Graph Search

CMPUT 366: Intelligent Systems

P&M §3.1-3.4

"Recap": Perfect Rationality vs. Bounded Rationality

Is it feasible for the agent to achieve the **ideal optimum**, or must it trade off **solution quality** against **computational cost**?

- **Perfect rationality:** The agent can derive the best course of action without accounting for **computational limitations**.
- **Bounded rationality:** Agent decides on best action that **it can find** within its computational limitations
  - **Anytime algorithm:** Solution quality improves with time

Recap: Dimensions

- Static vs. sequential action
- Goals vs. complex preferences
- Episodic vs. continuing
- State representation scheme
- Perfect vs. bounded rationality

1. Uncertainty
2. Interaction
3. Number of agents

Different dimensions **interact**; you can't just set them arbitrarily

Lecture Outline

1. Recap
2. Search Problems
3. Graph Search
4. Markov Assumption

Search

- It is often easier to **recognize** a solution than to **compute** it
- For **fully-observable, deterministic, offline, single-agent** problems, search exploits this property!
- Agent searches **internal representation** to find solution
    - All computation is purely internal to the agent.
    - Environment is fully deterministic, so no need for observations, just remember actions
- Formally represent as searching a **directed graph** for a path to a goal state
- **Question:** Why might this be a good idea?
    - Because it is very **general**. Many AI problems can be represented in this form, and the same algorithms can solve them all.

State Space

- A **state** describes all the relevant information about a possible configuration of the environment
- **Markov assumption**: How the environment got to a given configuration doesn't matter, just the current configuration.
- A state is an assignment of values to one or more **variables**
  - A single variable called "state"
  - x and y coordinates, temperature, battery charge, etc.
- **Actions** change the environment from one state to another

