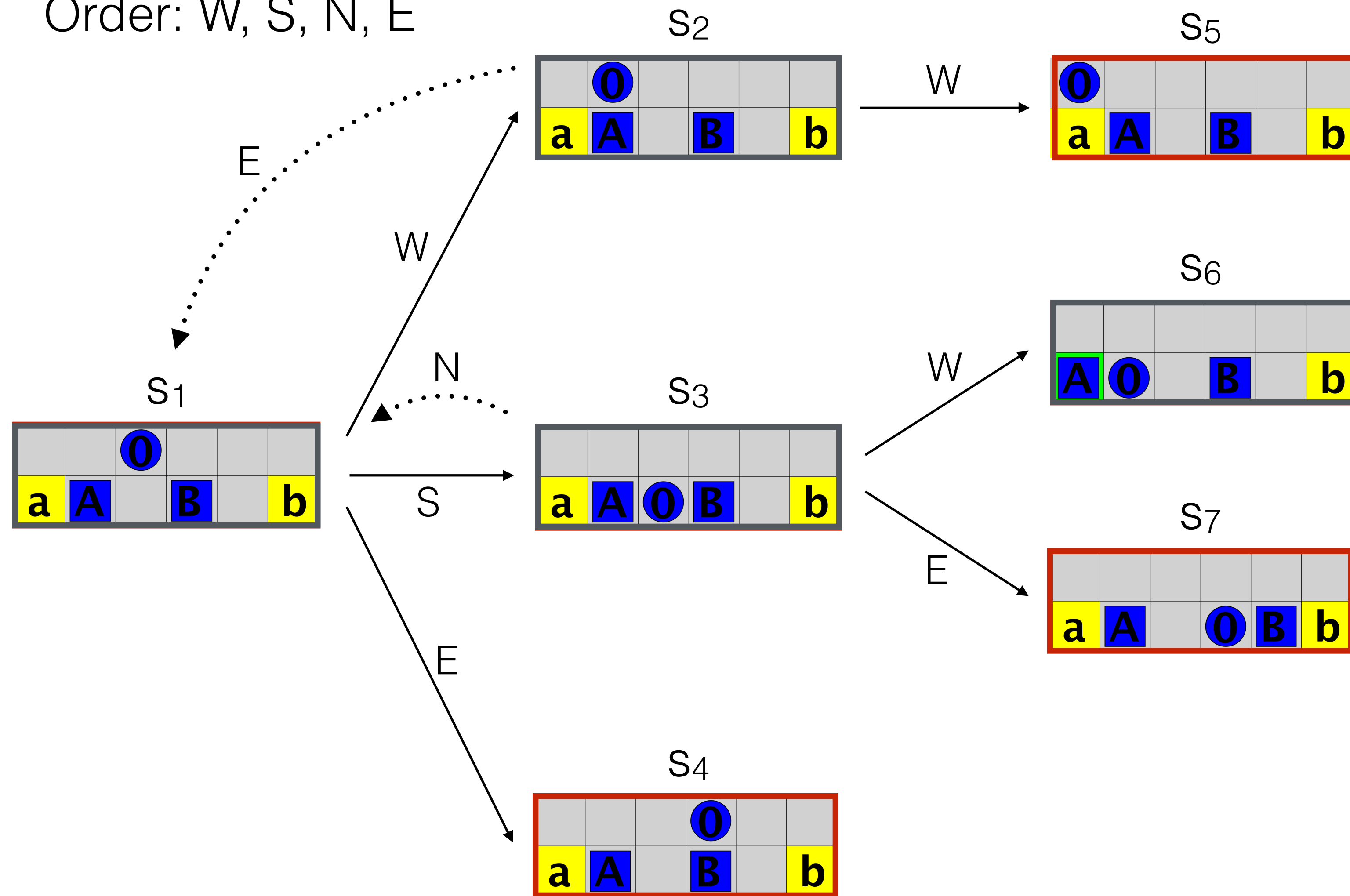
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

