CS 295A/395D: Artificial Intelligence

Elementary Game Theory

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30 March 2022

The University of Vermont

Agenda

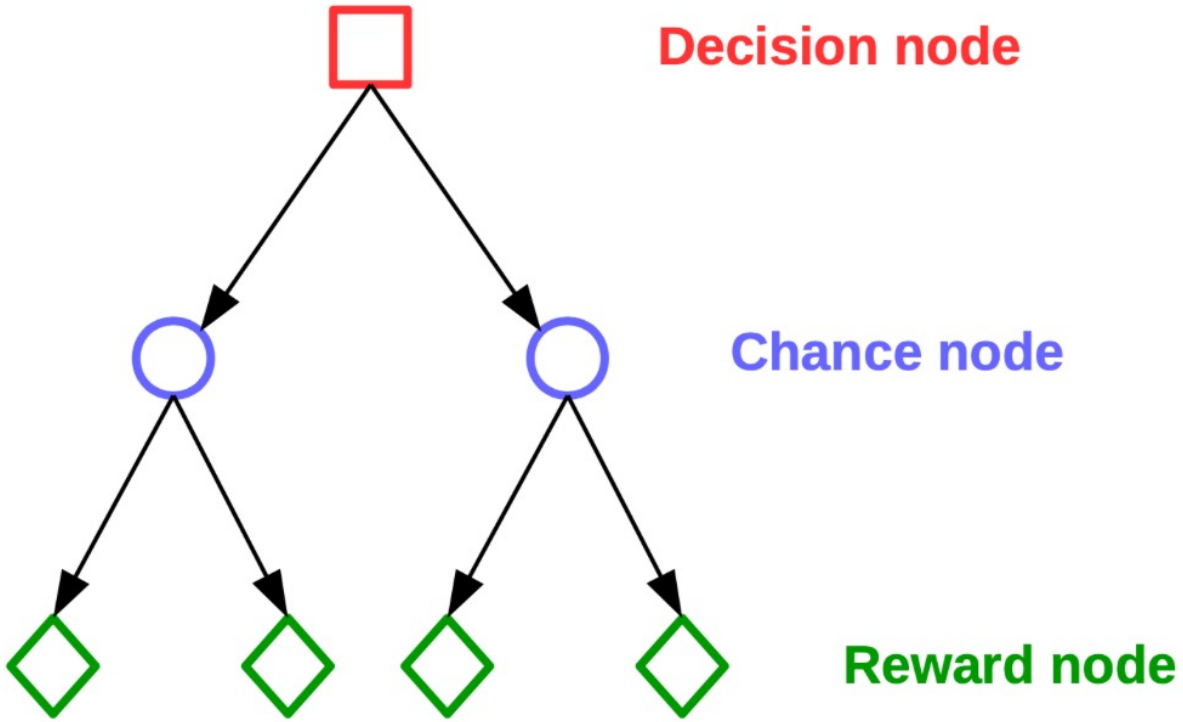
Review decision theory

Elementary game theory

- Optimum vs. optimal solutions
- Strategies
- Vocabulary

Logistics

- BB theory assignment out today
- Exam through game theory
  - Temporal reasoning pushed to next unit
  - Exam next Friday (April 8)
- Next unit: temporal reasoning and program synthesis
  - Removed machine learning



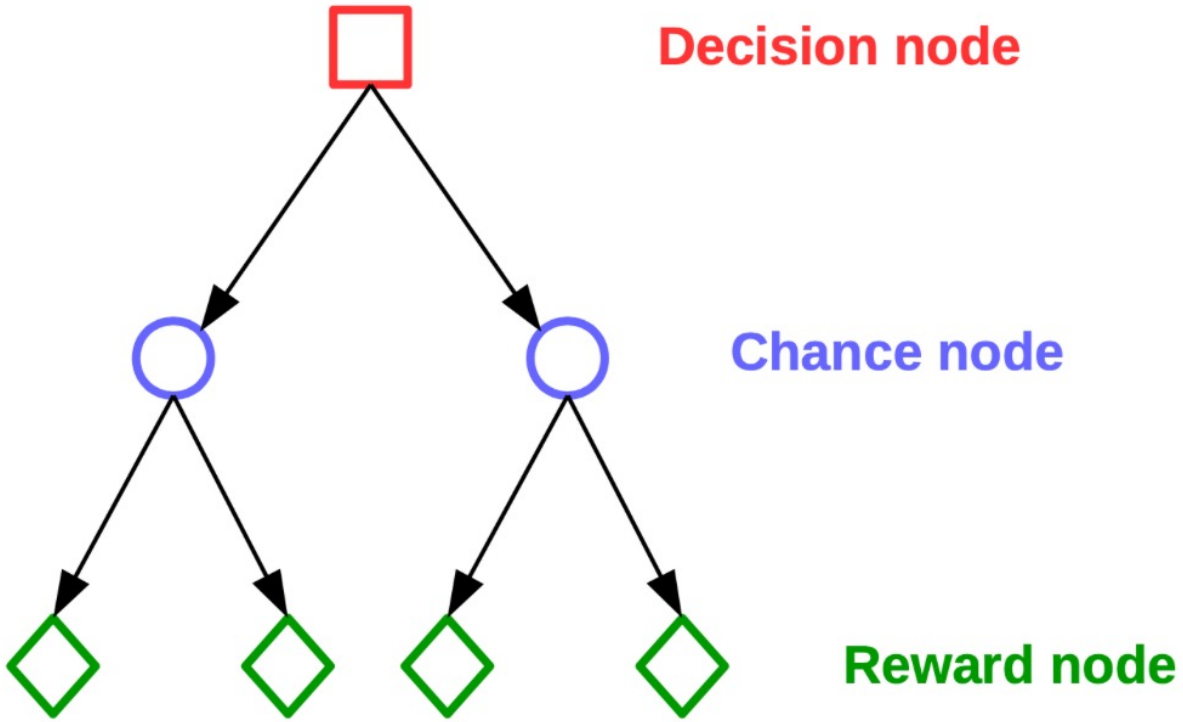
Note: "decision tree" also refers to a classification algorithm in machine learning and is completely different from the type of decision tree we will talk about here.

Recap: Decision Theory

We can express taking actions in a world with uncertainty via *decision trees*

Decisions trees are temporally-ordered nodes where each level corresponds to alternating:

- **Decision nodes –** state of the system; outgoing edges represent different actions
- **Chance nodes –** probability distributions over outcomes; outgoing edges represent reachable states with some probability
- **Reward nodes** – utility obtained from following the path



Note: "decision tree" also refers to a classification algorithm in machine learning and is completely different from the type of decision tree we will talk about here.