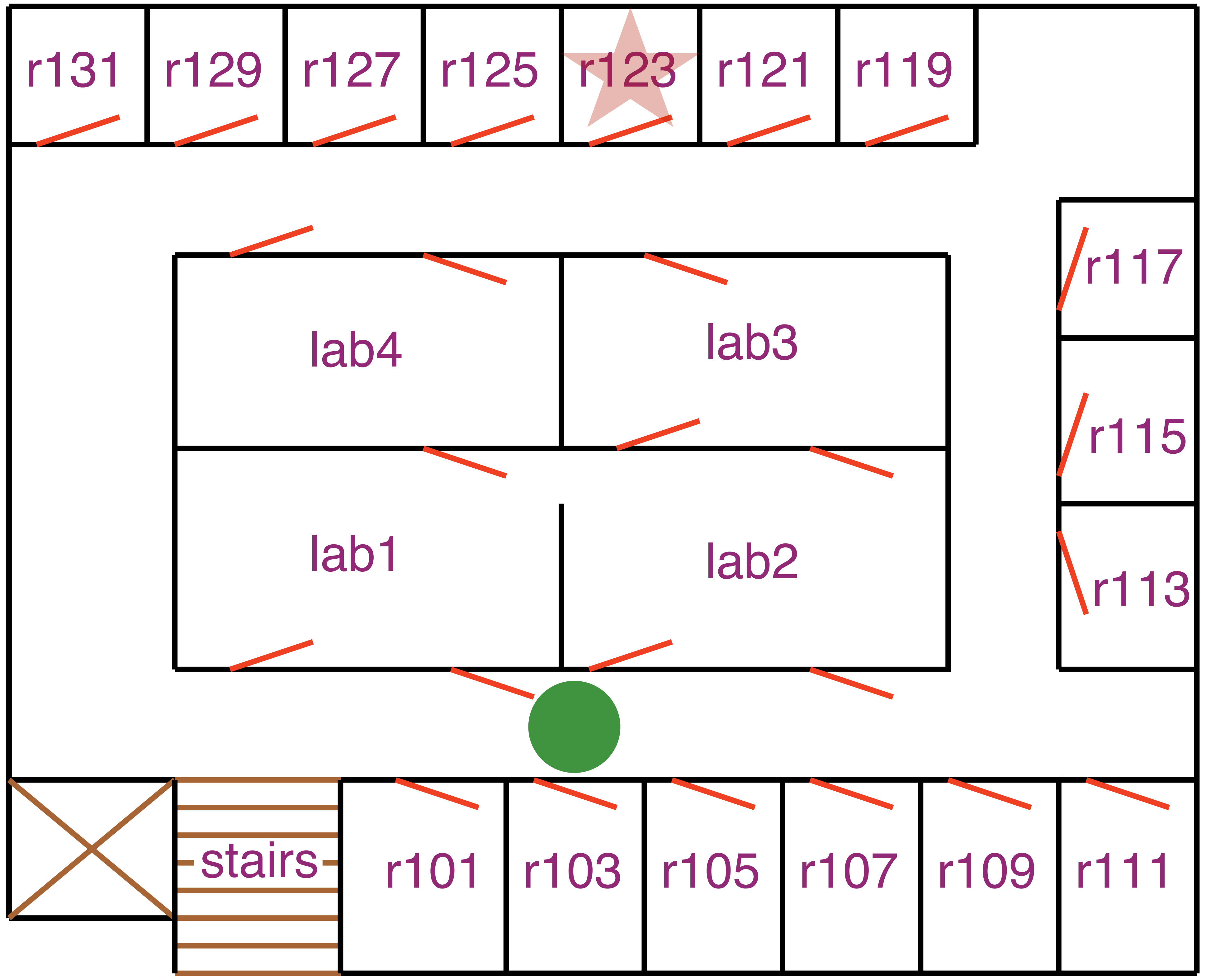
Search Problem

Definition: Search problem **(textbook: state-space problem)**

- A set of **states**
- A **start state** (or set of start states)
- A set of **actions** available at each state
- A **successor function** that maps from a state to a set of next states
    - The textbook calls this an **action function**
- A **goal function** that returns true when a state satisfies the goal

