# Graph Search

CMPUT 366: Intelligent Systems

P&M §3.1-3.4

# 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

# 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
- 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

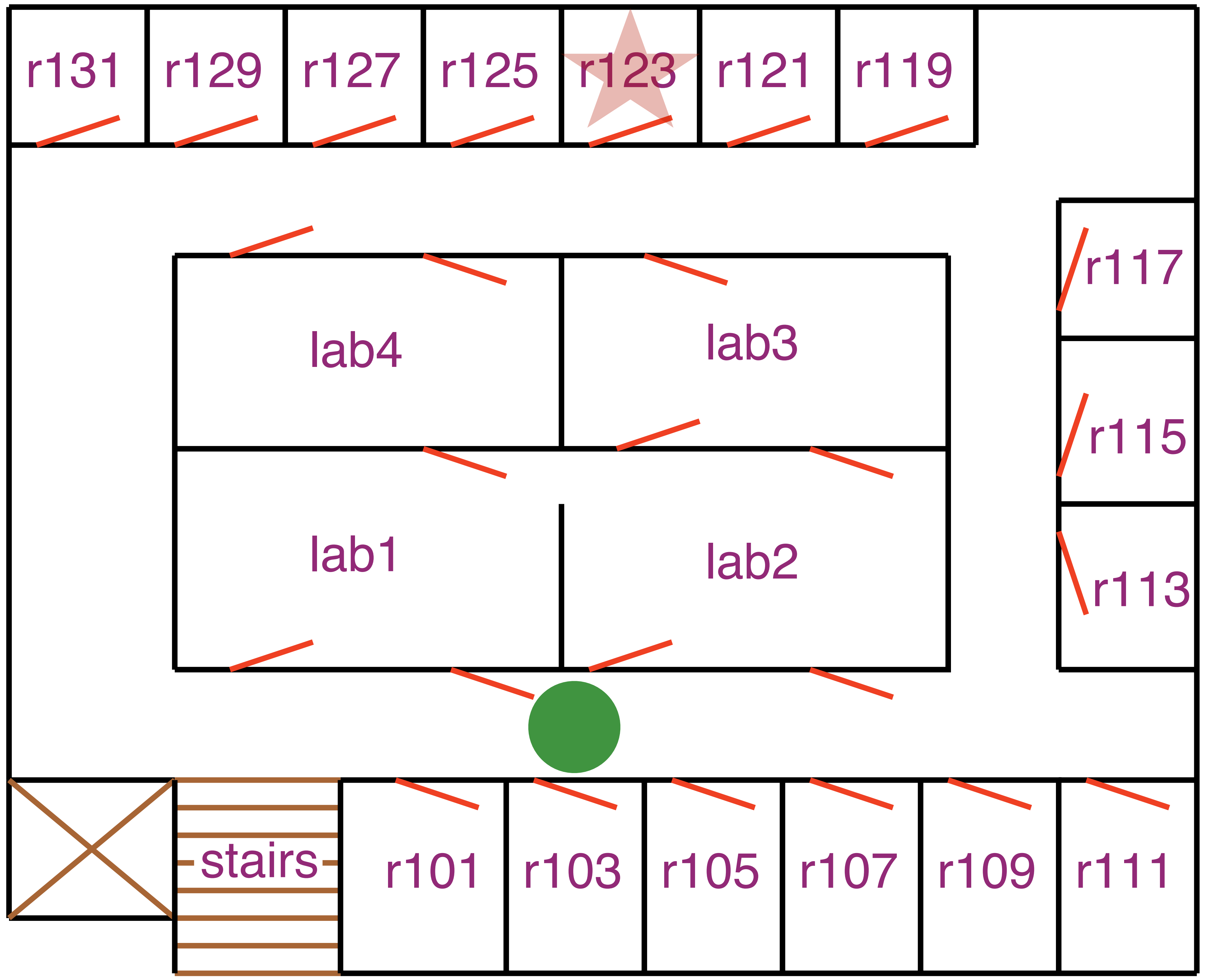
# Search Problem

**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

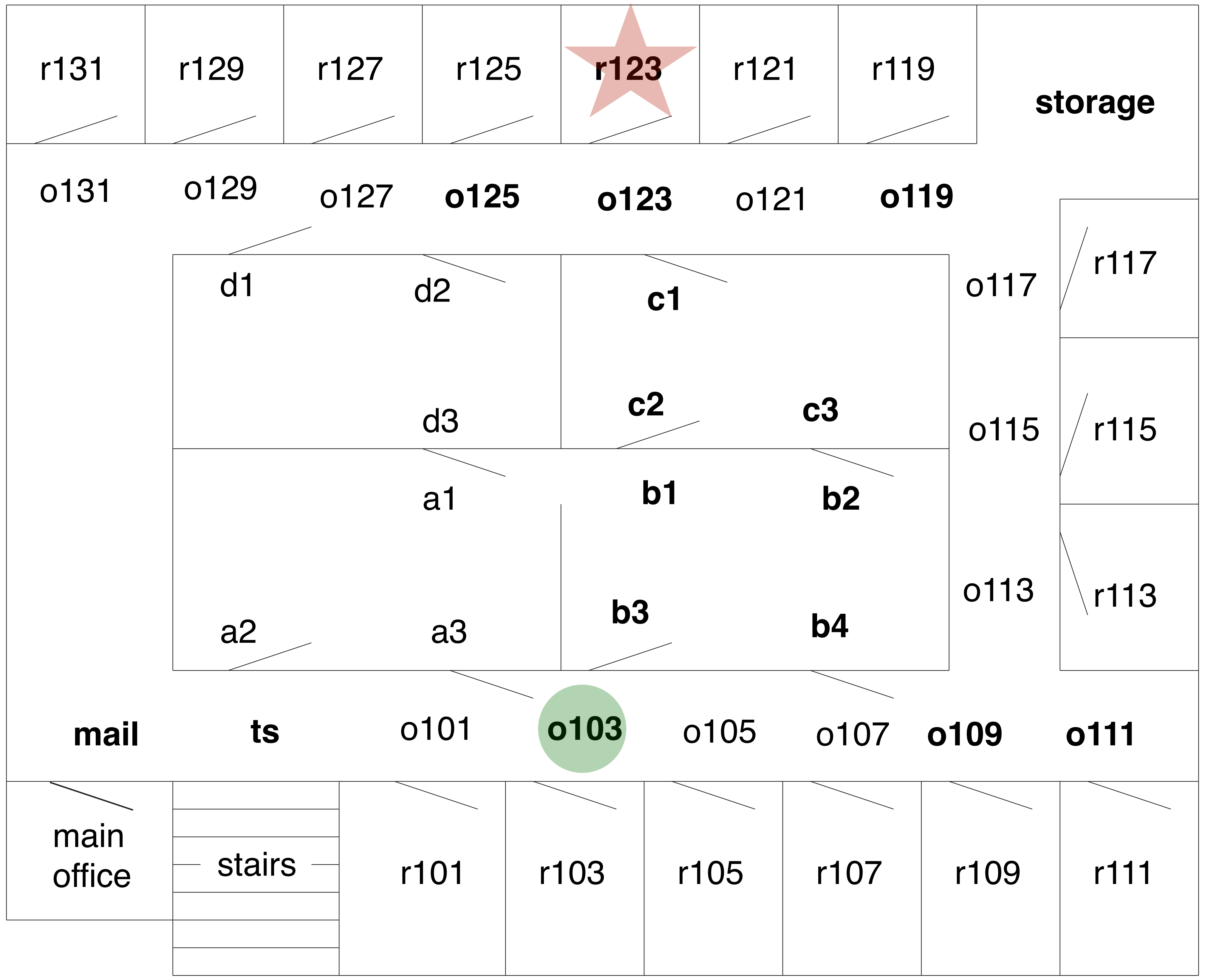
# Example: DeliveryBot

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) |



# 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

- Consider each start state
- Consider every state that can be reached from some state that has been previously considered
- 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., $<n_1,n_2> \in A$
- A **path** is a sequence of nodes $<n_1, n_2, \ldots, n_k>$ with $<n_{i-1},n_i> \in A$
- A solution is a **path** $<n_1, n_2, \ldots, n_k>$ from a **start node** to a **goal node**

