Game Theory for Sequential Interactions

CMPUT 261: Introduction to Artificial Intelligence

S&LB §5.0-5.2.2

Lecture Outline

1. Recap & Logistics
2. Perfect Information Games
3. Backward Induction

After this lecture, you should be able to:

- trace an execution of backward induction
- explain the difference between imperfect information and perfect information extensive form games
- define an information set
- identify the pure strategies in an extensive form game
- identify a maxmin strategy in an extensive form game

Logistics

- **Assignment 4:** late submissions available until **11:59pm tonight**
- **SPOT** (formerly USRI) surveys are now available: https://p20.courseval.net/etw/ets/et.asp?nxappid=UA2&nxmid=start
    - You should have gotten an email
    - Available until **tonight** (Dec 8)
- **Final exam** is **Tuesday Dec 13**
    - This lecture hall (T BW-1)
    - At **9:00 am** (*half an hour earlier* than usual lecture time)
    - Format: Like midterm, but longer
    - Material: EVERYTHING (but more focus on post-midterm material)

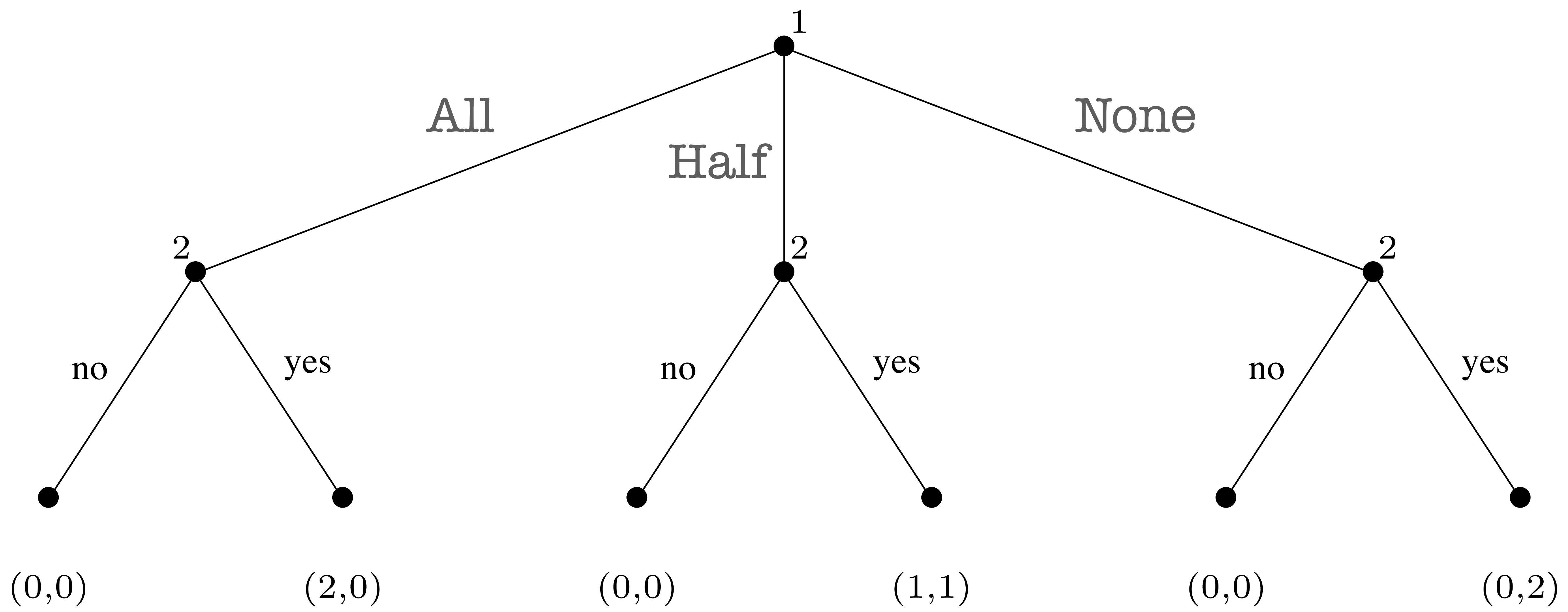
Recap: Game Theory

- Game theory studies the **interactions of rational agents**
    - Canonical representation is the **normal form game**
- Game theory uses **solution concepts** rather than optimal behaviour
    - "Optimal behaviour" is not clear-cut in multiagent settings
    - **Pareto optimal:** no agent can be made better off without making some other agent worse off
    - **Nash equilibrium:** no agent regrets their strategy given the choice of the other agents' strategies

	Ballet	Soccer
Ballet	2, 1	0, 0
Soccer	0, 0	1, 2

Extensive Form Games

- Normal form games don't have any notion of **sequence**: all actions happen **simultaneously**
- The **extensive form** is a game representation that explicitly includes temporal structure (i.e., a **game tree**)