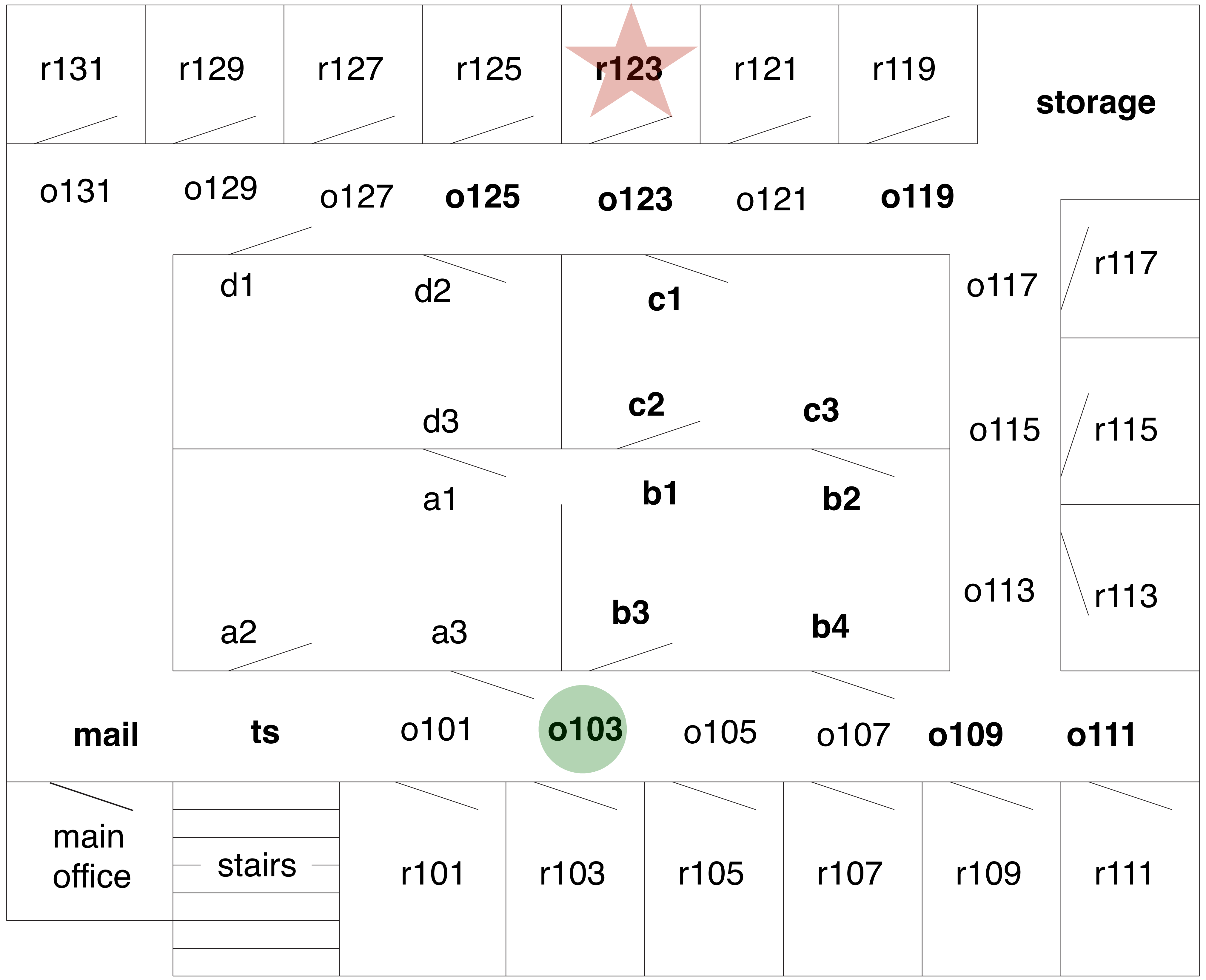
Example: DeliveryBot

DeliveryBot wants to get from outside room 103 to inside room 123



DeliveryBot as a Search Problem

States	{r131, o131, r129, o129, ...}
Actions	{go-north, go-south, go-east, go-west}
Start state	o103
Successor function	succ(r101) = {r101, o101}, succ(o101) = {o101, lab1, r101,o105, ts}, ...
Goal function	goal(state): (state == r123)



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Example: VacuumBot

- Two rooms, one cleaning robot
- Each room can be clean or dirty
- Robot has two actions:
  - **clean**: makes the room the robot is in clean
  - **move**: moves to the other room

Questions:

1. How many **states** are there?
2. How many **goal states**?

Solving Search Problems, informally

1. Consider each **start state**
2. Consider every state that can be **reached** from some state that has been previously considered
3. **Stop** when you encounter a **goal state**

Directed Graphs

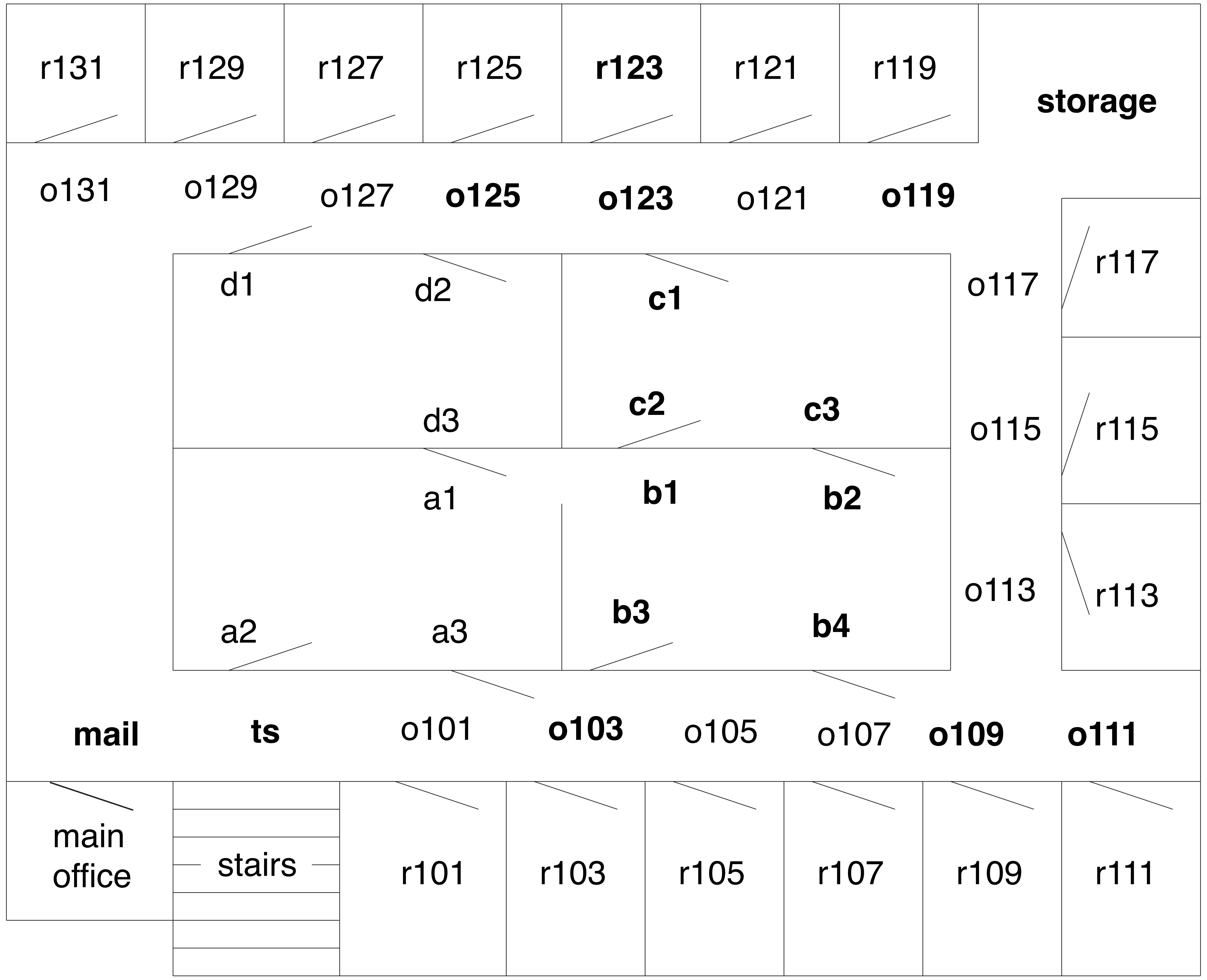
- A **directed graph** is a pair $G = (N, A)$
  - N is a set of **nodes**
  - A is a set of ordered pairs called **arcs**
- Node n_2 is a **neighbour** of n_1 if there is an arc from n_1 to n_2
  - i.e., $\langle n_1, n_2 \rangle \in A$
- A **path** is a sequence of nodes $\langle n_1, n_2, \ldots, n_k \rangle$ with $\langle n_{i-1}, n_i \rangle \in A$
- A **solution** is a path $\langle n_1, n_2, \ldots, n_k \rangle$ from a **start node** to a **goal node**