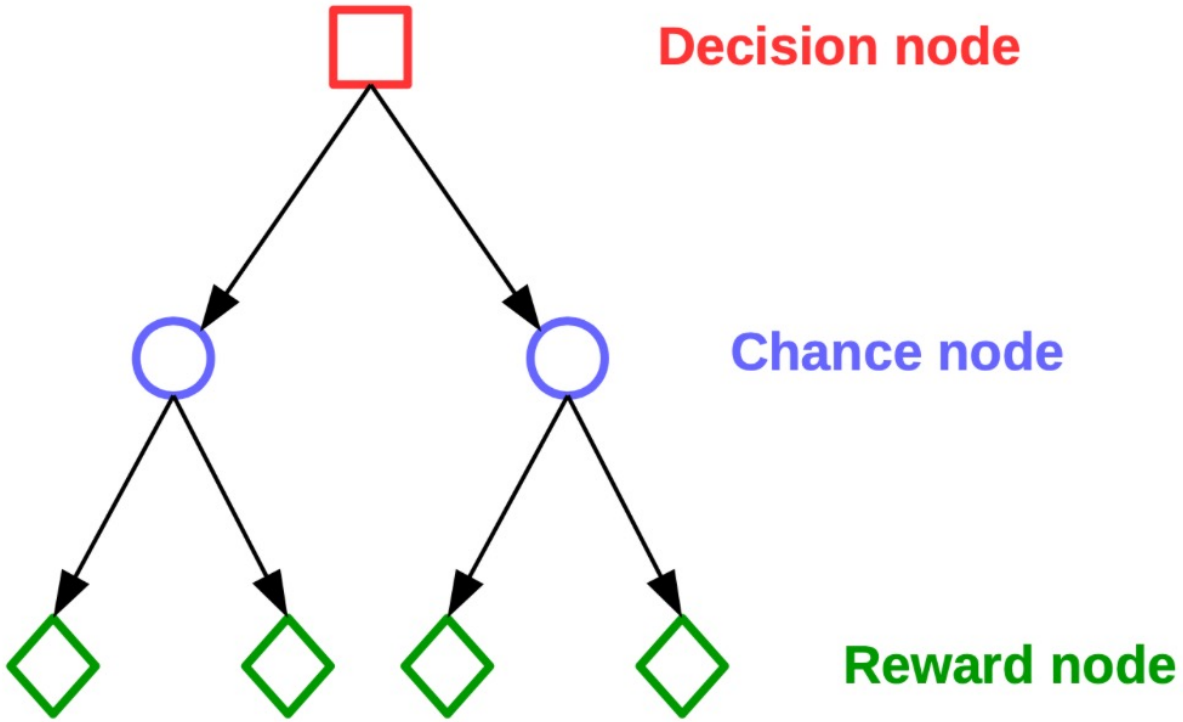
Recap: Maximize expected utility

$$EU[\, a \mid e_1, e_2, \ldots \,] = \sum_{s'} P(\, S_{t+1} = s' \mid a, e_1, e_2, \ldots)\, U(s')$$

Best action is the action a that maximizes

$$EU[\, a \mid e_1, e_2, \ldots \,]$$

Sum of the utility of actions taken.



Note: "decision tree" also refers to a classification algorithm in machine learning and is completely different from the type of decision tree we will talk about here.