# Search Graph

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

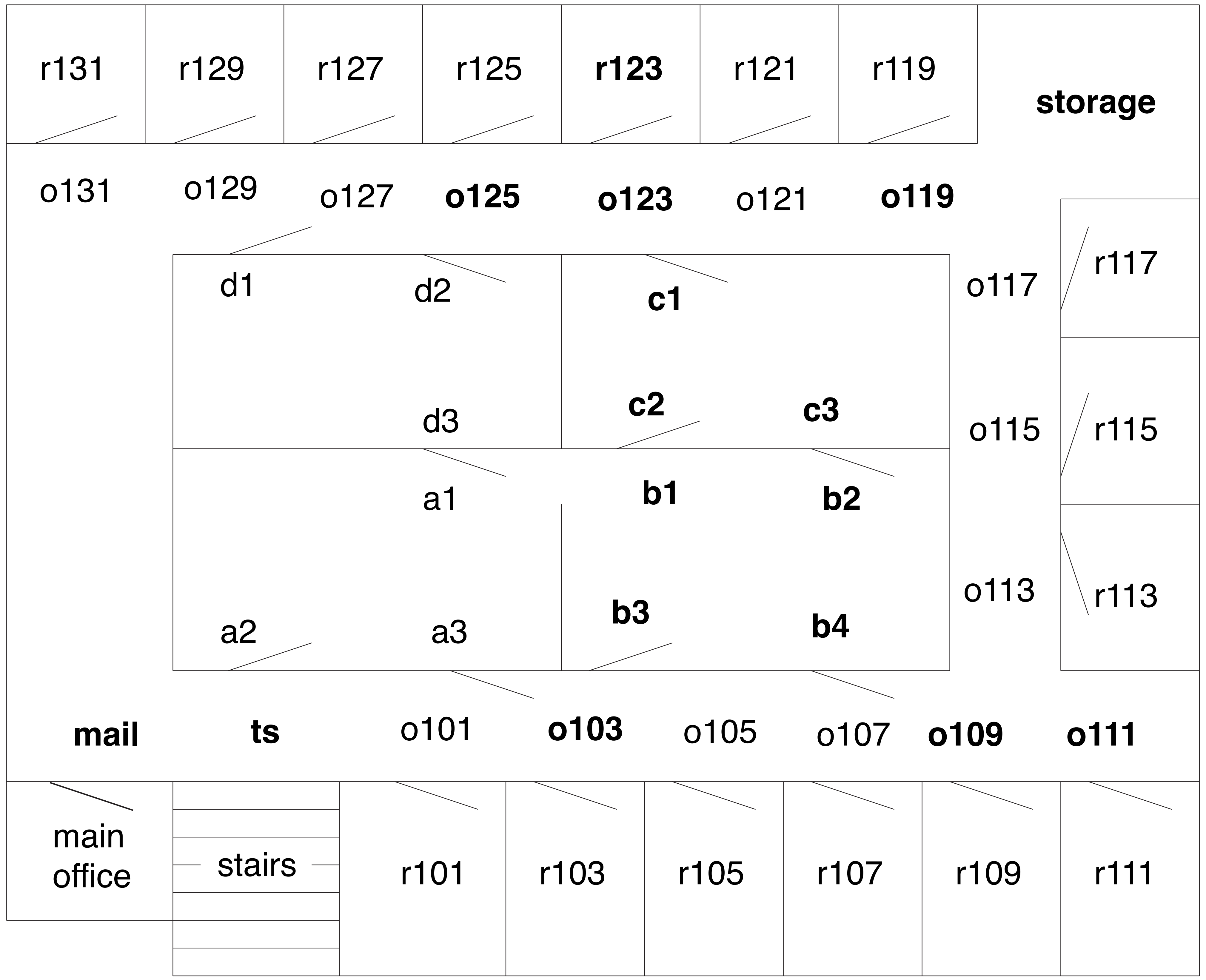