Search Graph

We can represent any state space problem as a **search graph**:

1. Nodes are the **states**
2. Neighbours are the **successors** of a state
    - i.e., add one **arc** from state s to each of s's **successors**
3. *Optional:* Label each arc with the **action** that leads to the successor state

DeliveryBot:
State Space Graph



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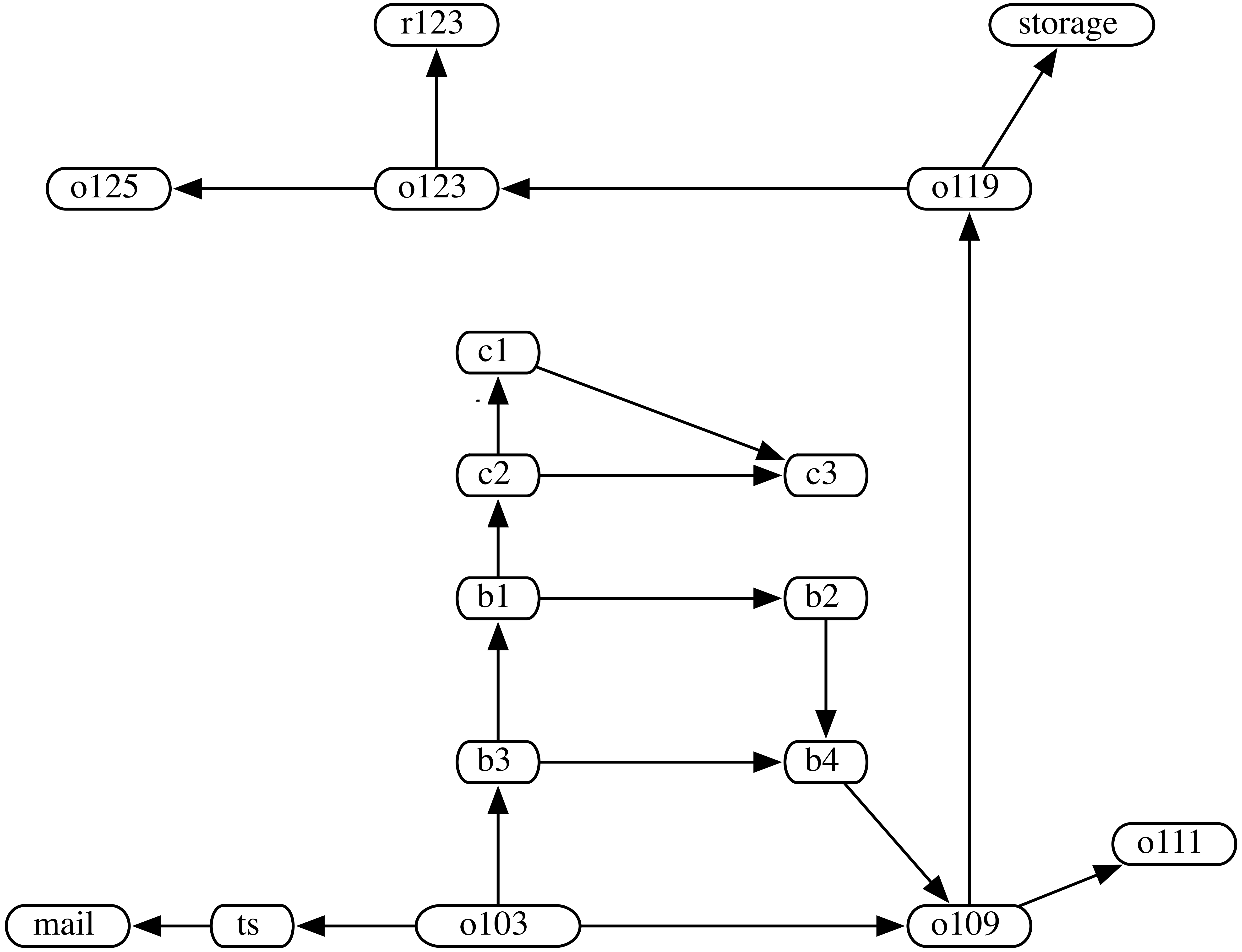