Perfect Information

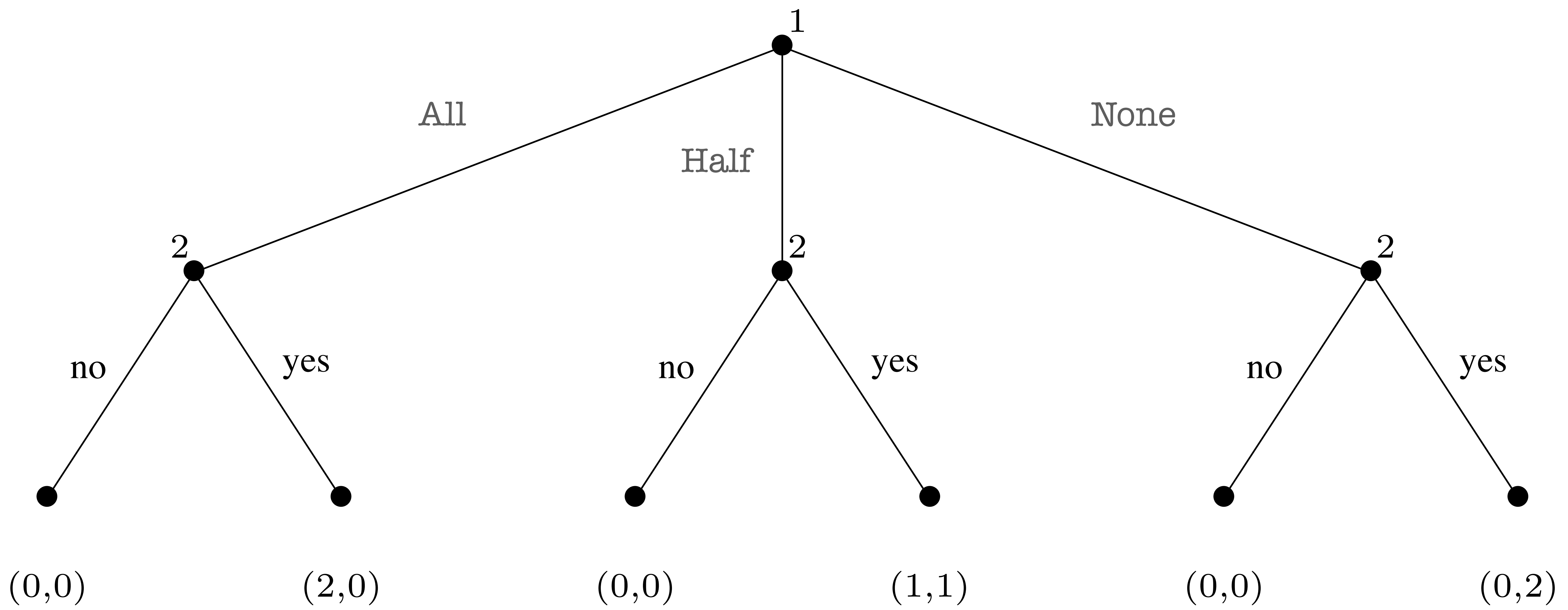
There are two kinds of extensive form game:

1. **Perfect information:** Every agent **sees all actions** of the other players (including "**Nature**")
    - e.g.: Chess, checkers, Pandemic
2. **Imperfect information:** Some actions are **hidden**
    - Players may not know exactly where they are in the tree
    - e.g.: Poker, rummy, Scrabble

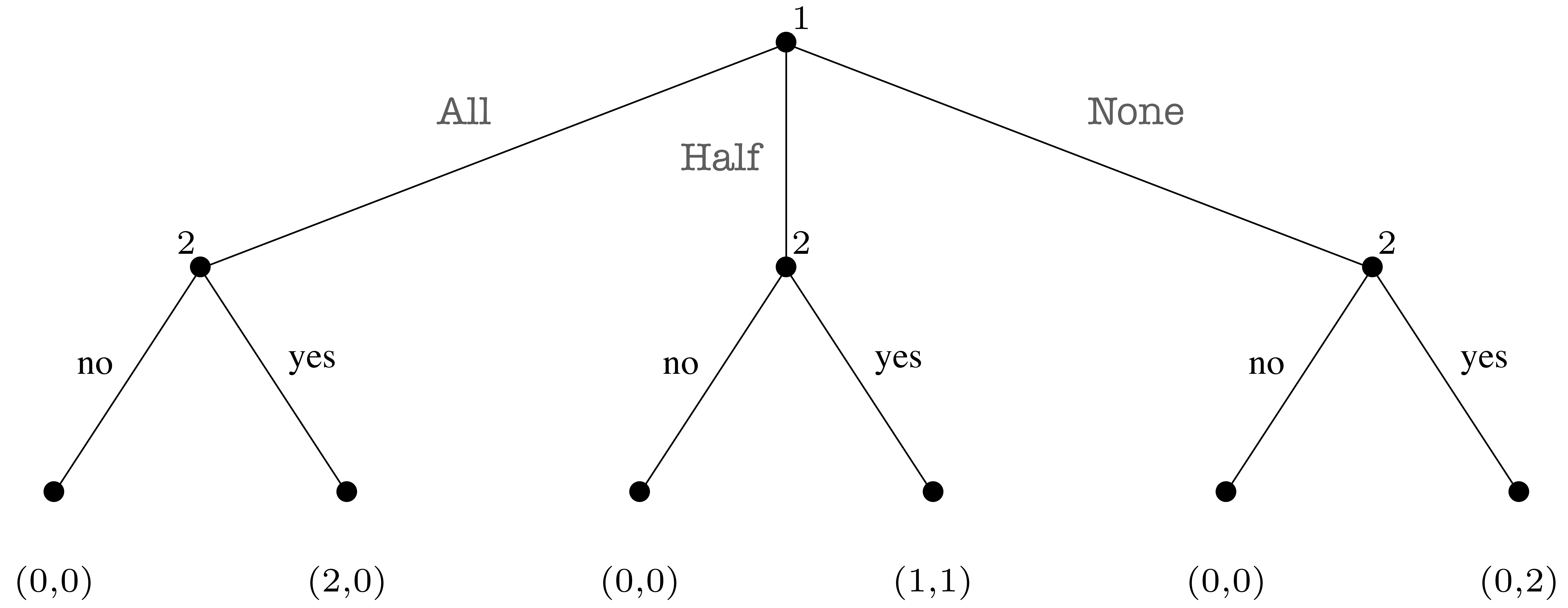
Perfect Information Extensive Form Game

Definition:
A **finite perfect-information game in extensive form** is a tuple
$G = (N, A, H, Z, \chi, \rho, \sigma, u)$, where