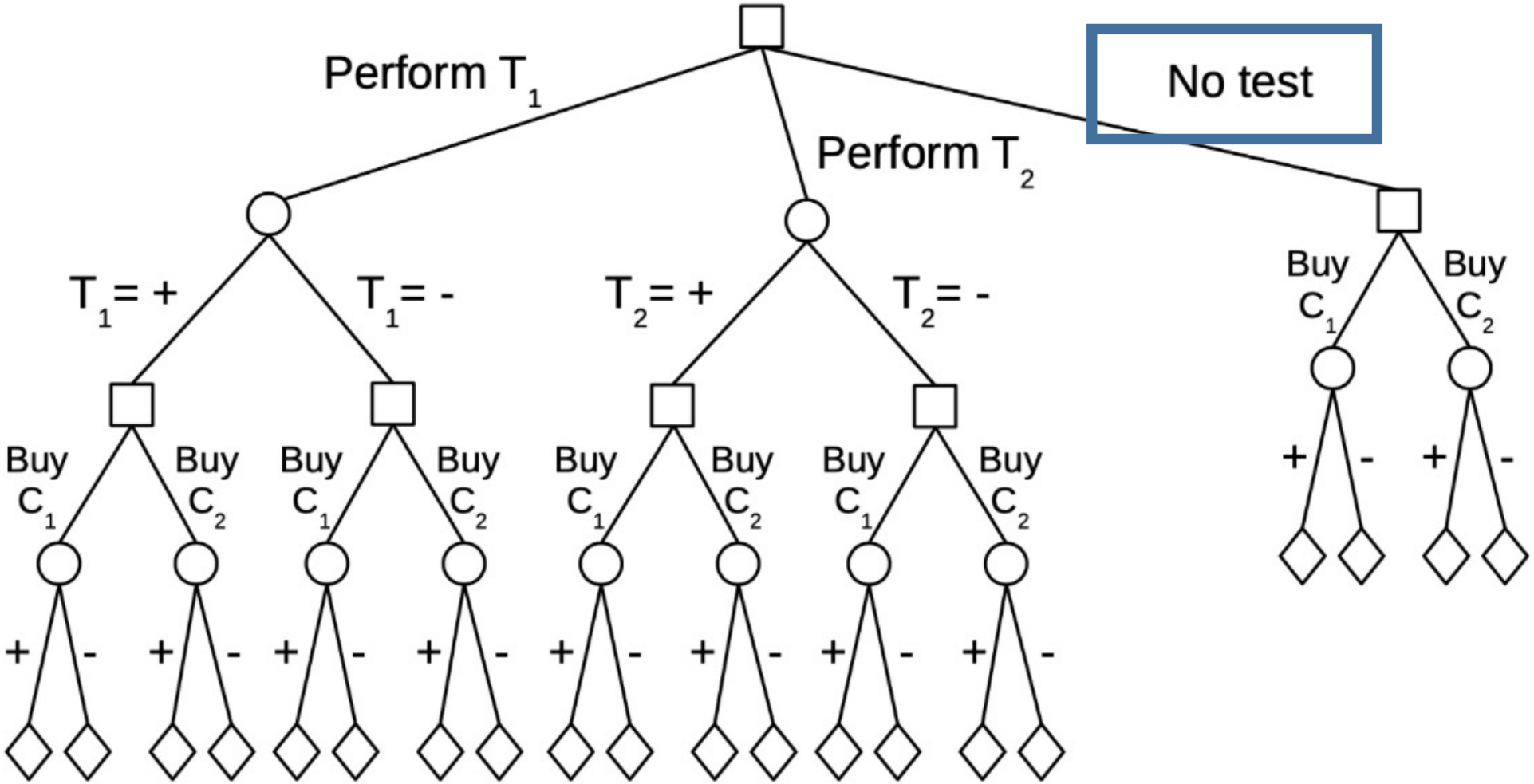
Recap: Comparing actions

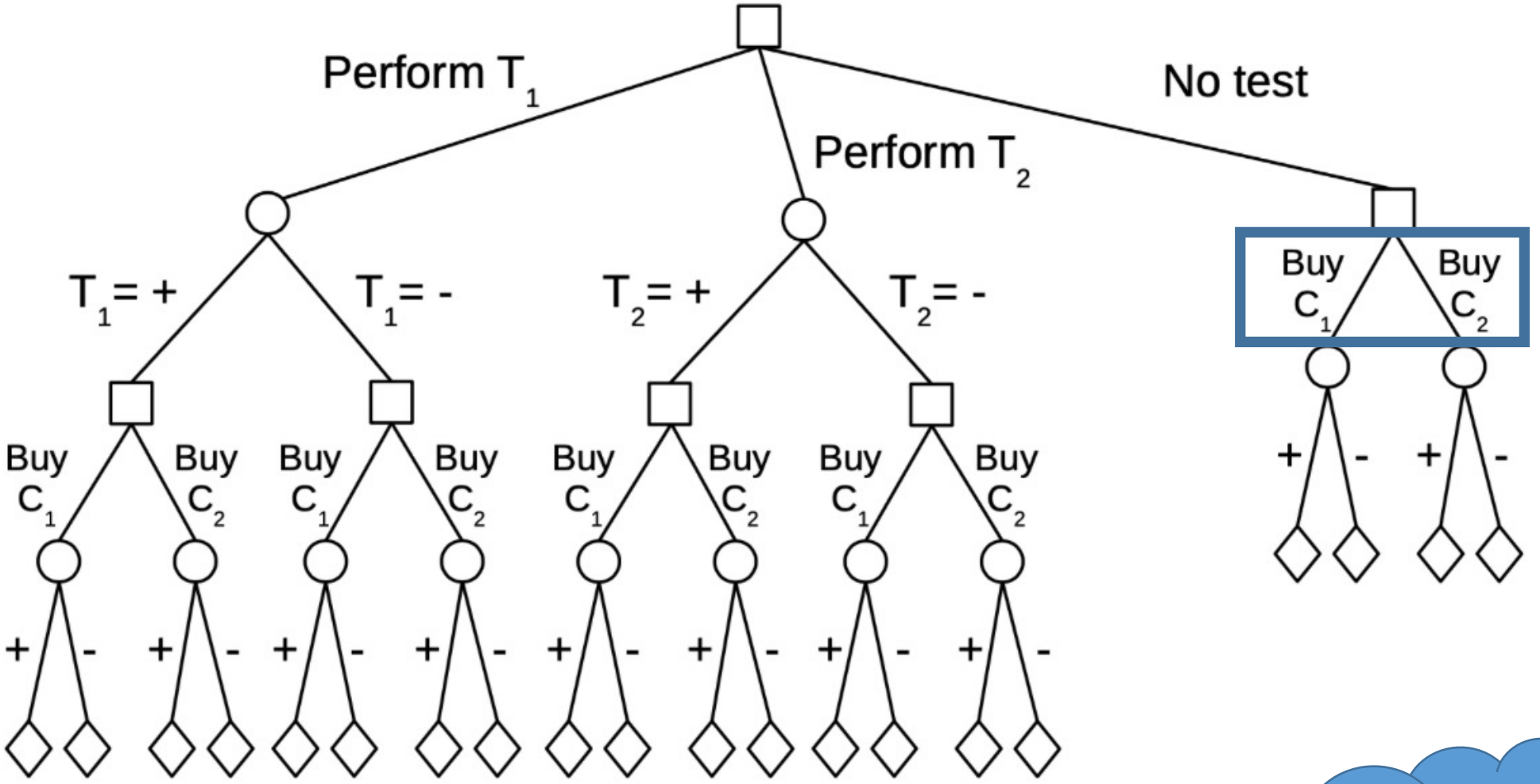
$$EU[\, a \mid e_1, e_2, \ldots \,] = \sum_{s'} P(\, S_{t+1} = s' \mid a, e_1, e_2, \ldots)\, U(s')$$

Probability mass function – over all sources of uncertainty associated with this action.

Utility function

- Basic actions: reward
- Actions with subsequent actions with uncertain outcomes: EU of those actions

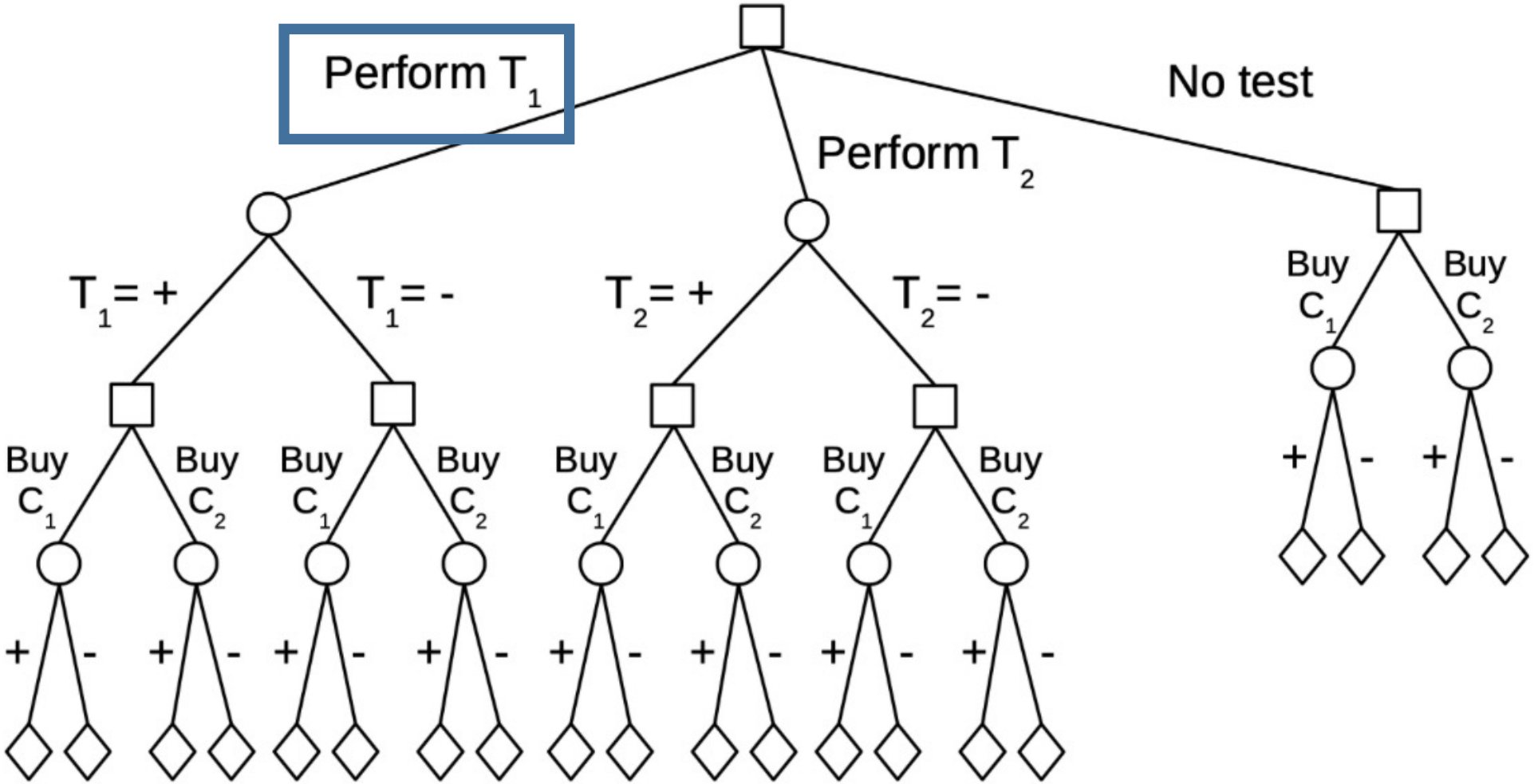

Perform T_1
Perform T_2
No test
T_1 = +
T_1 = -
T_2 = +
T_2 = -
Buy C_1
Buy C_2
+
-