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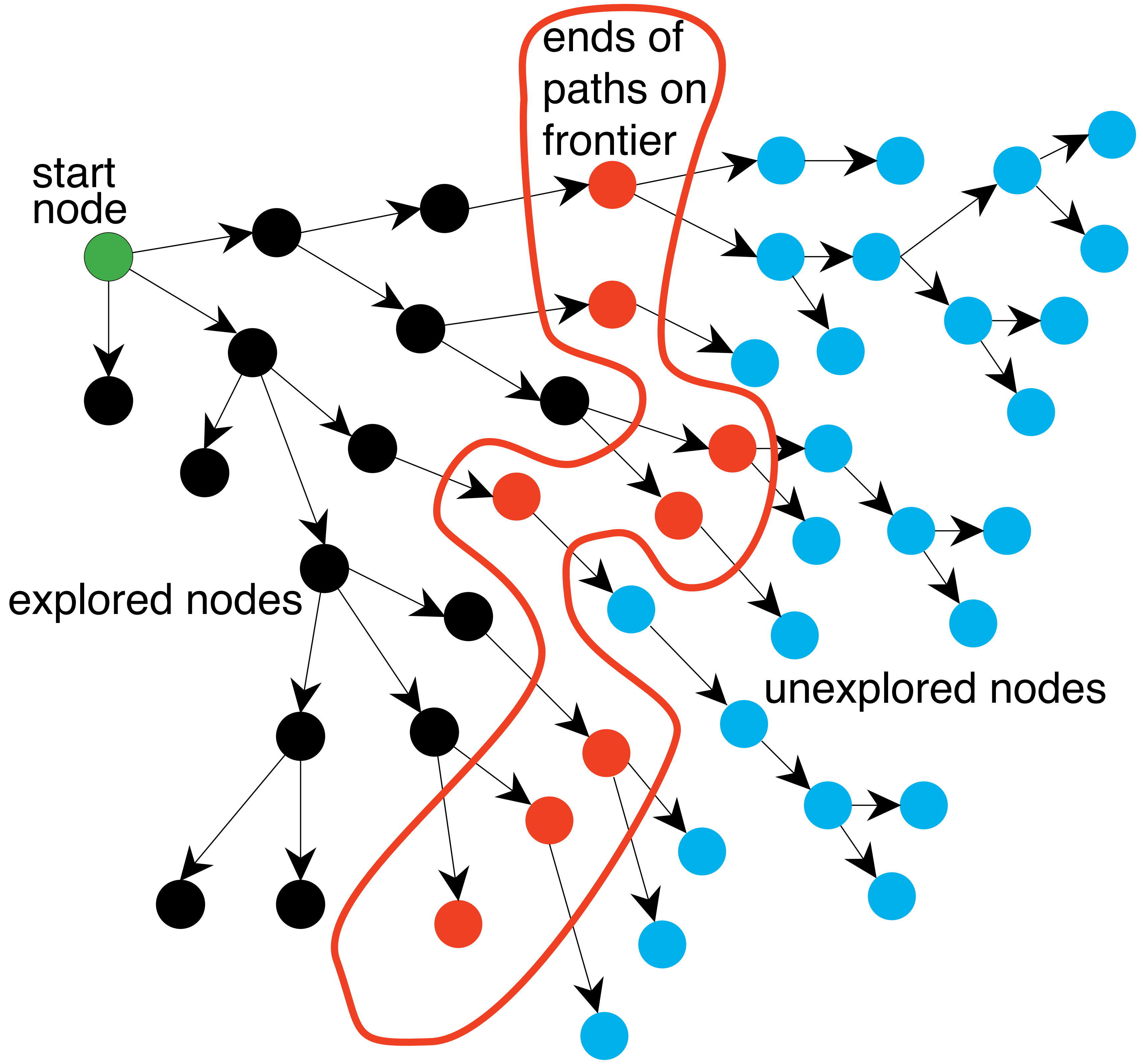
Generic Graph Search Algorithm

- Given a graph, start nodes, and goal, incrementally explore paths from the start nodes
- Maintain a **frontier** of paths that have been explored
- As search proceeds, the frontier **expands** into the unexplored nodes until a goal is encountered.
- The way the frontier is expanded defines the **search strategy**



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Generic Graph Search Algorithm

Input: a *graph*; a set of *start nodes*; a *goal* function

```
frontier := { <s> | s is a start node}
while frontier is not empty:
    select and remove a path <$n_1$, $n_2$, ..., $n_k$> from frontier
    if goal($n_k$):
        return <$n_1$, $n_2$, ..., $n_k$>
    for each neighbour n of $n_k$:
        add <$n_1$, $n_2$, ..., $n_k$, n> to frontier
end while
```

- Can continue the procedure after algorithm returns
- Which value is **selected** from the frontier defines the **search strategy**

Search Problem with Costs

What if solutions have differing qualities?