- N is a set of n **players**,
- A is a single set of **actions**,
- H is a set of nonterminal **choice nodes**,
- Z is a set of **terminal nodes** (disjoint from H),
- $\chi : H \rightarrow 2^A$ is the **action function**,
- $\rho : H \rightarrow N$ is the **player function**,
- $\sigma : H \times A \rightarrow H \cup Z$ is the **successor function**,
- $u = (u_1, u_2, \ldots, u_n)$ is a **utility function** for each player, $u_i : Z \rightarrow \mathbb{R}$



Fun Game: The Sharing Game



- Two siblings must decide how to share two $100 coins
- Sibling 1 suggests a division, then sibling 2 **accepts** or **rejects**
  - If **rejected**, nobody gets any coins.

Pure Strategies

Question: What are the **pure strategies** in an extensive form game?

Definition:
Let $G = (N, A, H, Z, \chi, \rho, \sigma, u)$ be a perfect information game in extensive form. Then the **pure strategies of player i** consist of the cross product of actions available to player i at each of their choice nodes, i.e.,

$$\prod_{h \in H | \rho(h) = i} \chi(h)$$

- A pure strategy associates an action with **each** choice node, even those that will **never be reached**
    - Even nodes that will never be reached as a result of the strategy itself!

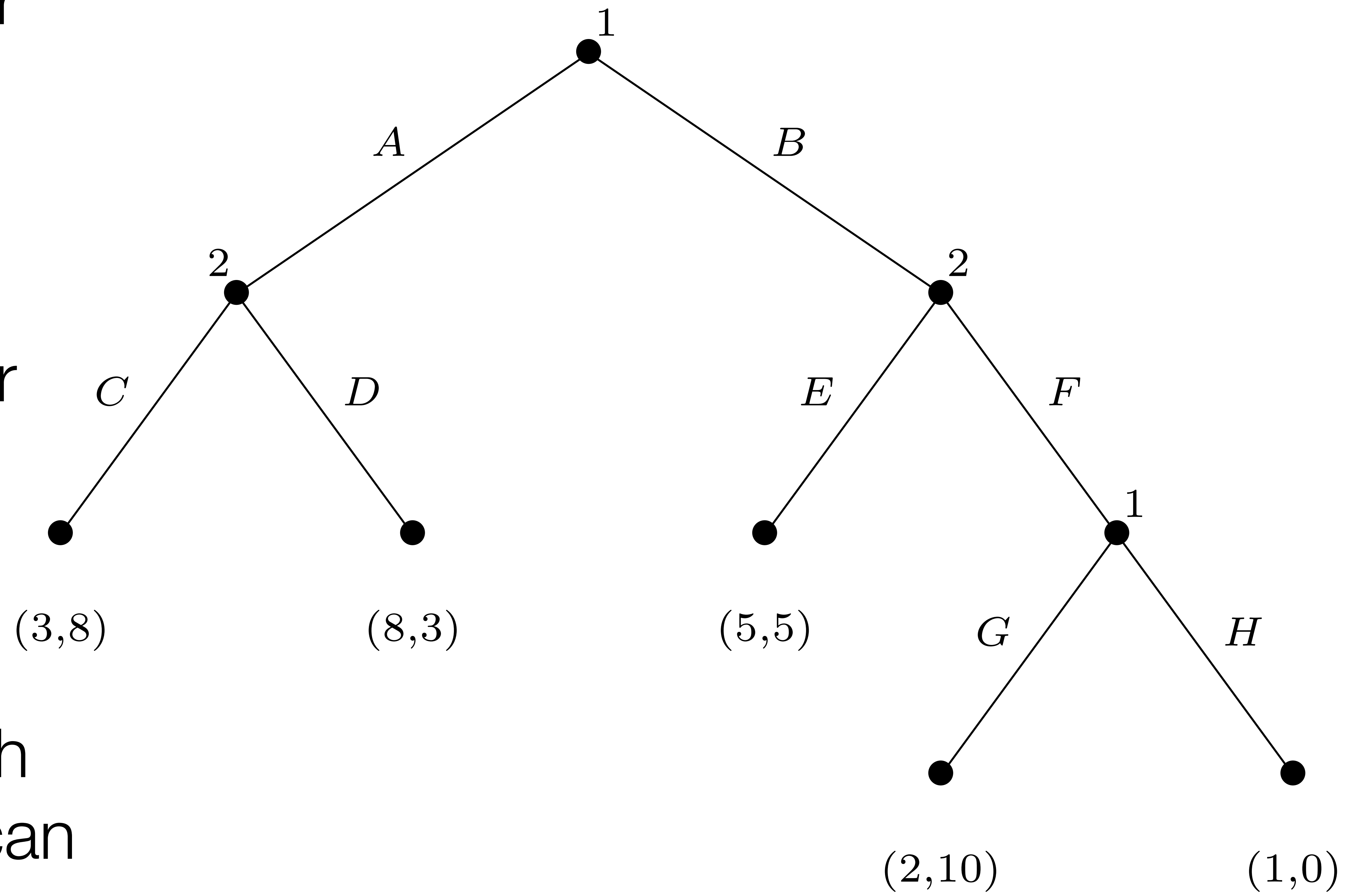
Pure Strategies Example

Question: What are the **pure strategies** for **player 2**?