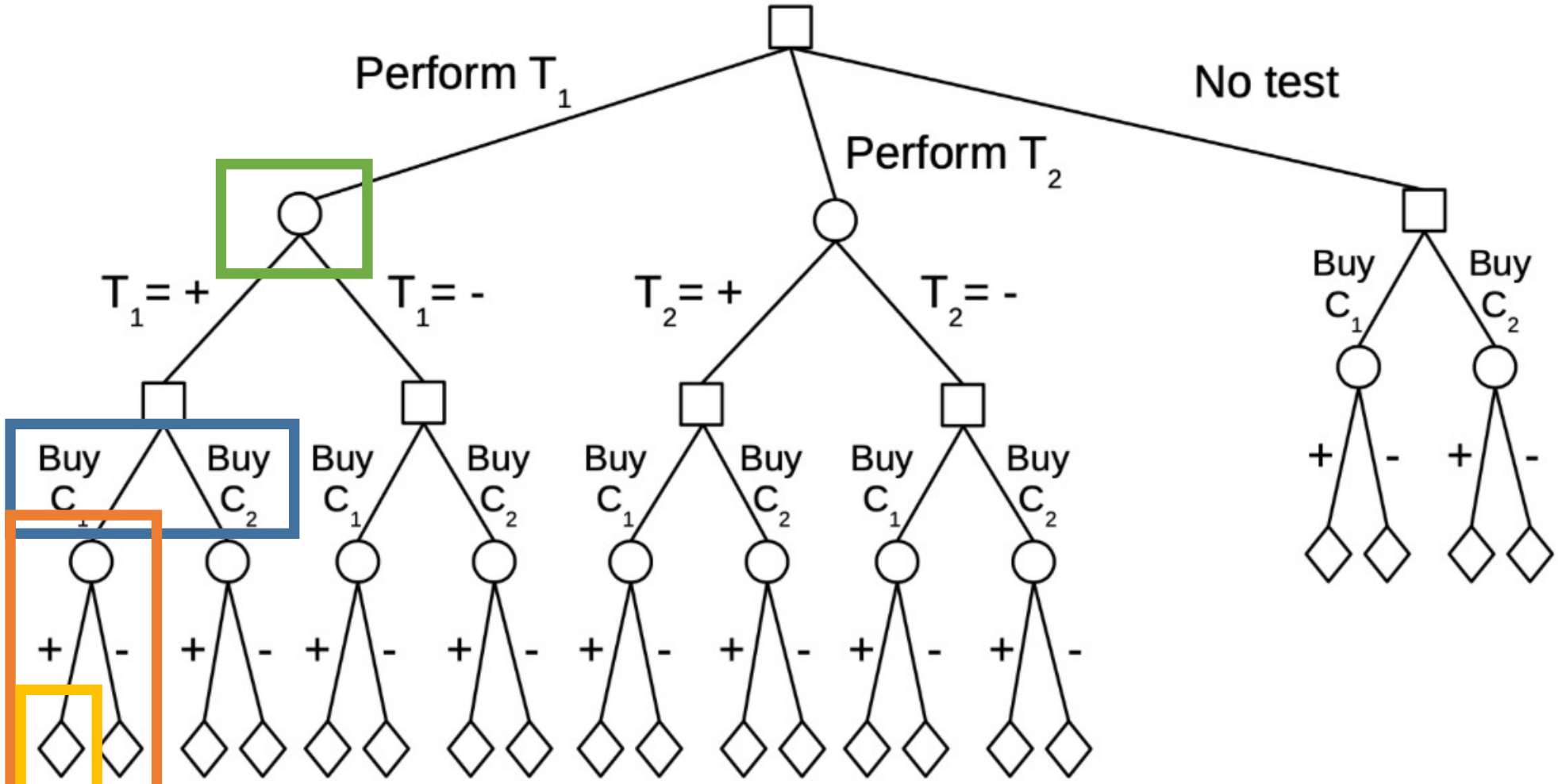


$$EU[C_1] = P(C_1 = +)\big(cost(C_1)\big) + P(C_1 = -)(cost(C_1) + repair(C_1))$$

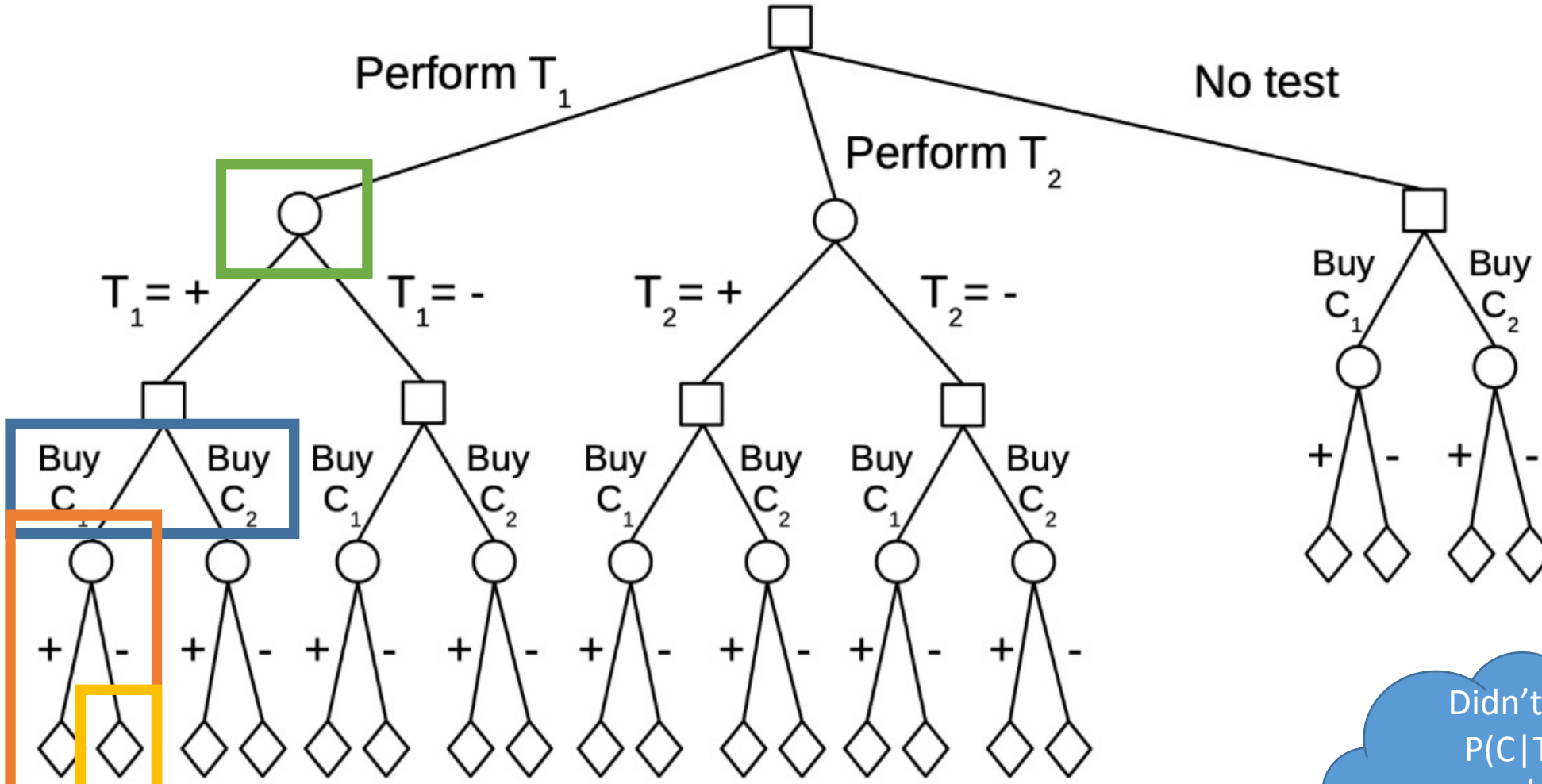
$$EU[C_2] = P(C_2 = +)\big(cost(C_2)\big) + P(C_2 = -)(cost(C_2) + repair(C_2))$$