- Add **costs** to each arc: cost($<n_{i-1}, n_i>$)
- **Cost of a solution** is the sum of the arc costs:

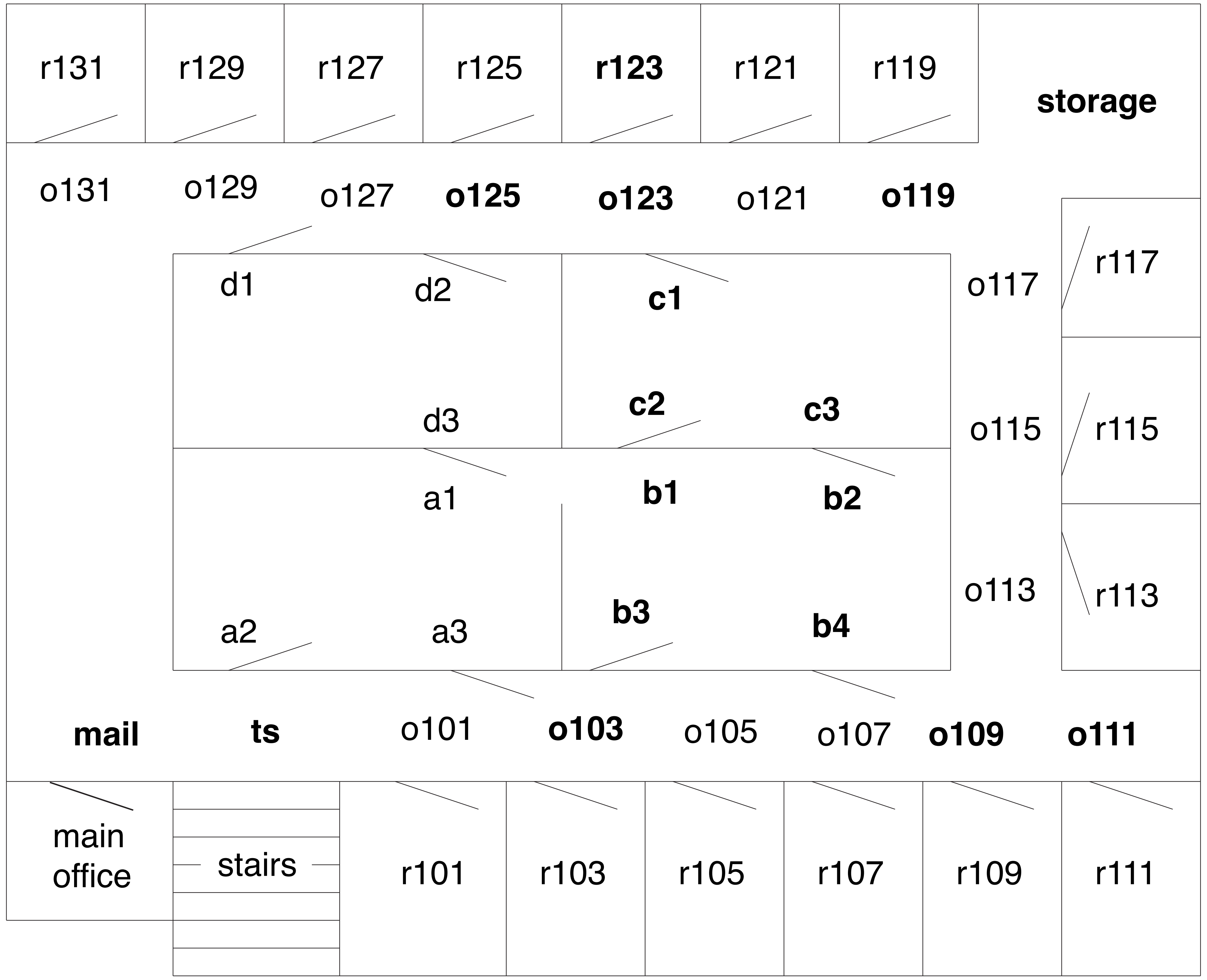
$$\text{cost}\left(\langle n_0, n_1, \ldots, n_k \rangle\right) = \sum_{i=1}^{k} \text{cost}\left(\langle n_{i-1}, n_i \rangle\right)$$

- An **optimal solution** is one with the lowest cost

Questions:

1. Is this scheme sufficiently **general**?
2. What if we only care about the **number of actions** that the agent takes?
3. What if we only care about the **quality** of the solution we find?