Greedy best-first search example

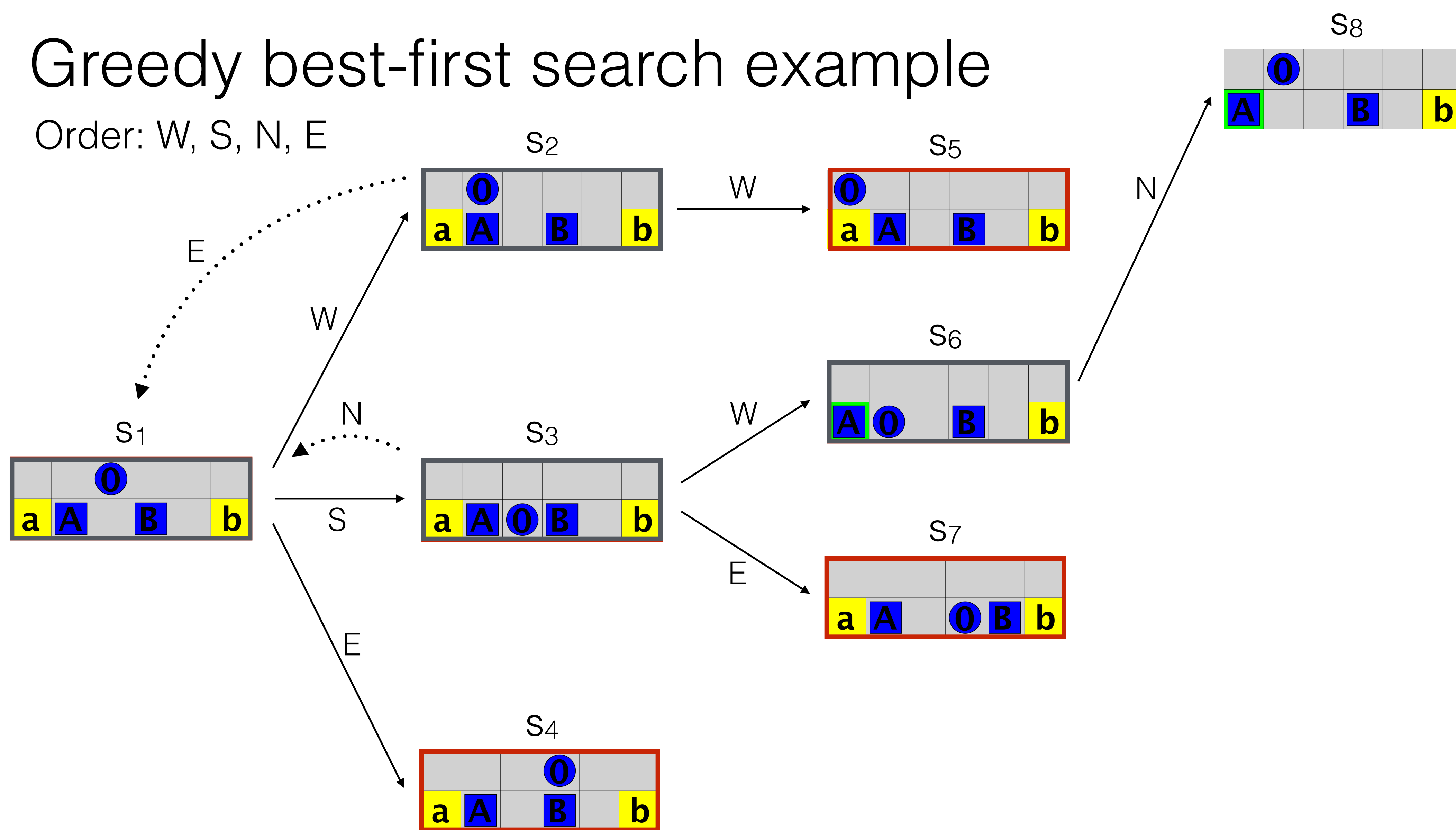
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

Greedy best-first search example

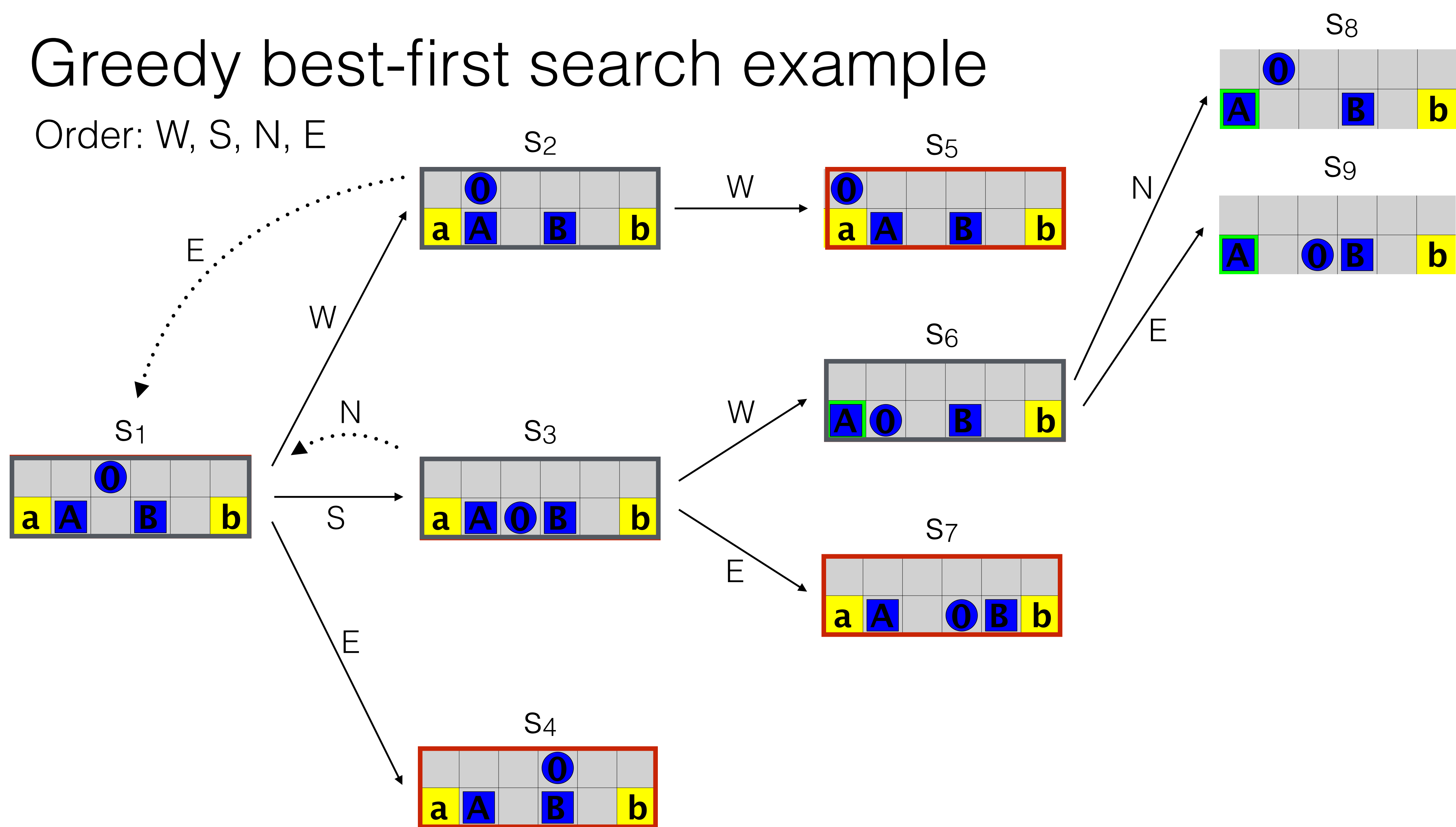
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