- $\{(C, E), (C, F), (D, E), (D, F)\}$

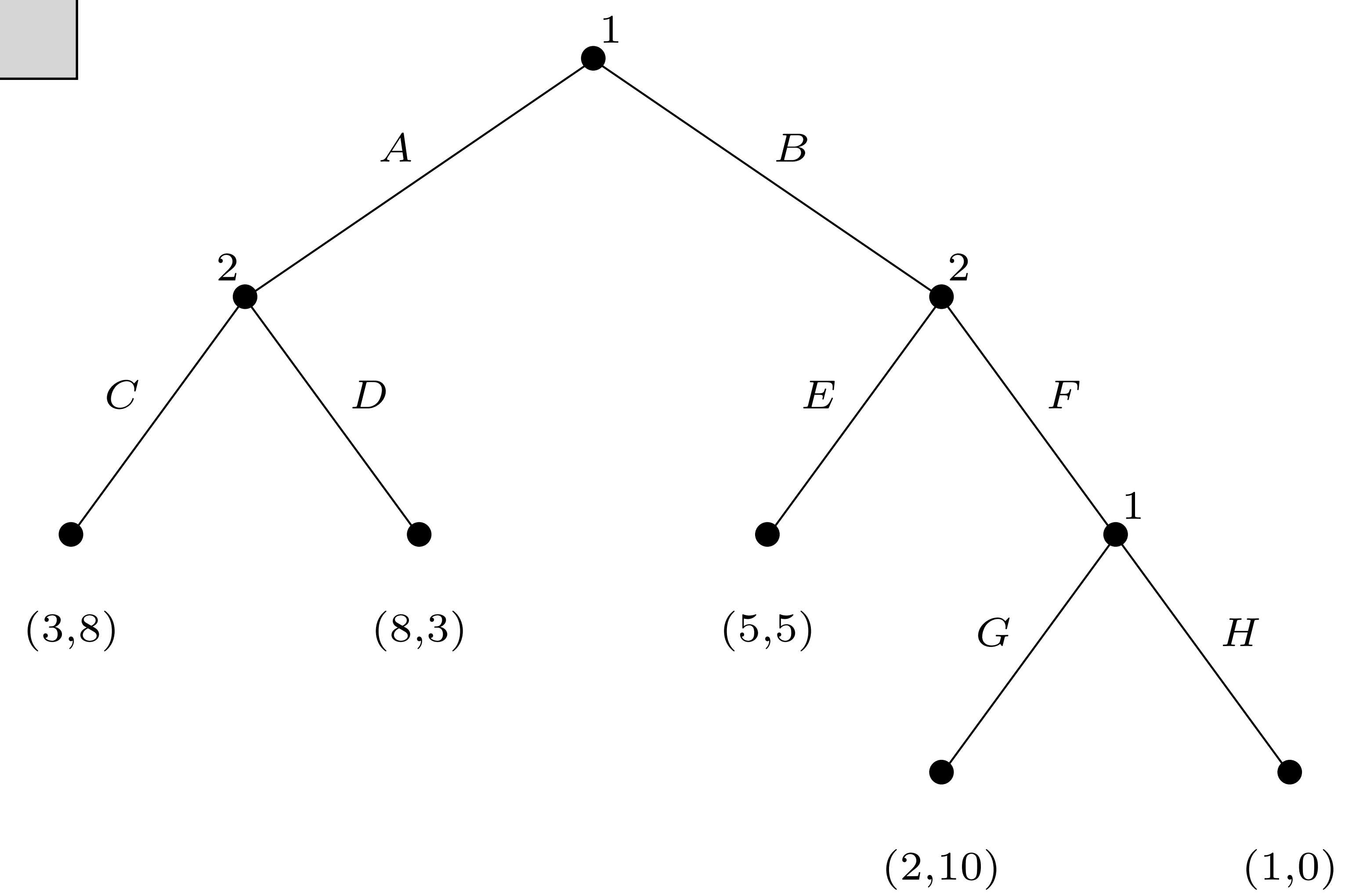
Question: What are the **pure strategies** for **player 1**?

- $\{(A, G), (A, H), (B, G), (B, H)\}$
- Note that these associate an action with the second choice node even when it can never be reached



Induced Normal Form

Question:
Which representation is more **compact**?



	C,E	C,F	D,E	D,F
A,G	3,8	3,8	8,3	8,3
A,H	3,8	3,8	8,3	8,3
B,G	5,5	2,10	5,5	2,10
B,H	5,5	1,0	5,5	1,0

- Any pair of pure strategies uniquely identifies a **terminal node**, which identifies a **utility** for each agent (**why?**)
- We have now defined a set of **agents**, **pure strategies**, and **utility functions**
- Any extensive form game defines a corresponding **induced normal form game**

Reusing Old Definitions

- We can plug our new definition of **pure strategy** into our existing definitions for:
  - Mixed strategy
  - Best response
  - Nash equilibrium (both pure and mixed strategy)

Question:

What is the definition of a **mixed strategy** in an extensive form game?