Pick the car with the higher EU


Perform T1
Perform T2
No test
T1 = +
T1 = -
T2 = +
T2 = -
Buy C1
Buy C2
+
-

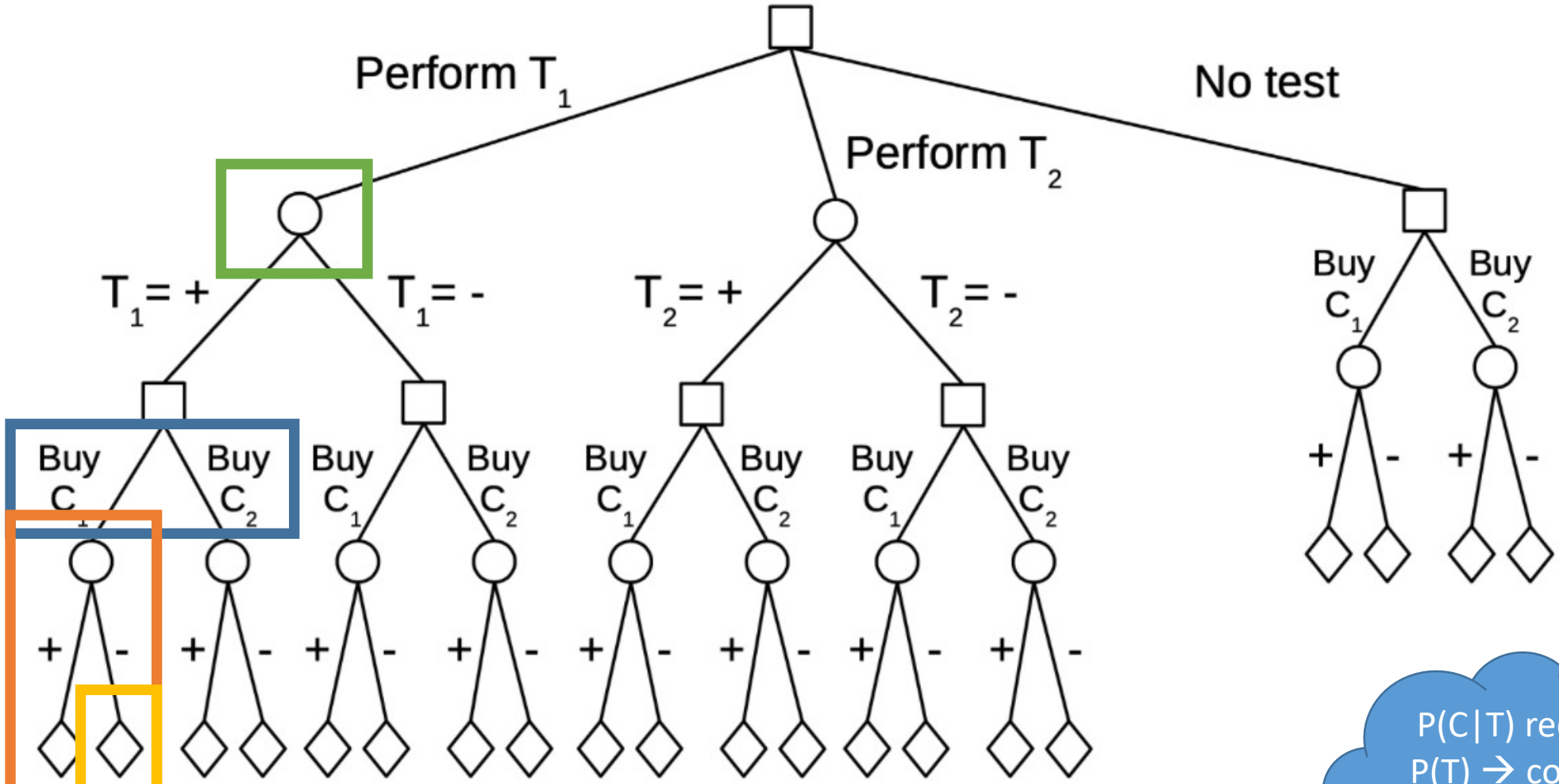


$$EU[C_1 \mid T_1 = +] = P(C_1 = + \mid T_1 = +)(cost(C_1) + cost(T_1)) + P(C_1 = - \mid T_1 = +)(cost(C_1) + repair(C_1) + cost(T_1))$$



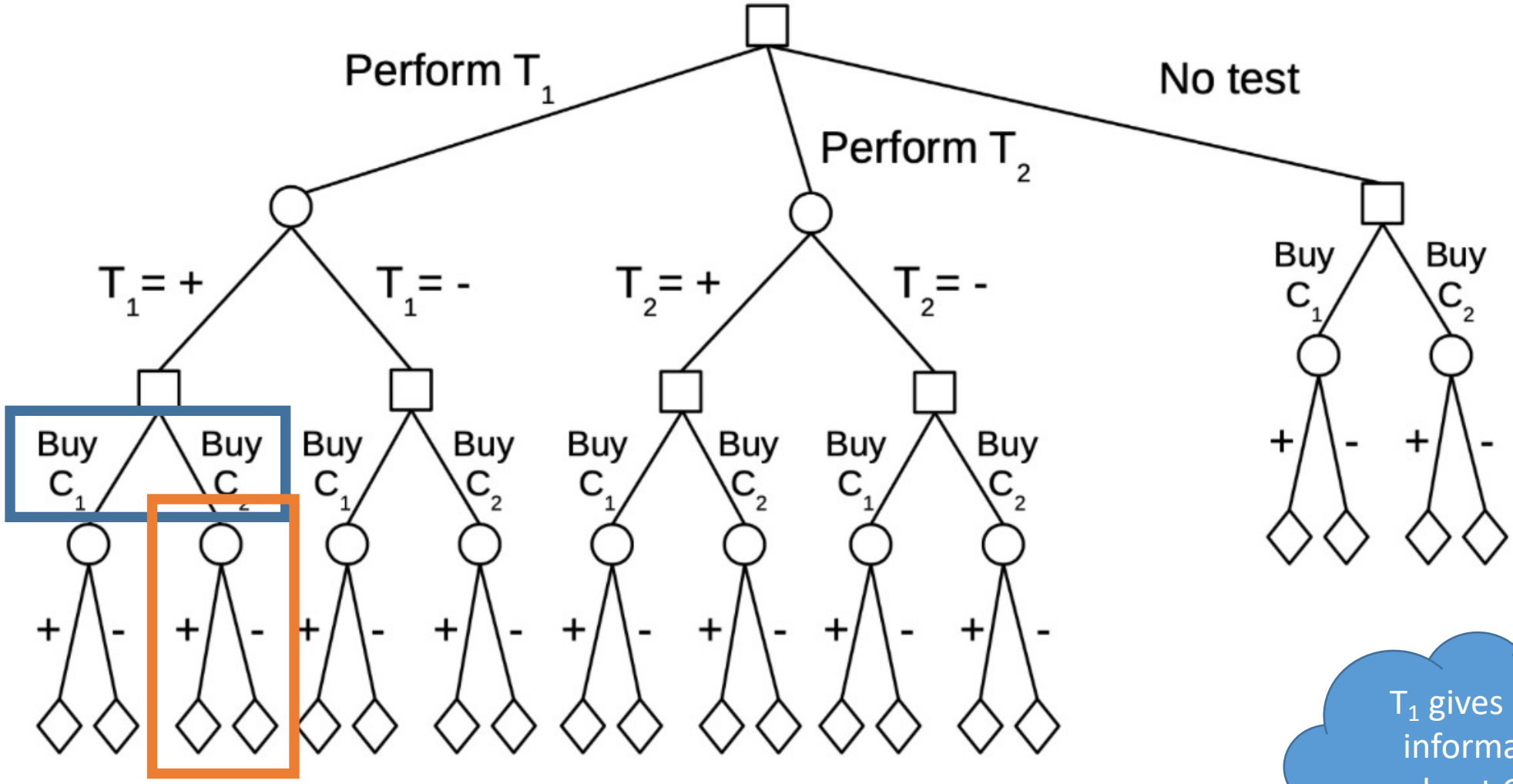
$$EU[C_1 \mid T_1 = +] = P(C_1 = + \mid T_1 = +)(cost(C_1) + cost(T_1))$$
$$+ P(C_1 = - \mid T_1 = +)[cost(C_1) + repair(C_1) + cost(T_1)]$$