Greedy best-first search example

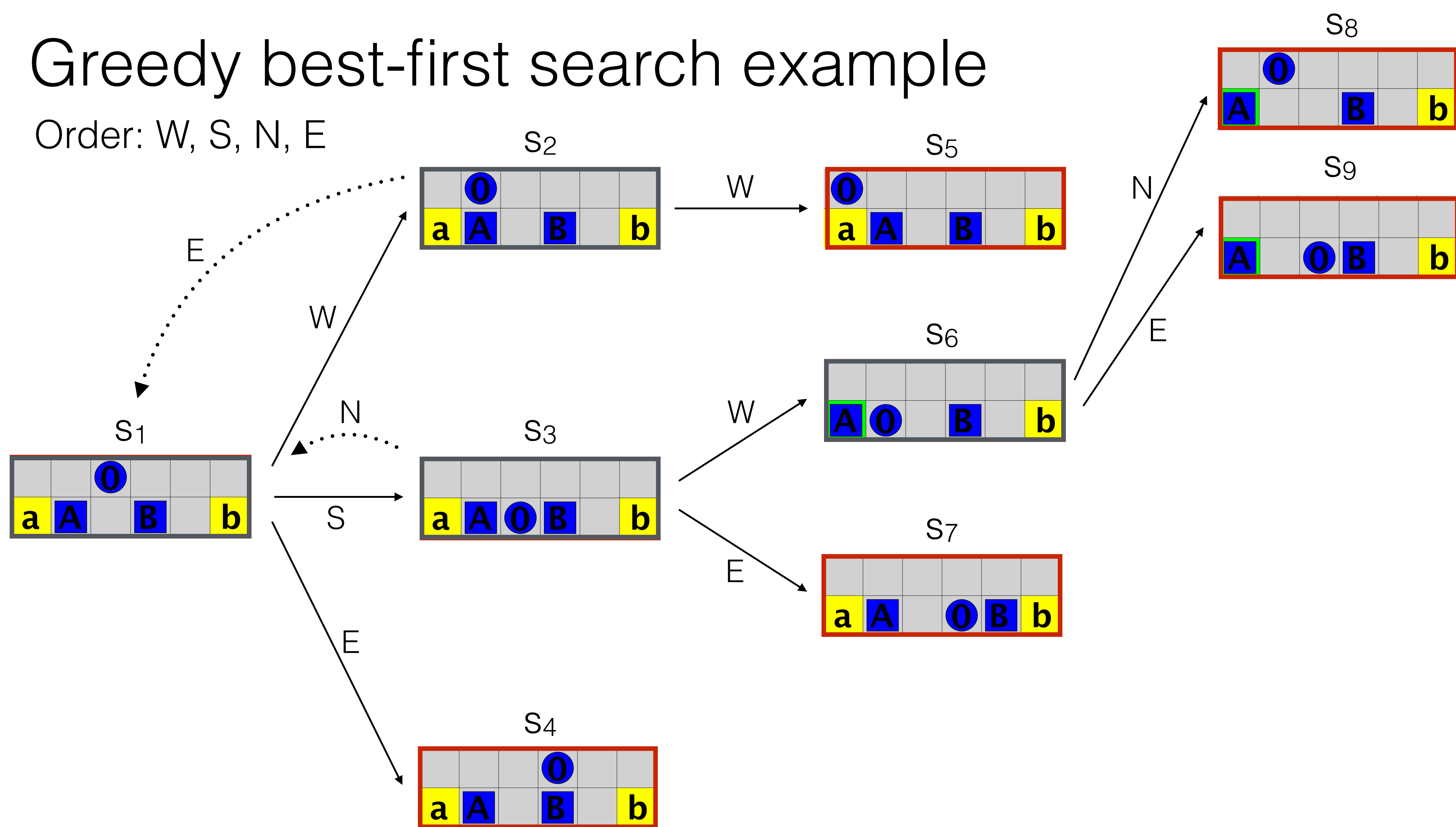
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