1. Nodes are the **states**

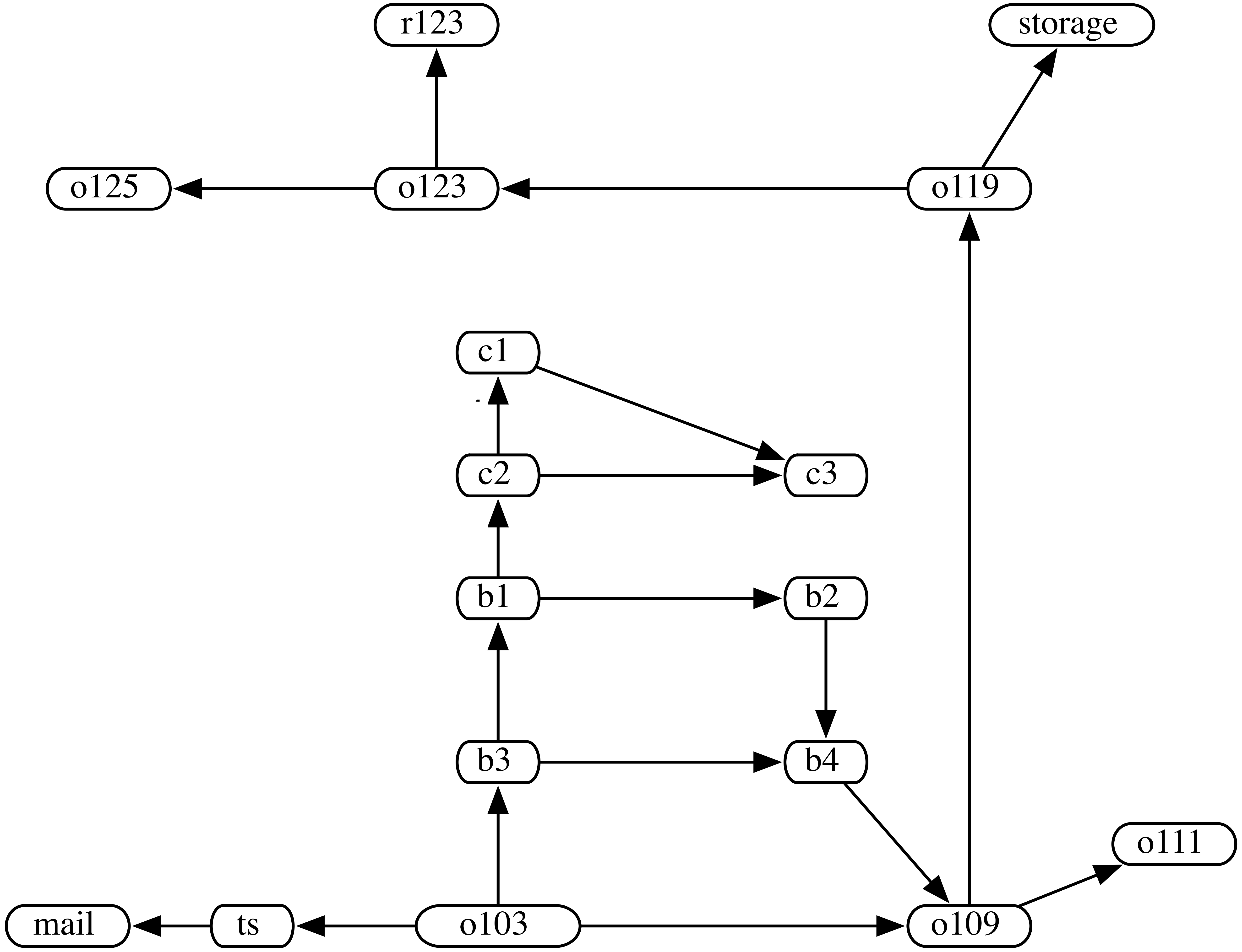
2. Neighbours are the **successors** of a state