Didn't have P(C|T) → needed to compute via Bayes Rule



$$EU[C_1 \mid T_1 = +] = P(C_1 = + \mid T_1 = +)(cost(C_1) + cost(T_1)) + P(C_1 = - \mid T_1 = +)[cost(C_1) + repair(C_1) + cost(T_1)]$$

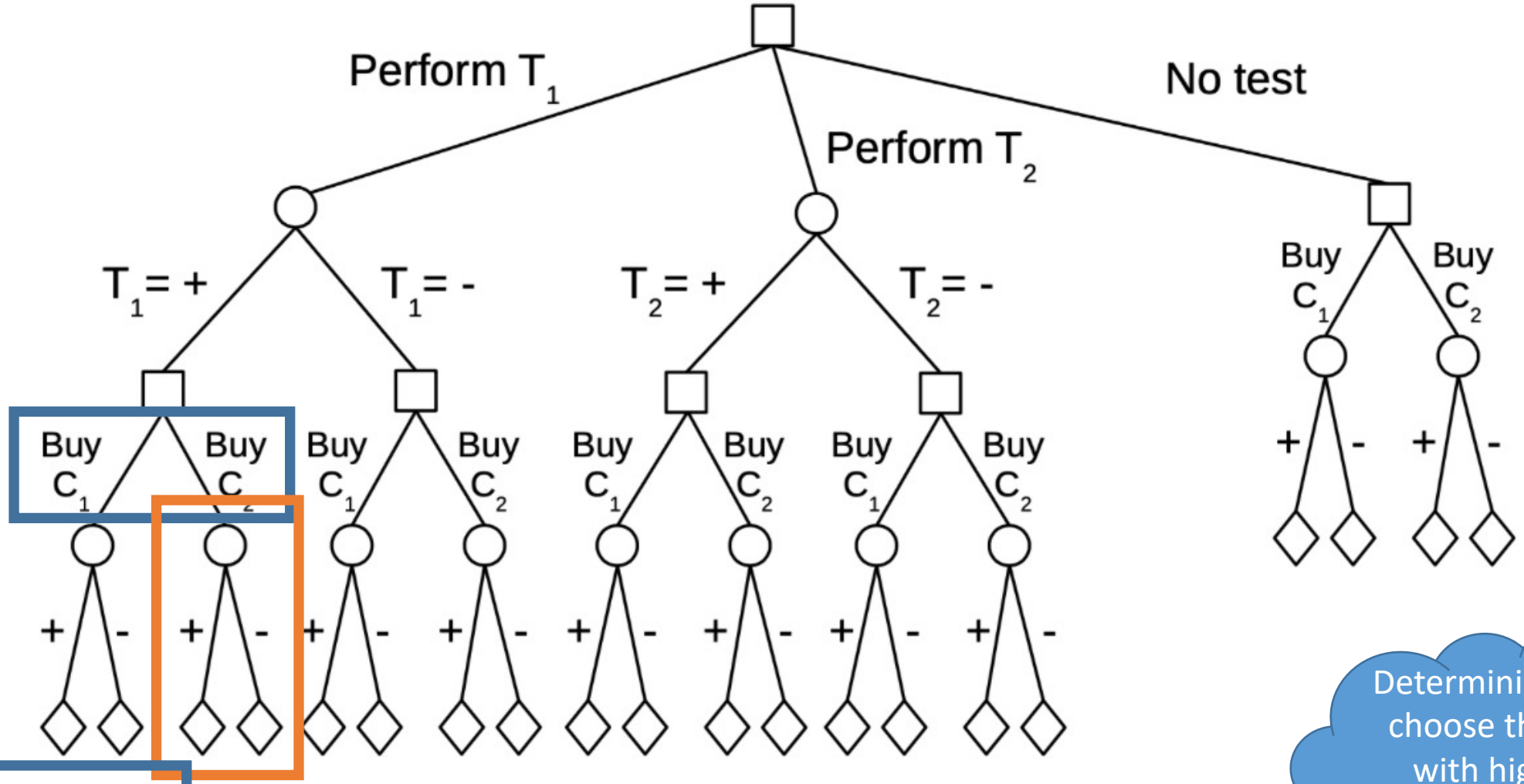
P(C|T) required P(T) → compute via law of total probability



$$EU[C_1 \mid T_1 = +] = P(C_1 = + \mid T_1 = +)(cost(C_1) + cost(T_1)) + P(C_1 = - \mid T_1 = +)(cost(C_1) + repair(C_1) + cost(T_1))$$