Greedy best-first search example

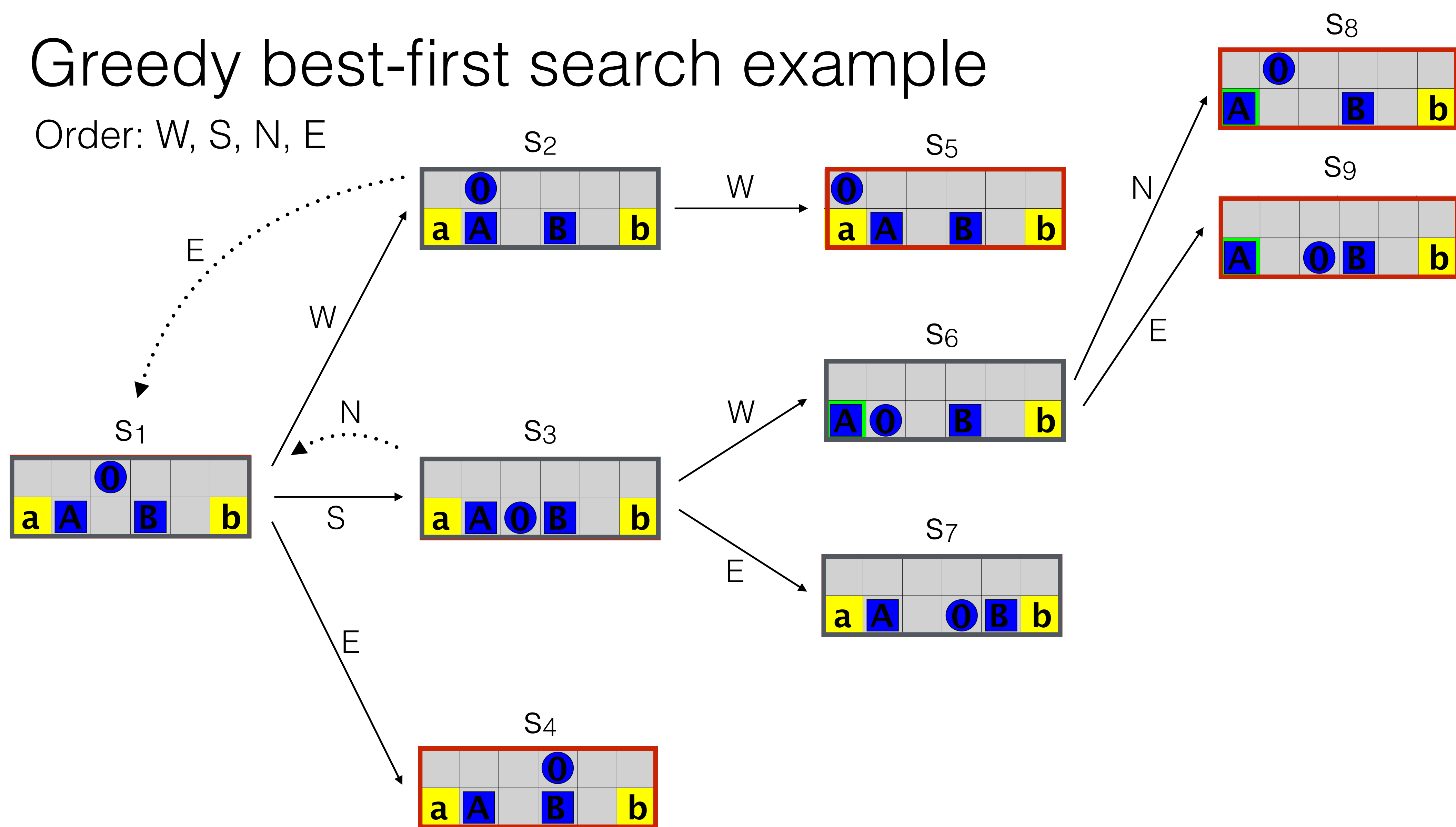
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

Greedy best-first search example

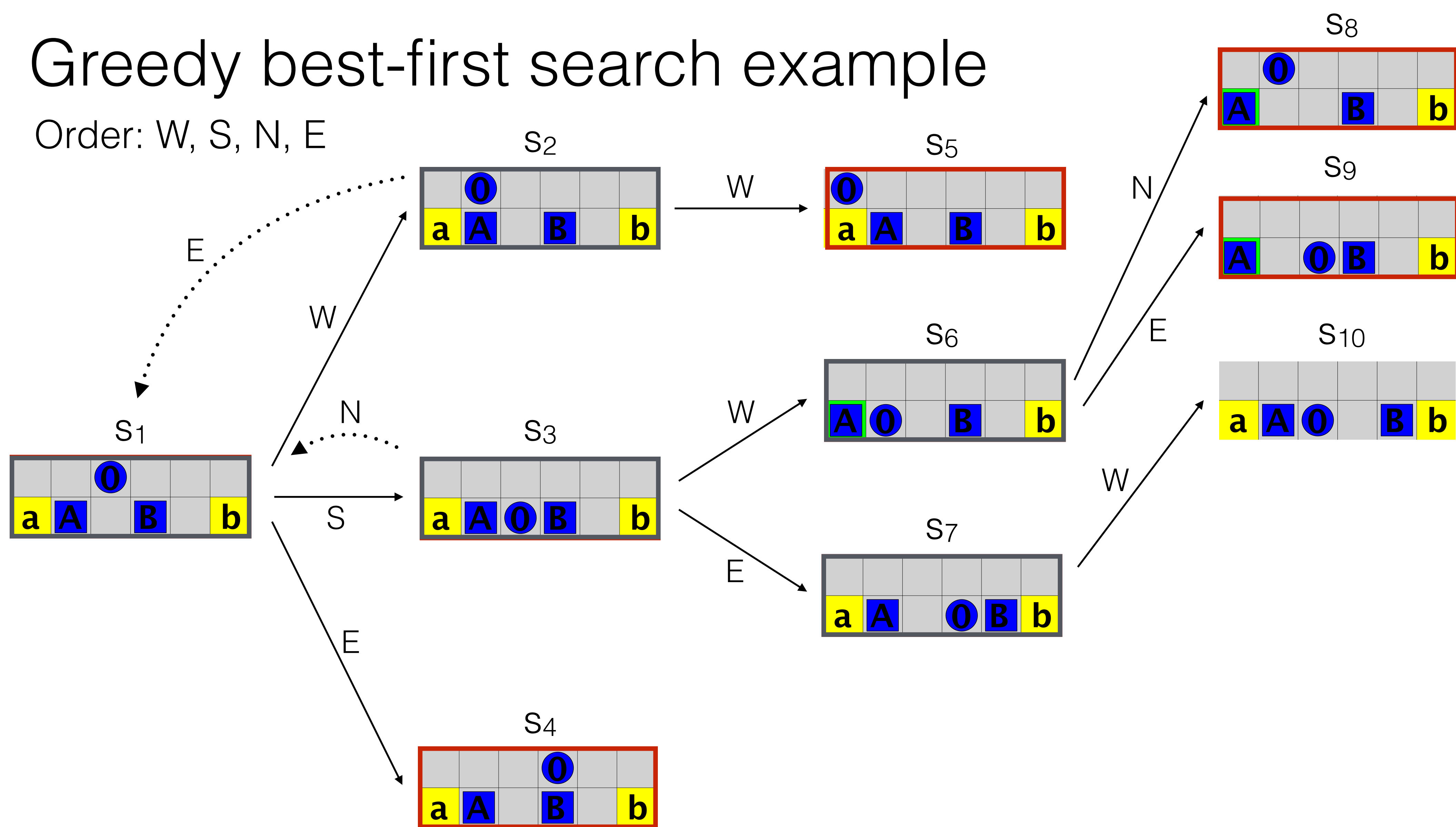
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