Pure Strategy Nash Equilibria

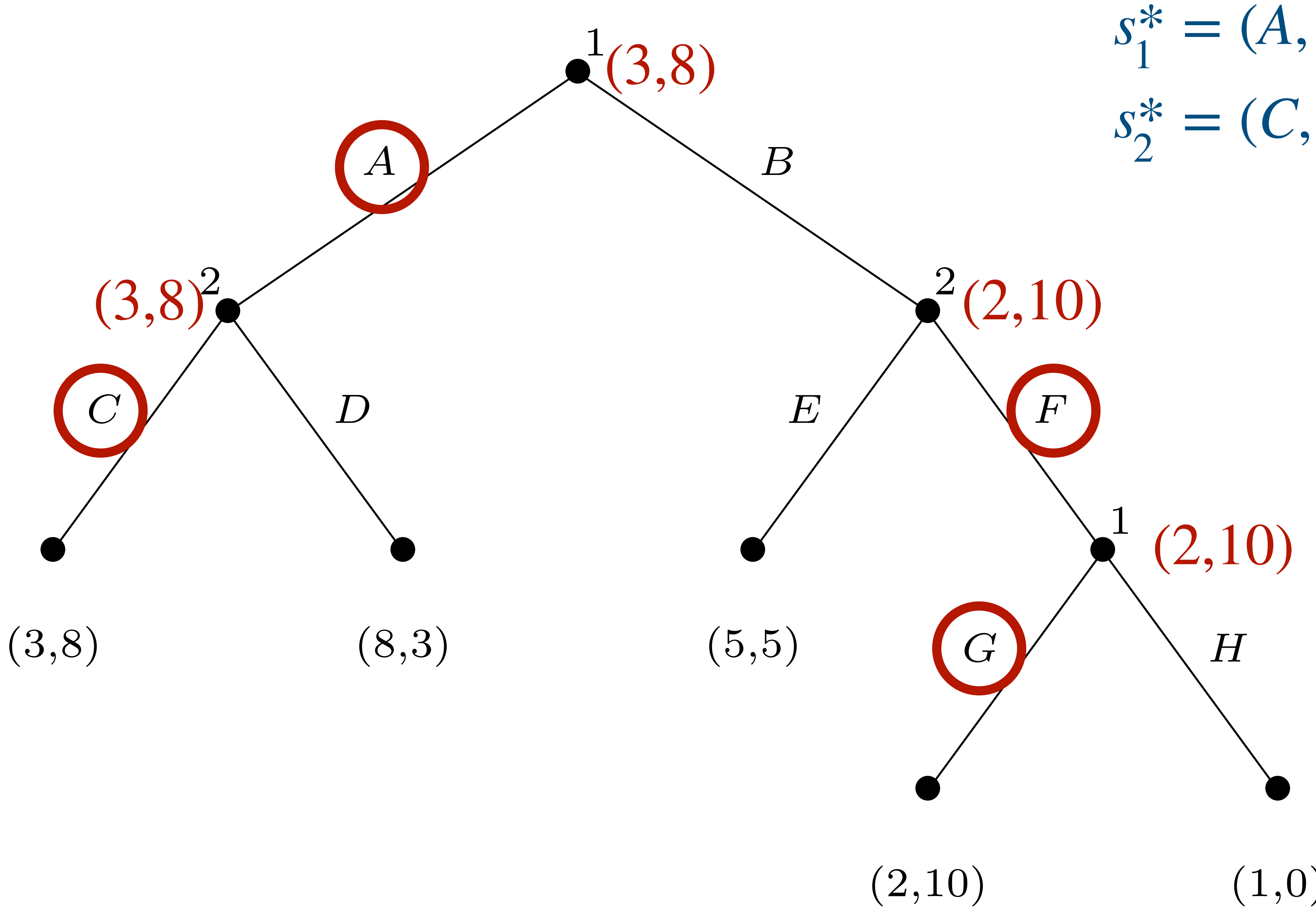
Theorem: [Zermelo, 1913]
Every finite perfect-information game in extensive form has at least one **pure strategy Nash equilibrium**.

- Starting from the bottom of the tree, no agent needs to **randomize**, because they already know the best response
- There might be **multiple** pure strategy Nash equilibria in cases where an agent has multiple best responses at a **single choice node**

Backward Induction

- **Backward induction** is a straightforward algorithm that is guaranteed to compute a **pure strategy Nash equilibrium**.