T_1 gives us no information about C_2 → independent

$$EU[C_2 \mid T_1 = +]$$

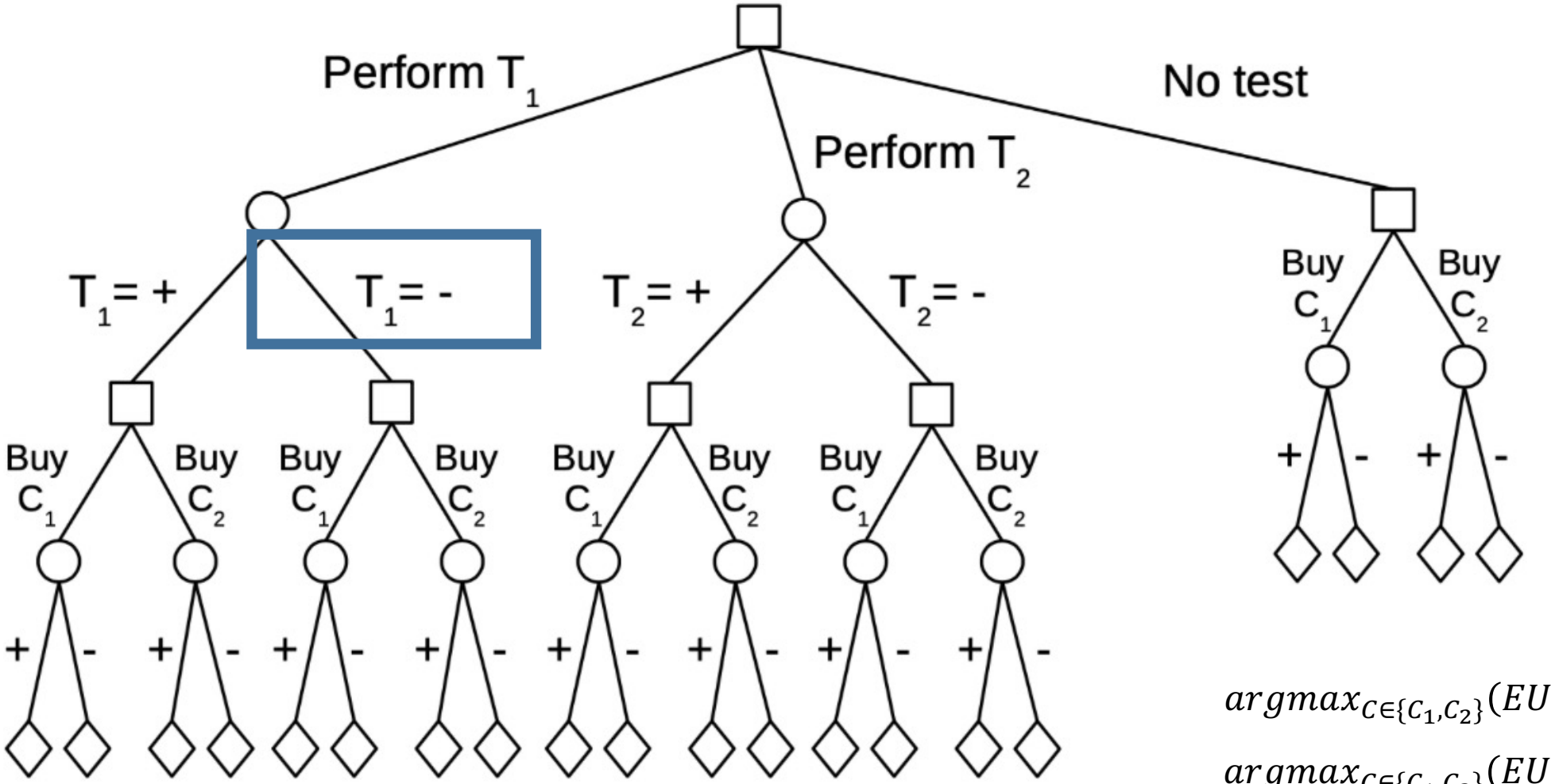


$$EU[C_1 \mid T_1 = +] = P(C_1 = + \mid T_1 = +)(cost(C_1) + cost(T_1)) + P(C_1 = - \mid T_1 = +)(cost(C_1) + repair(C_1) + cost(T_1))$$

$$EU[C_2 \mid T_1 = +] = P(C_2 = +)(cost(C_2) + cost(T_1)) + P(C_2 = -)\big(cost(C_2) + repair(C_2) + cost(T_1)\big)$$

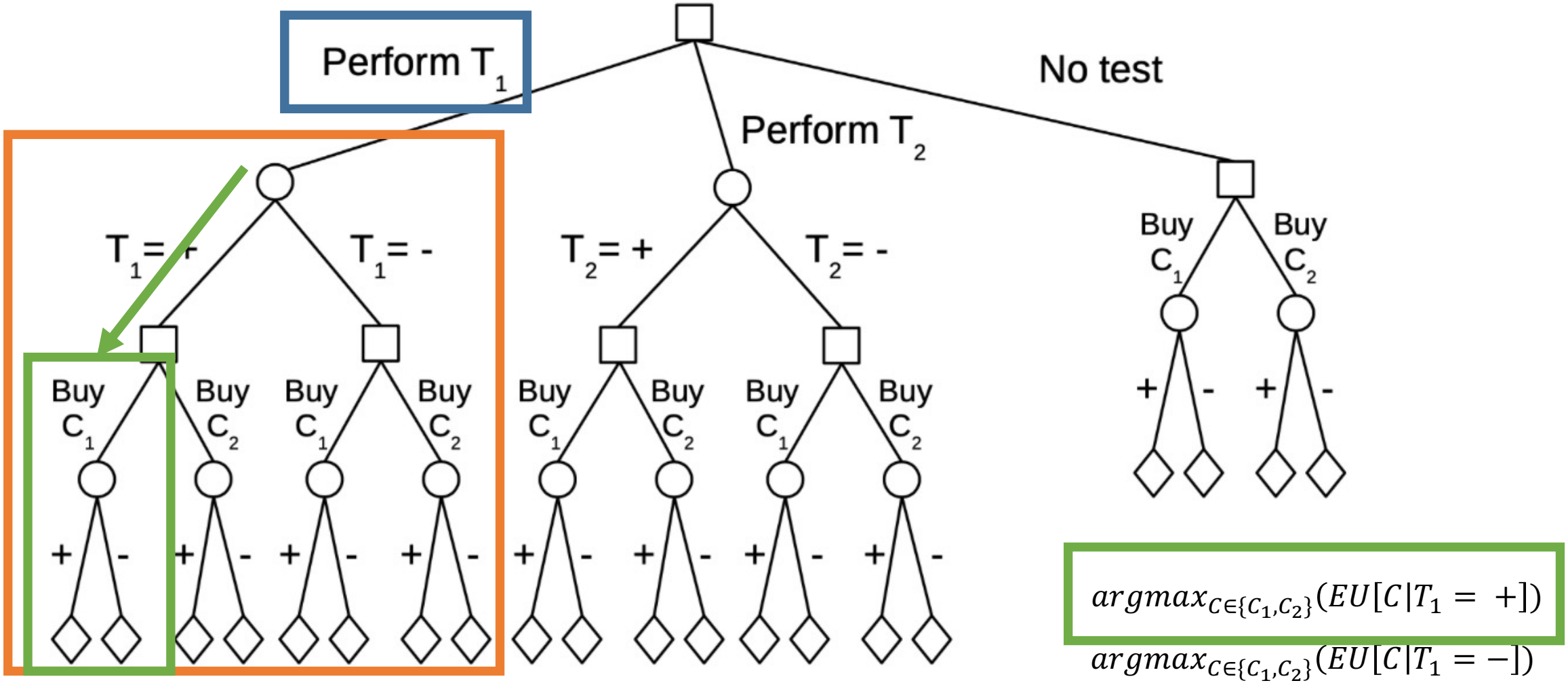
Deterministically choose the car with higher expected utility given $T_1 = +$