Greedy best-first search example

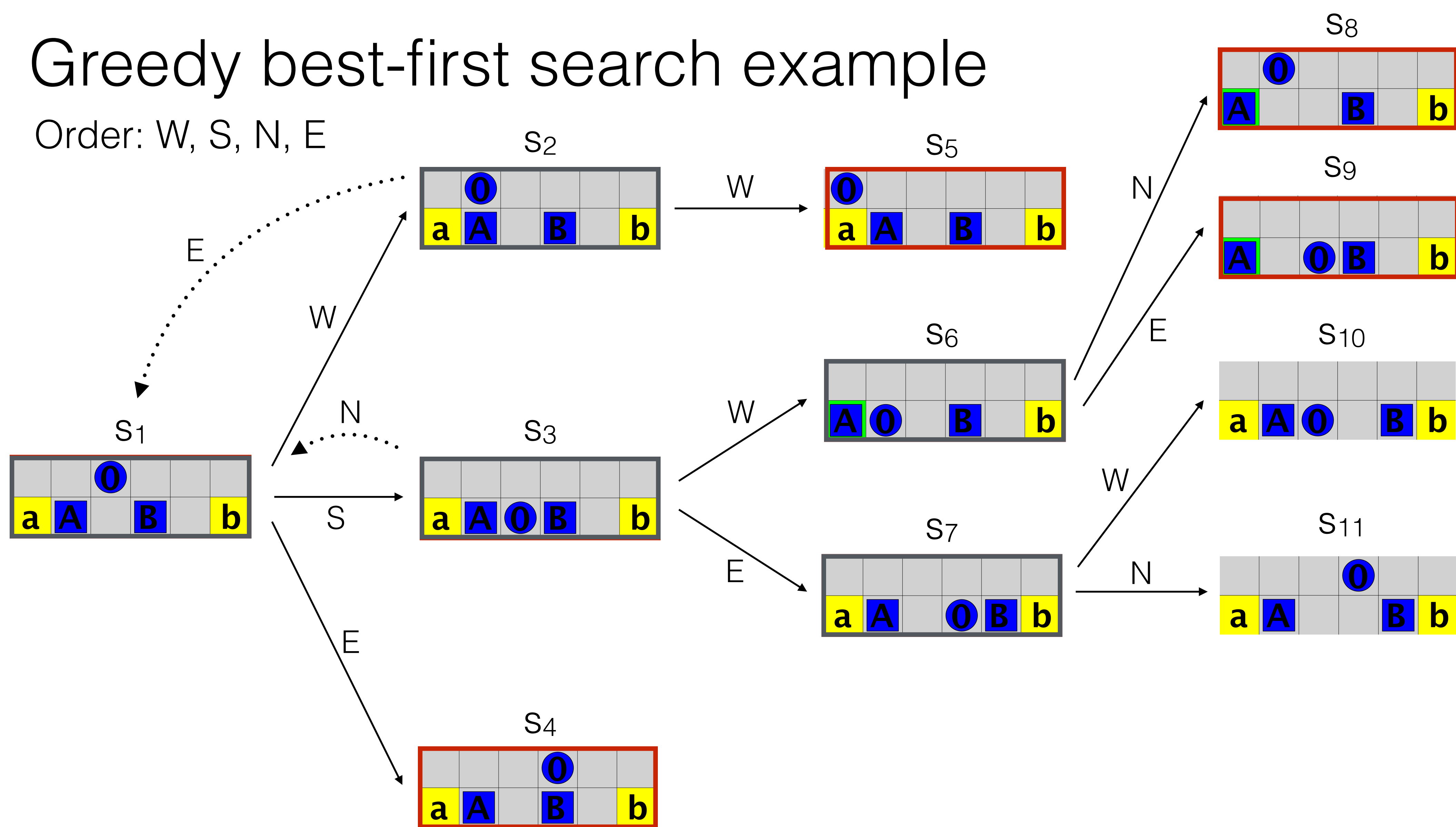
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