    - 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

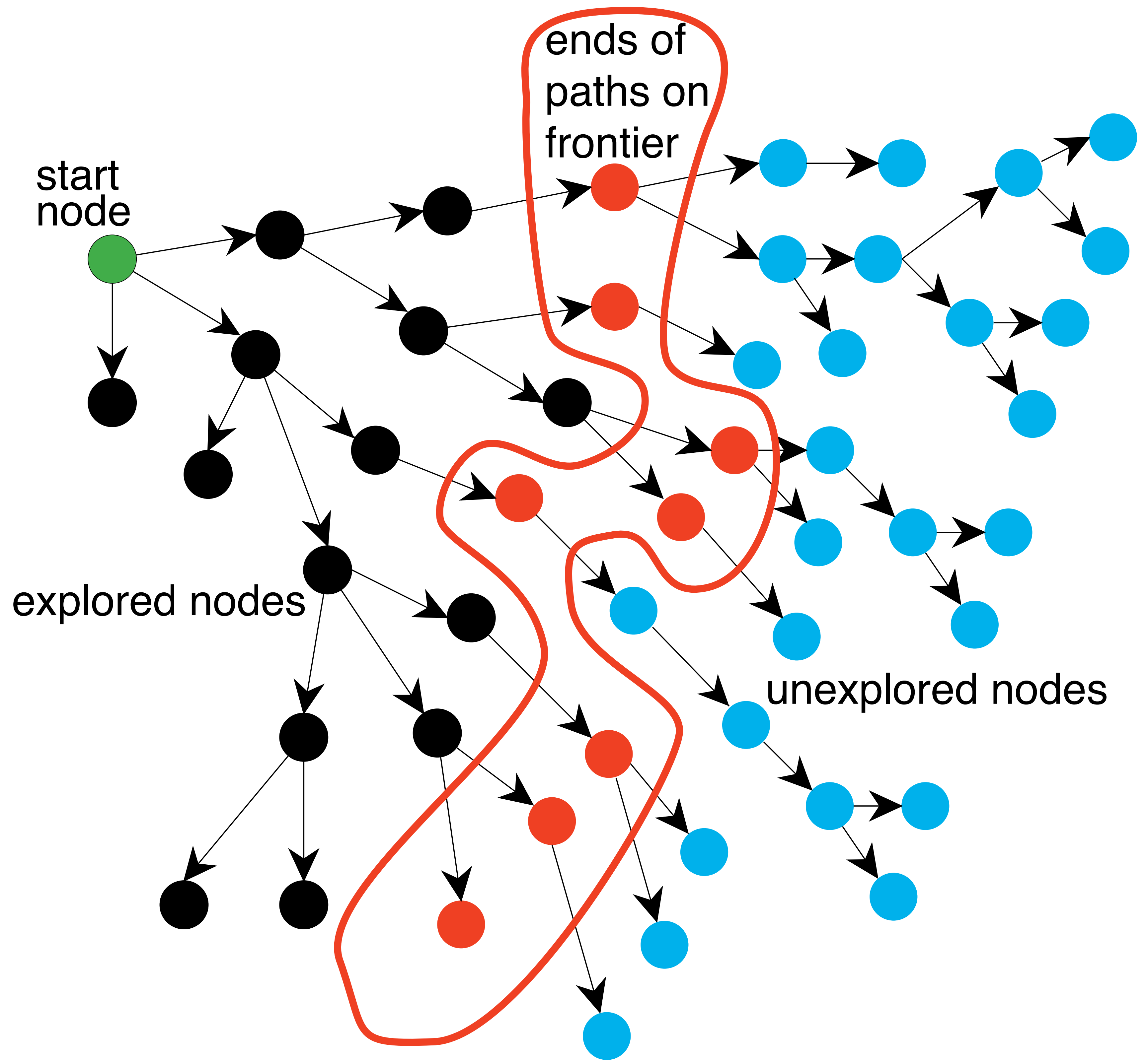
# DeliveryBot: State Space Graph



# 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**



# 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 $<n_1, n_2, \ldots, n_k>$ from *frontier*
    if *goal*($n_k$):
        **return** $<n_1, n_2, \ldots, n_k>$
    **for each** neighbour $n$ of $n_k$:
        **add** $<n_1, n_2, \ldots, n_k, n>$ 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($\langle n_{i-1}, n_i \rangle$)
- **Cost of a solution** is the sum of the arc costs:

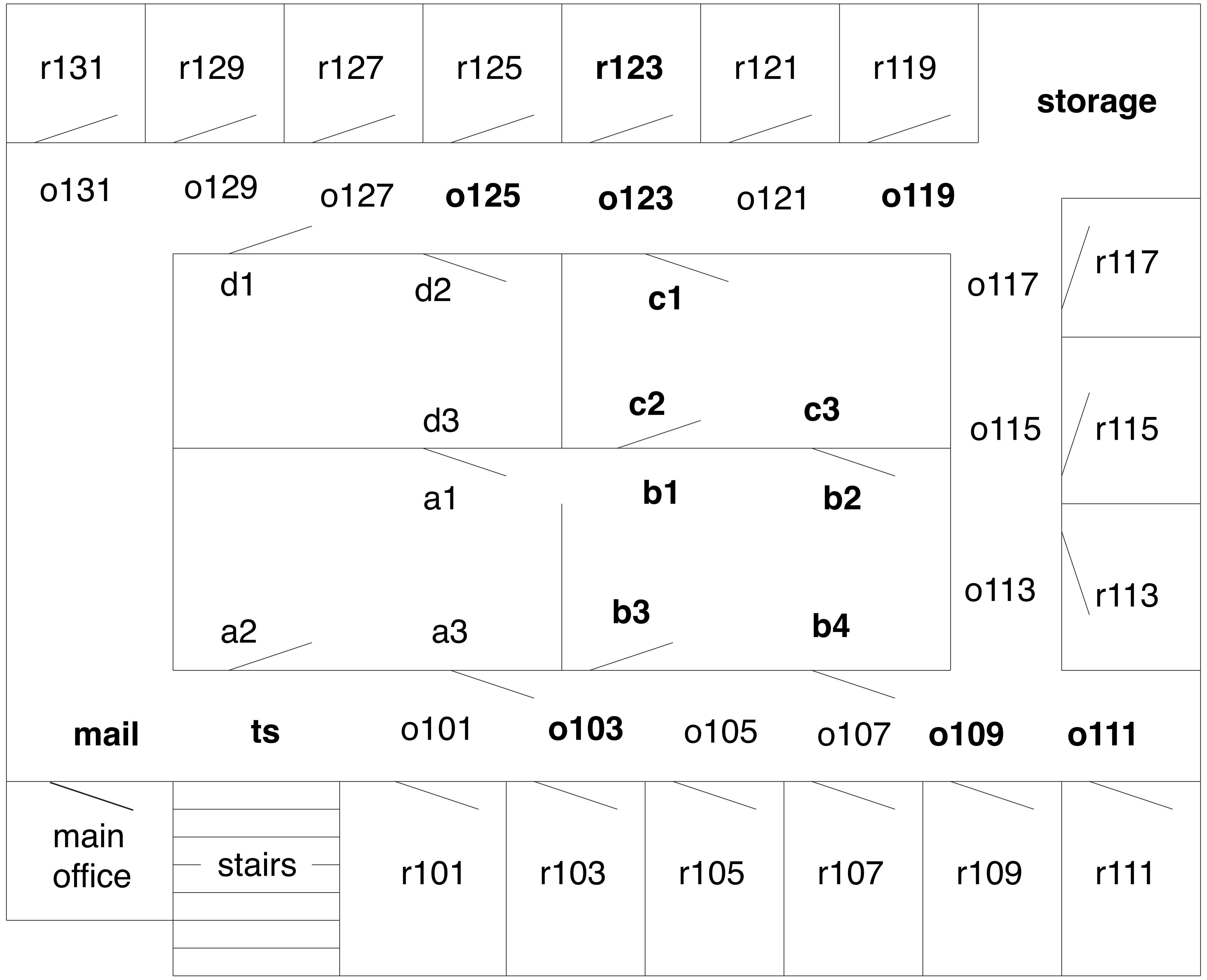
$$\text{cost}\left(\langle n_0, n_1, \ldots, n_k \rangle\right) = \sum_{i=1}^{k} \text{cost}\left(\langle n_{i-1}, n_i \rangle\right)$$