- **Idea:** Replace subgames lower in the tree with their equilibrium values



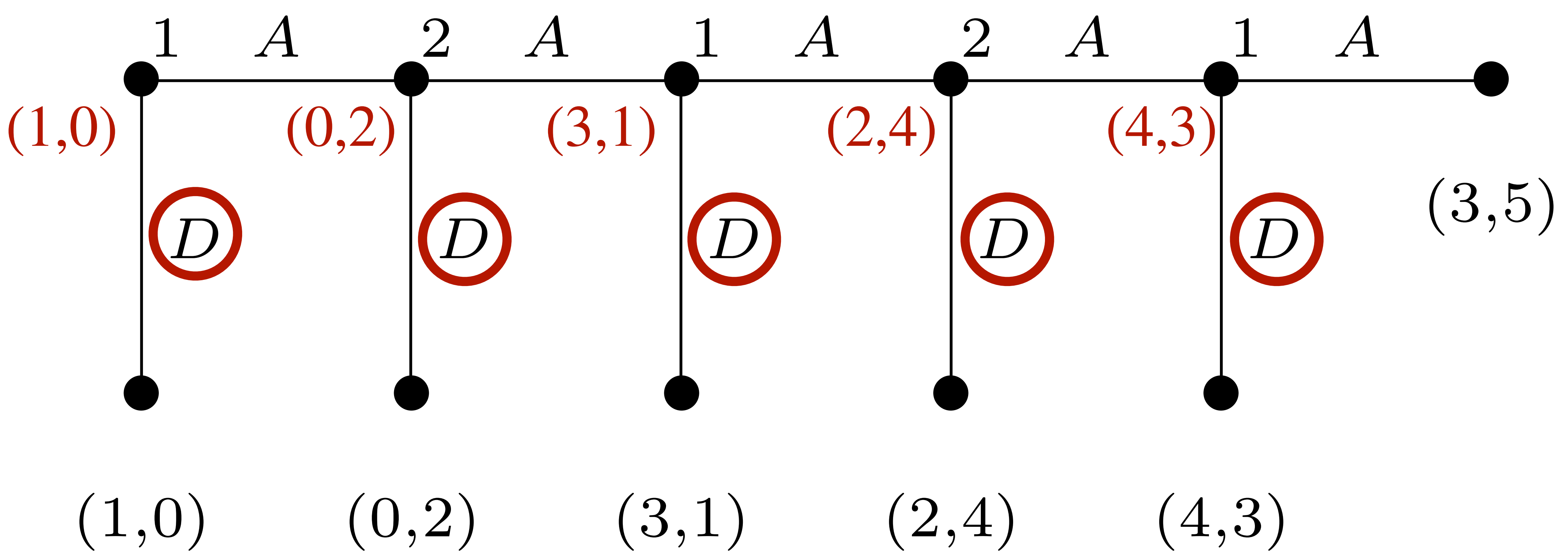
$s_1^* = (A, G)$

$s_2^* = (C, F)$

Question:

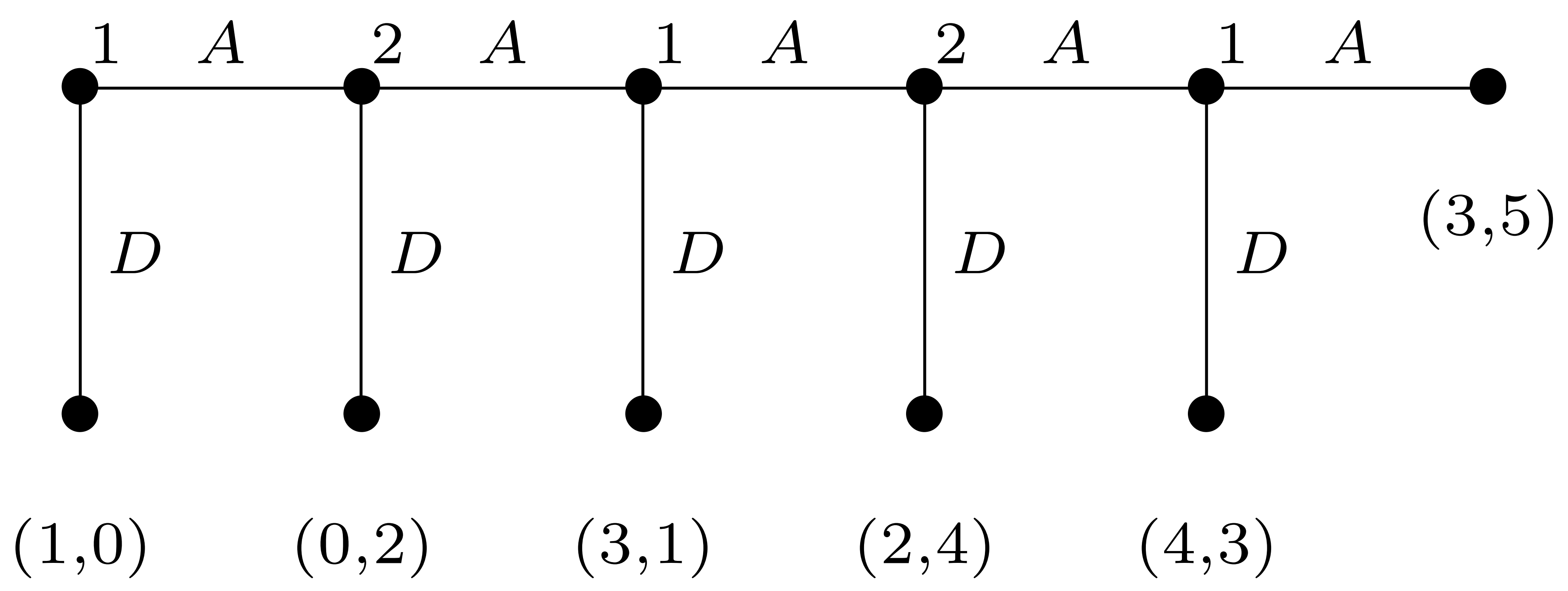
Could you use backward induction to compute a **maxmin** strategy? How?

Fun Game: Centipede



- At each stage, one of the players can go **Across** or **Down**
- If they go **Down**, the game ends.

Backward Induction Criticism



- The **unique** equilibrium is for each player to play **Down at the first opportunity.**
- **Empirically**, this is not how real people tend to play!
- **Theoretically**, what should you do if you arrive at an **off-path** node?
  - How do you update your beliefs to account for this probability 0 event?
  - If player 1 knows that you will update your beliefs in a way that causes you not to play **Down**, then playing **Down** is no longer their only rational choice...