Greedy best-first search example

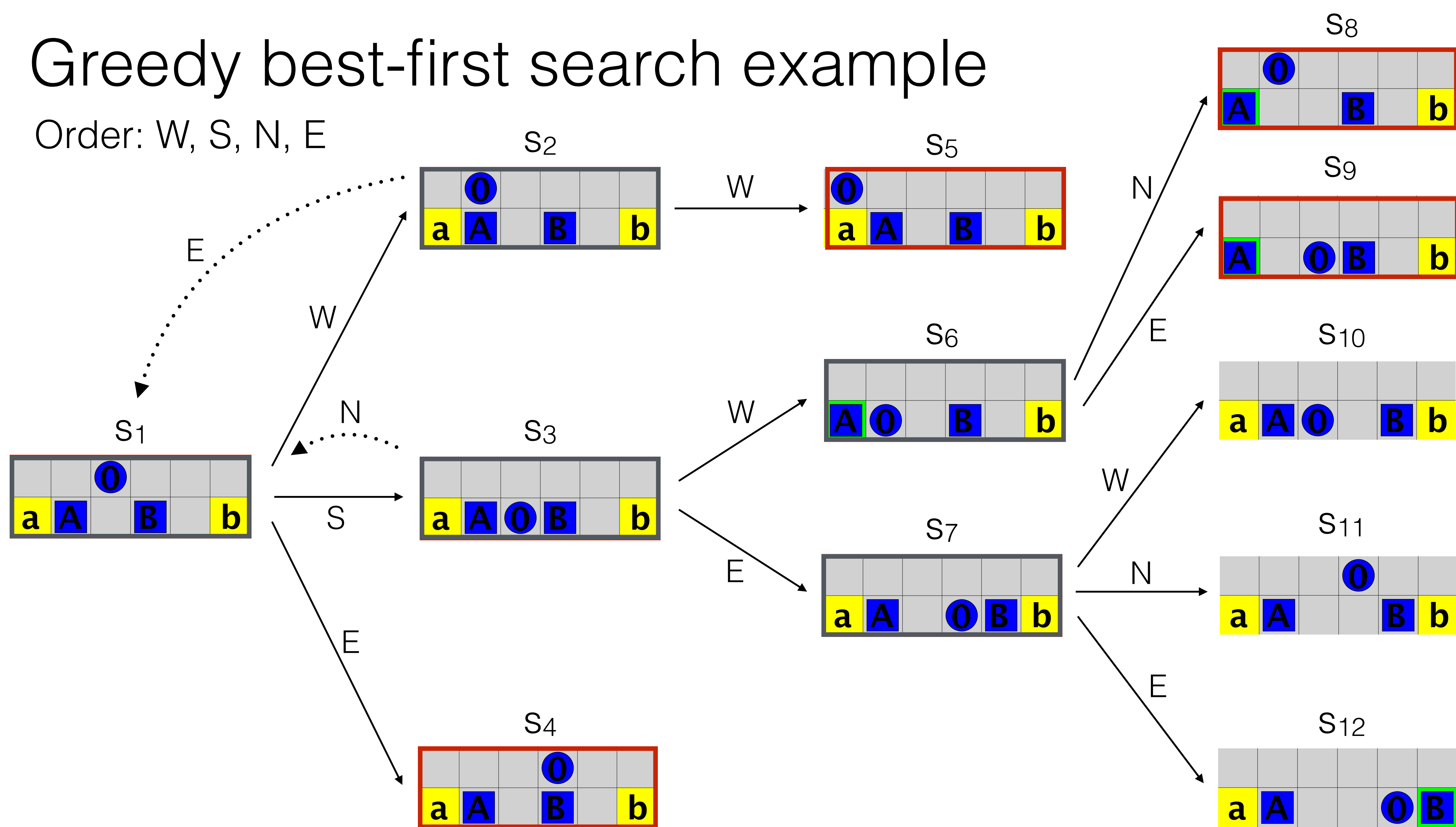
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