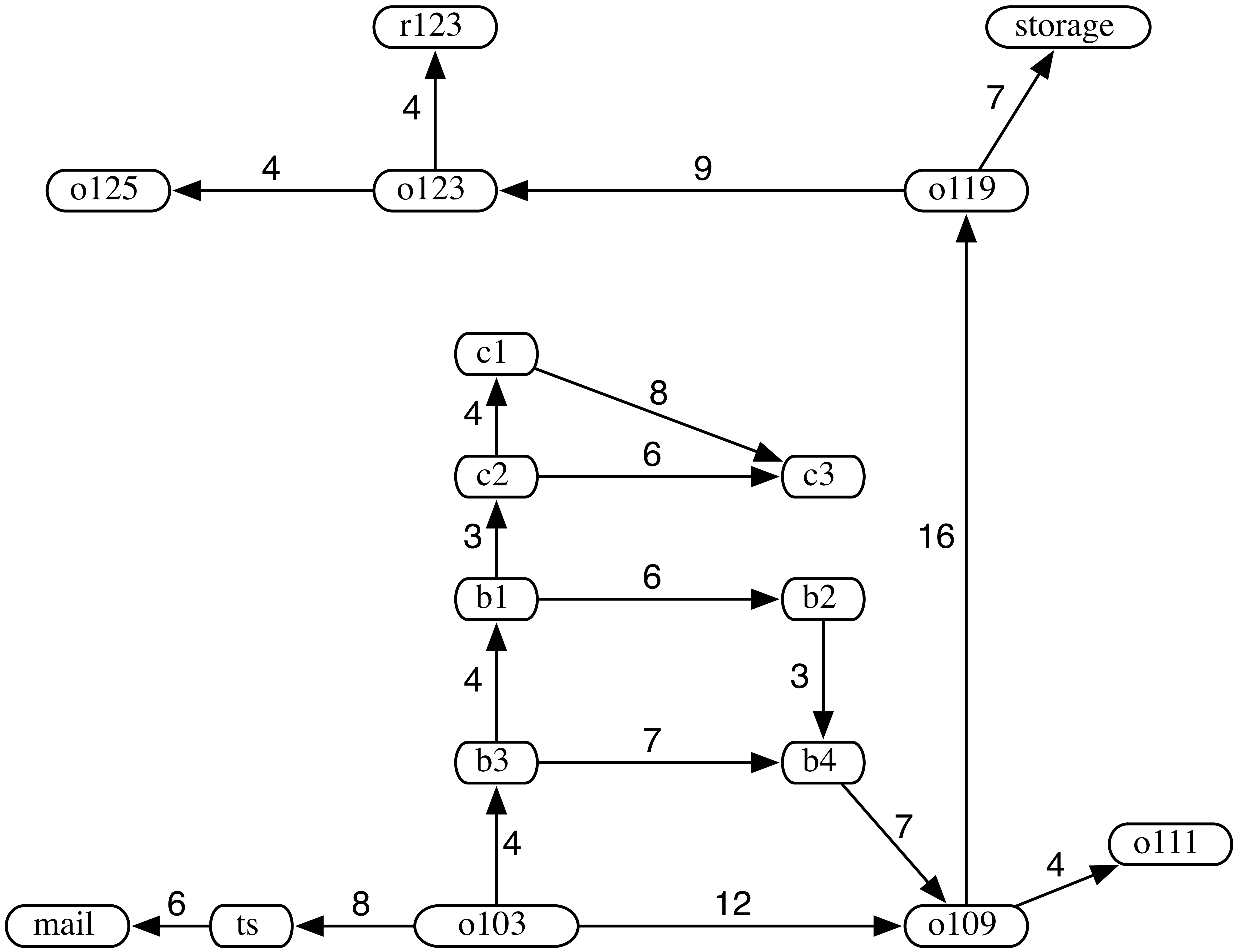
- An **optimal solution** is one with the lowest cost

**Questions:**

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

# DeliveryBot with Costs



# 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