Imperfect Information, informally

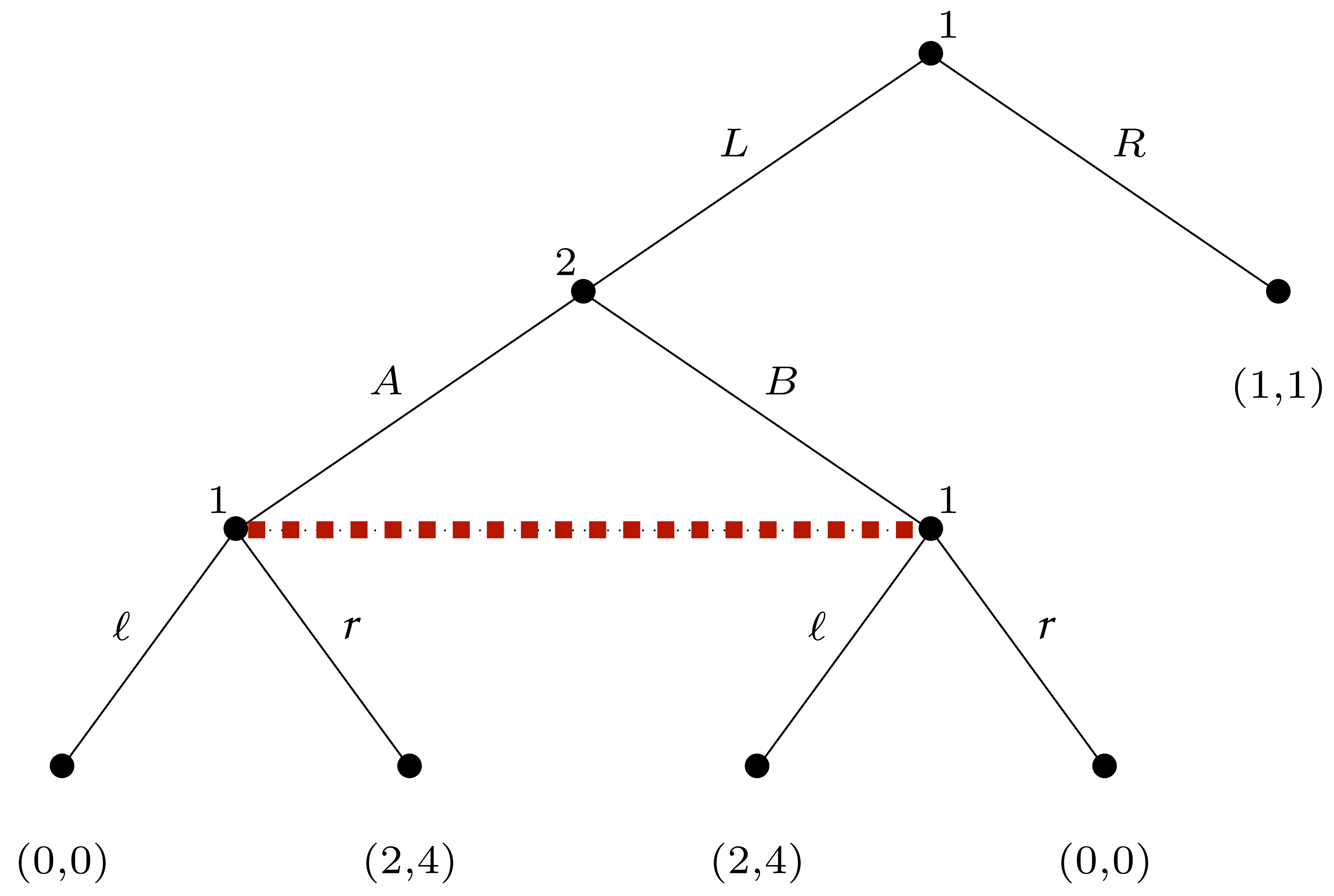
- **Perfect information** games model **sequential** actions that are **observed by all players**
  - **Randomness** can be modelled by a special **Nature** player with constant utility and known mixed strategy
- But many games involve **hidden** actions
  - Cribbage, poker, Scrabble
  - Sometimes actions of the **players** are hidden, sometimes **Nature's** actions are hidden, sometimes both
- **Imperfect information extensive form games** are a model of games with sequential actions, some of which may be **hidden**

Imperfect Information Extensive Form Game

Definition:
An **imperfect information game in extensive form** is a tuple $G = (N, A, H, Z, \chi, \rho, \sigma, u, I)$, where

- $(N, A, H, Z, \chi, \rho, \sigma, u)$ is a perfect information extensive form game, and
- $I = (I_1, \ldots, I_n)$, where $I_i = (I_{i,1}, \ldots, I_{i,k_i})$ is an **equivalence relation** on (i.e., partition of) $\{h \in H : \rho(h) = i\}$ with the property that $\chi(h) = \chi(h')$ and $\rho(h) = \rho(h')$ whenever there exists a $j \in N$ for which $h \in I_{i,j}$ and $h' \in I_{i,j}$.

Imperfect Information Extensive Form Example



- The members of the equivalence classes are also called **information sets**
- Players **cannot distinguish** which **history** they are in within an information set
- **Question:** What are the information sets for each player in this game?

Pure Strategies

Question: What are the **pure strategies** in an **imperfect information** extensive-form game?