DeliveryBot with Costs



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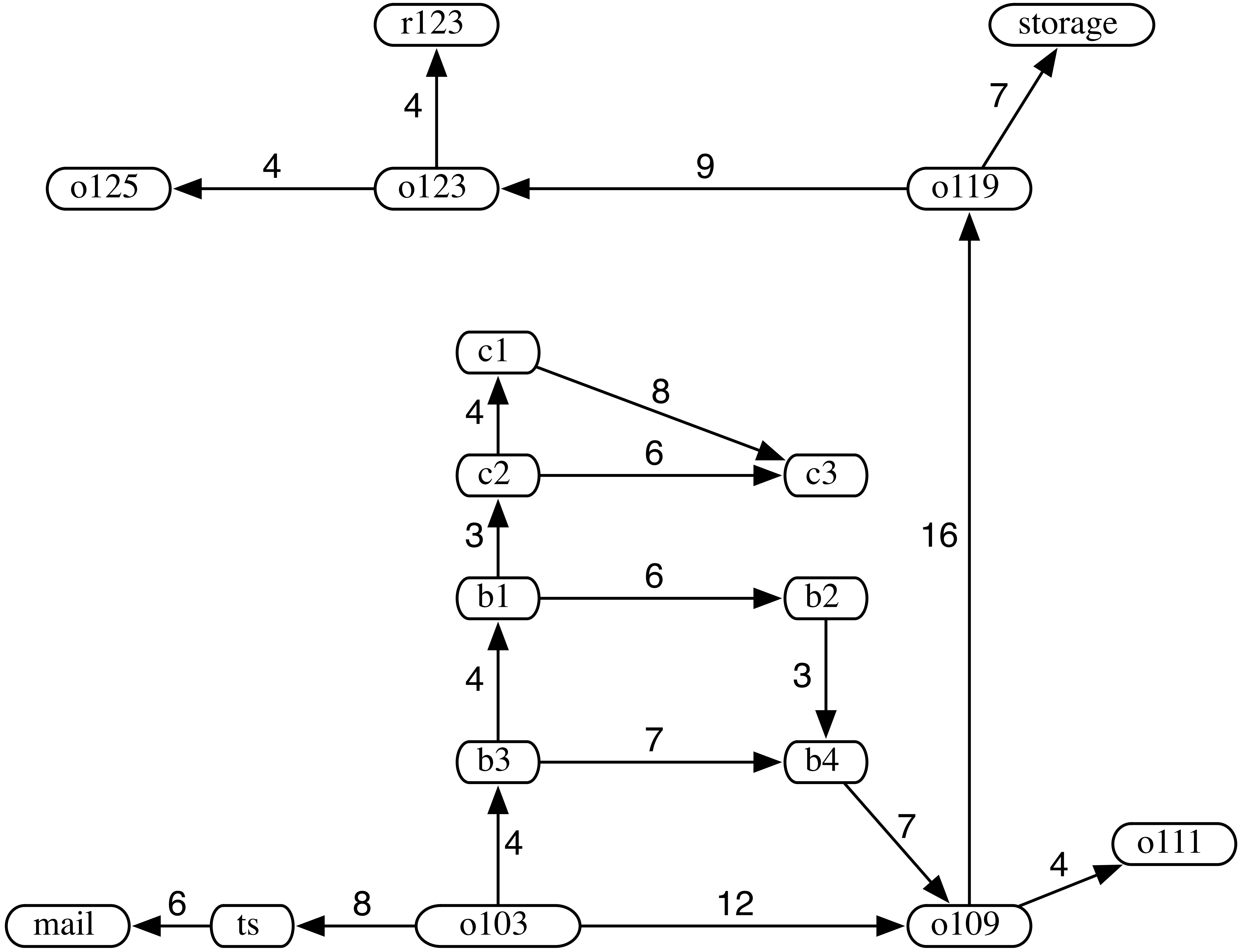