Greedy best-first search example

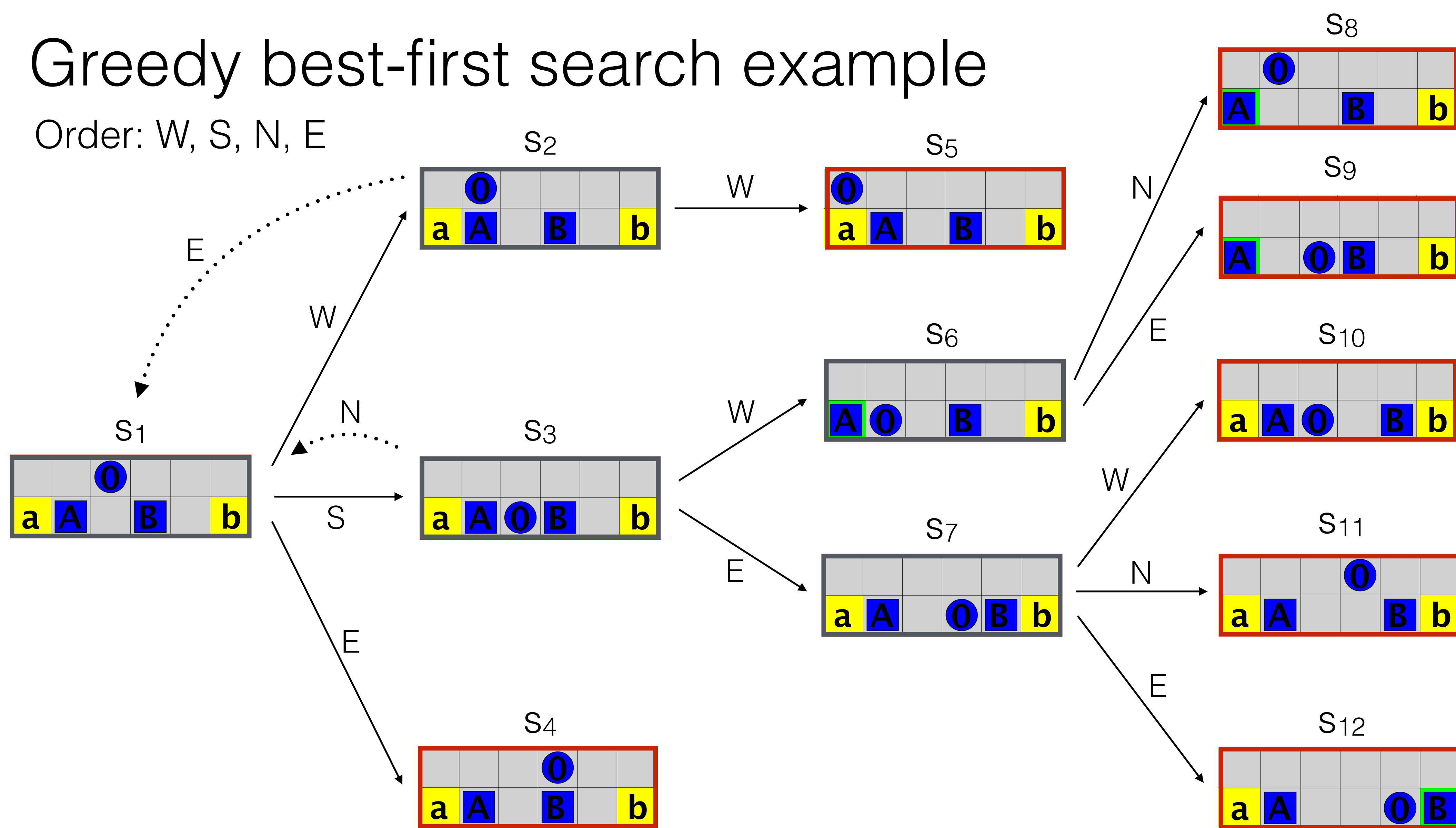
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

Greedy best-first search example

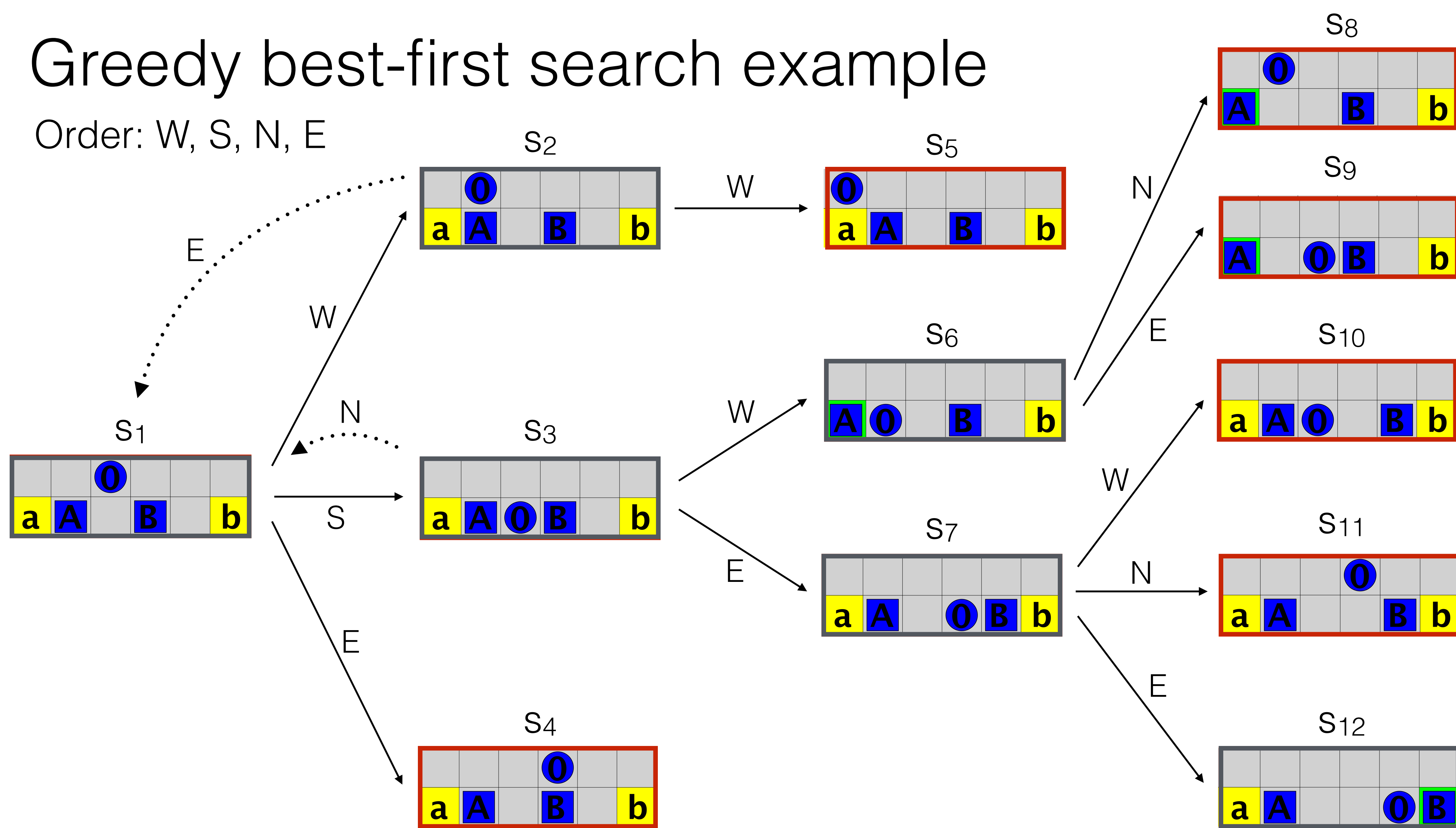
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