Definition:
Let $G = (N, A, H, Z, \chi, \rho, \sigma, u, I)$ be an imperfect information game in extensive form. Then the **pure strategies of player i** consist of the cross product of actions available to player i at each of their **information sets**, i.e.,

$$\prod_{I_{i,j} \in I_i} \chi(h)$$

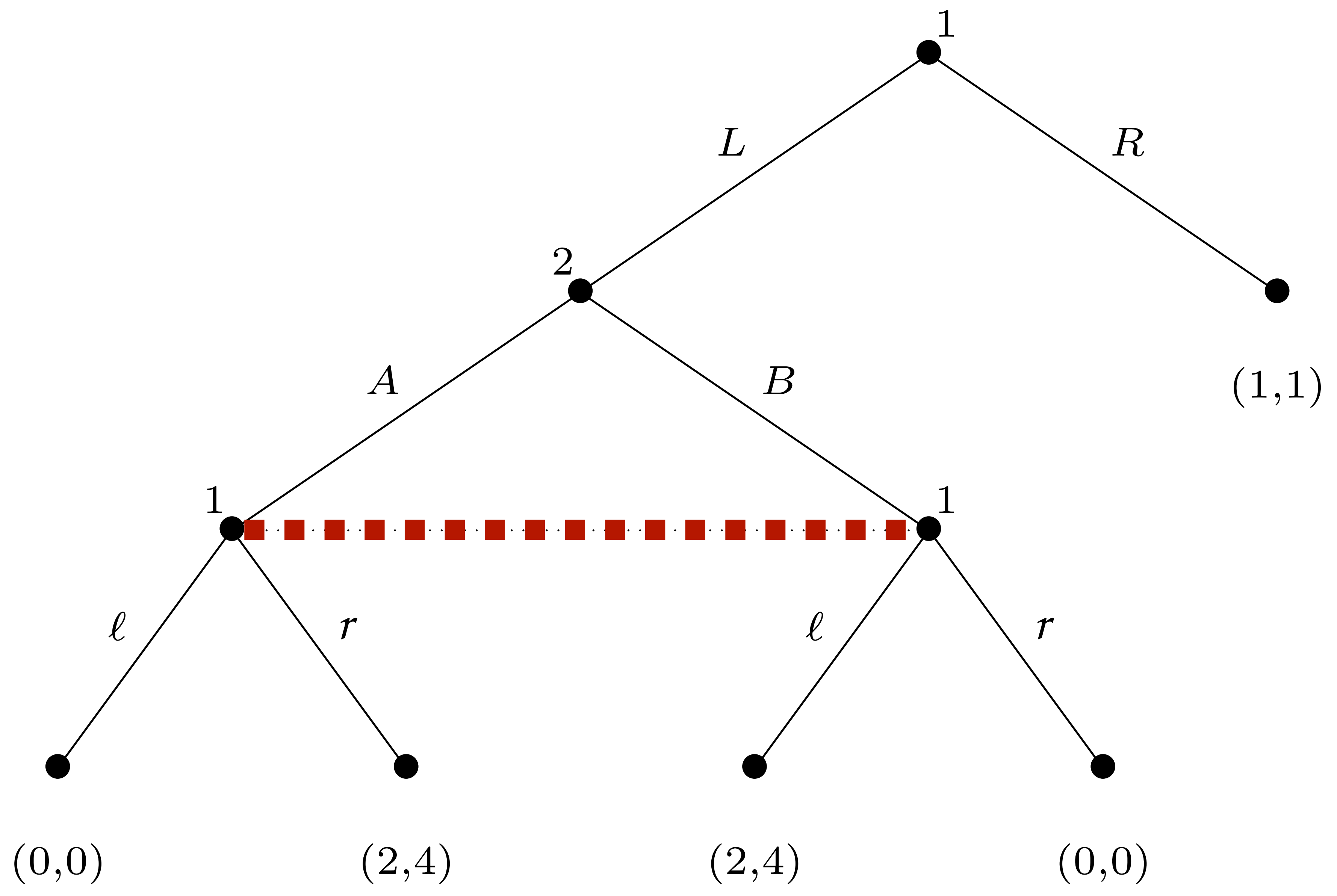
- A pure strategy associates an action with **each** information set, even those that will **never be reached**

Questions:

In an imperfect information game:

1. What are the **mixed strategies**?
2. What is a **best response**?
3. What is a **Nash equilibrium**?

Induced Normal Form



	A	B
L,ℓ	0,0	2,4
L,r	2,4	0,0
R,ℓ	1,1	1,1
R,r	1,1	1,1

Question:
Can you represent an arbitrary **perfect information** extensive form game as an **imperfect information** game?

- Any pair of pure strategies uniquely identifies a **terminal node**, which identifies a **utility** for each agent
- We have now defined a set of **agents**, **pure strategies**, and **utility functions**
- Any extensive form game defines a corresponding **induced normal form game**

Summary

- **Mixed strategies** are distributions over **pure strategies**
  - In normal form games, pure strategies are just **single actions**
- **Extensive form games** model **sequential** actions
- **Pure strategies** for extensive form games map **choice nodes** to **actions**
  - **Induced normal form:** normal form game with these pure strategies
  - Notions of mixed strategy, best response, etc. **translate directly**
- **Perfect information:** Every agent **sees all actions** of the other players
  - **Backward induction** computes a **pure strategy Nash equilibrium** for any perfect information extensive form game
- **Imperfect information:** Some actions are hidden from some agents
  - So some choice nodes are indistinguishable from each other for their agent
  - These nodes are grouped into **information sets**