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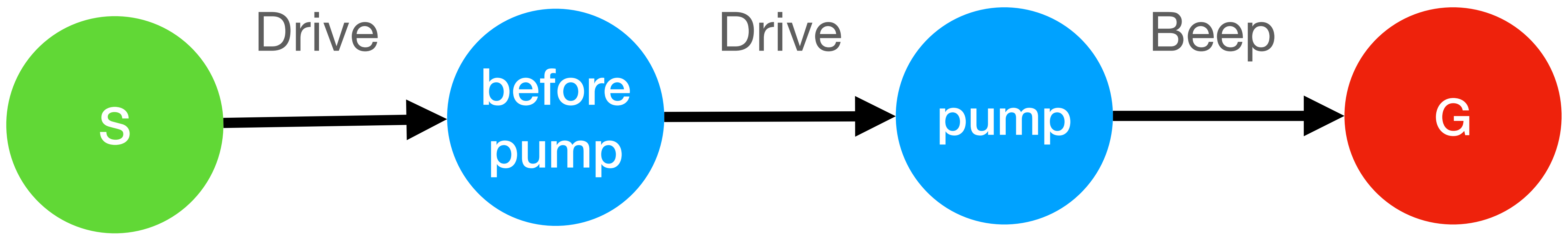
Markov Assumption: GasBot

The **Markov assumption** is **crucial** to the graph search algorithm



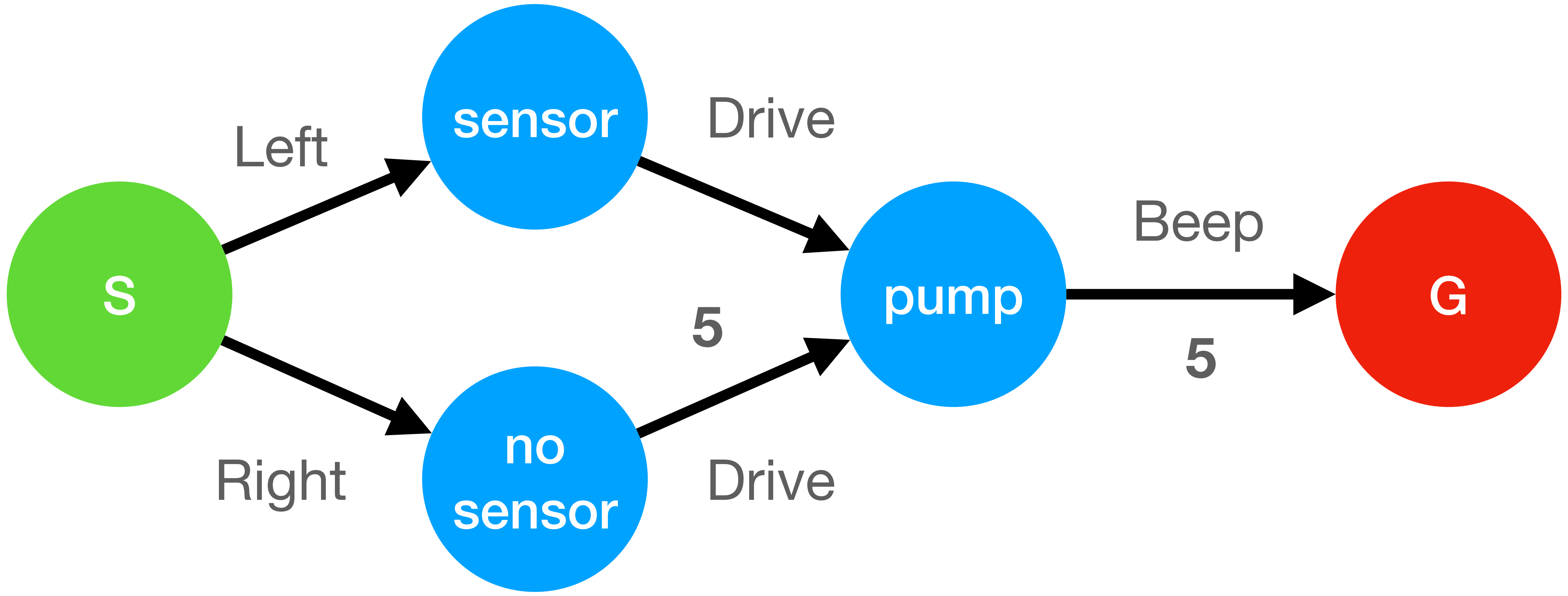
cost(pump, gas):
5 if went through sensor
10 otherwise

Getting to the pump:
from the **left** goes through sensor
from the **right** does not

Question: Does this environment satisfy the Markov assumption?
Why or why not?

Markov Assumption: GasBot

The **Markov assumption** is **crucial** to the graph search algorithm



1. Does *this* environment satisfy the Markov assumption? Why or why not?

2. How *else* could we have fixed up the previous example?

Summary

- Many AI tasks can be represented as **search problems**
  - A single generic **graph search algorithm** can then solve them all!
- A search problem consists of **states**, **actions**, **start states**, a **successor function**, a **goal** function, optionally a **cost** function
- **Solution quality** can be represented by labelling **arcs** of the search graph with **costs**