Greedy best-first search example

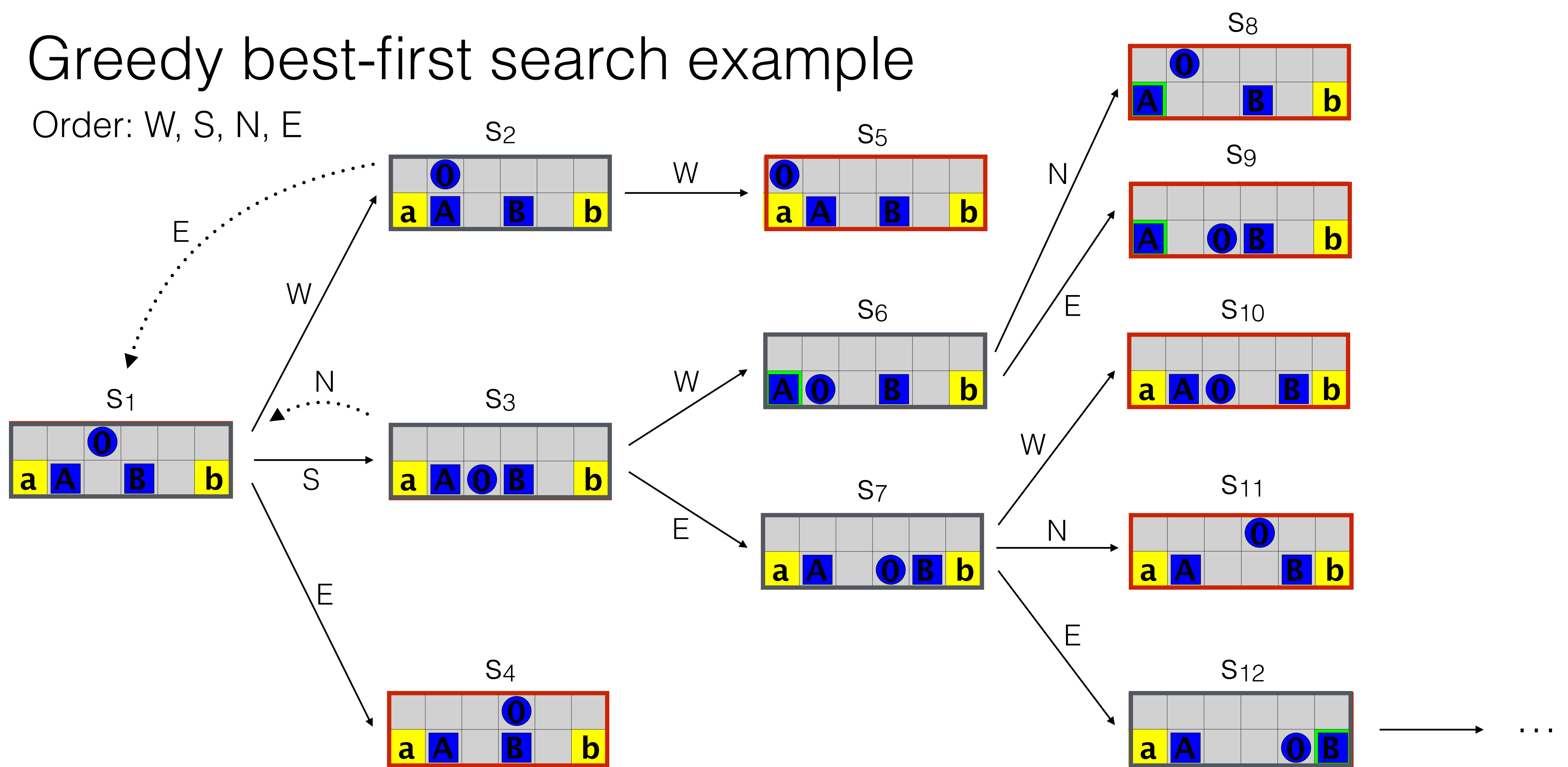
Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

Greedy best-first search example

Order: W, S, N, E



Red border: in frontier. **Grey border:** in exploredNodes.

Exercise session today:

Start working on Assignment 1.

Deadline in a little less than two weeks.