$$argmax_{C \in \{C_1, C_2\}}(EU[C \mid T_1 = +])$$



$argmax_{C \in \{C_1, C_2\}}(EU[C|T_1 = +])$

$argmax_{C \in \{C_1, C_2\}}(EU[C|T_1 = -])$



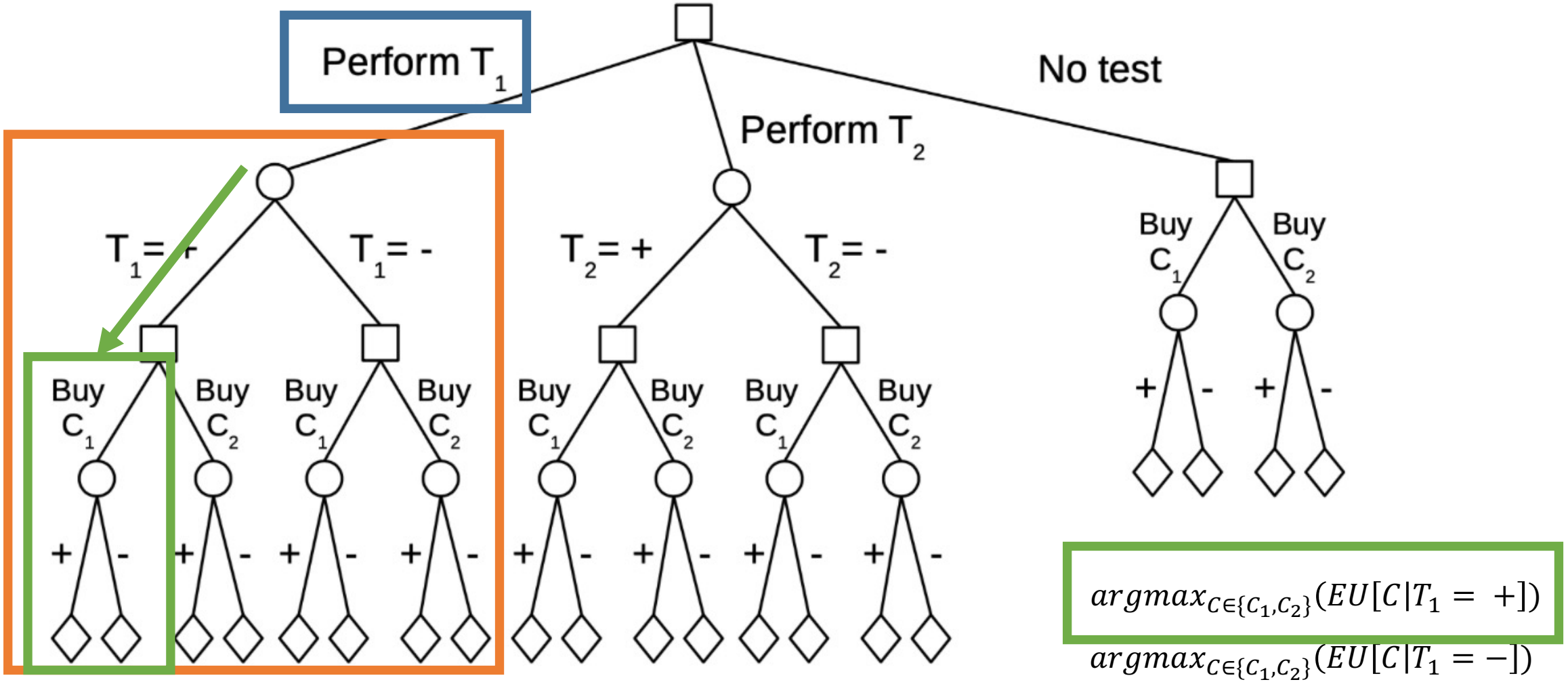
$argmax_{C \in \{C_1, C_2\}}(EU[C|T_1 = +])$

$argmax_{C \in \{C_1, C_2\}}(EU[C|T_1 = -])$

$$EU[T_1] = P(T_1 = +)U(T_1 = +) + P(T_1 = -)U(T_1 = -)$$

????

If we deterministically choose C_1 when T_1 = +, …

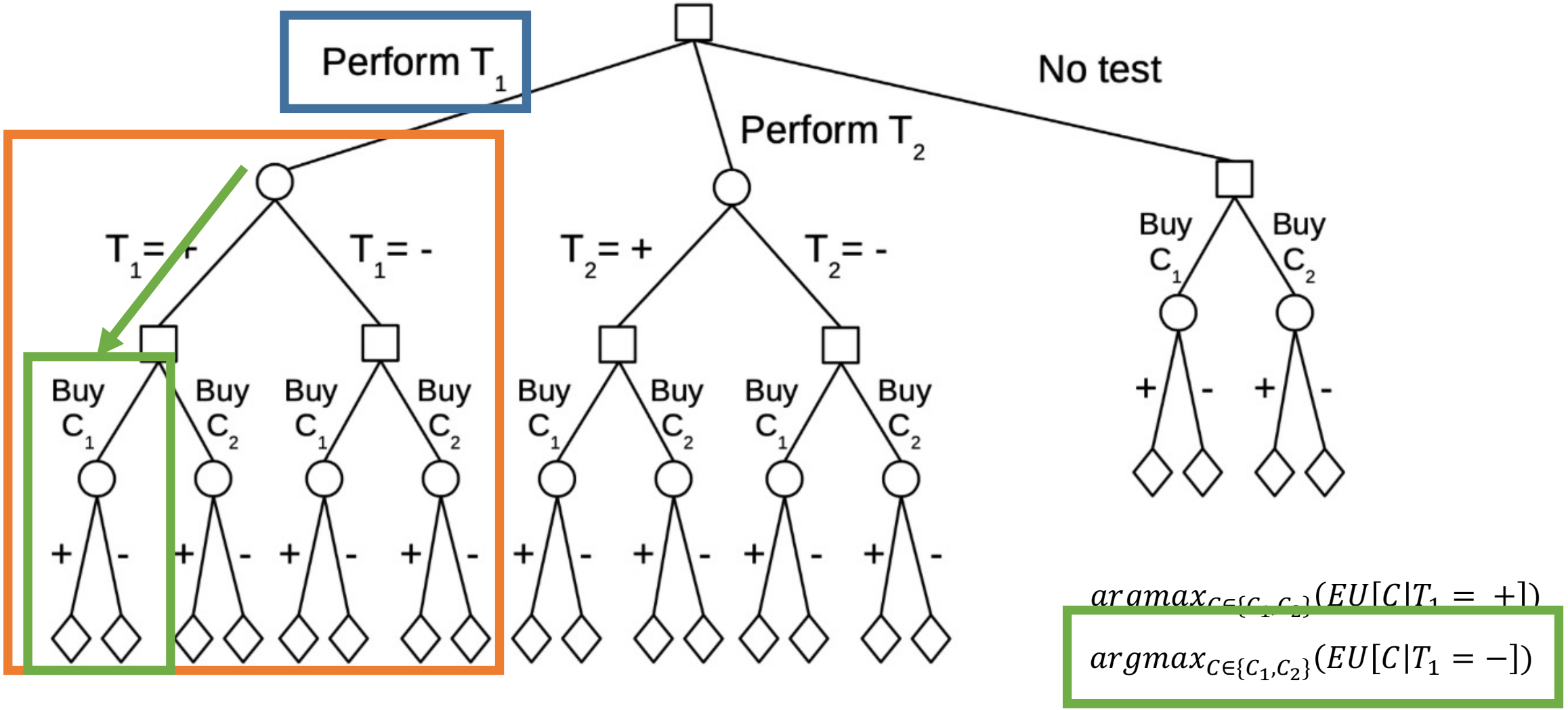


$argmax_{C \in \{C_1, C_2\}}(EU[C|T_1 = +])$

$argmax_{C \in \{C_1, C_2\}}(EU[C|T_1 = -])$

$$EU[T_1] = P(T_1 = +)EU(C_1|T_1 = +) + P(T_1 = -)U(T_1 = -)$$

If we deterministically choose C_1 when T_1 = +, …

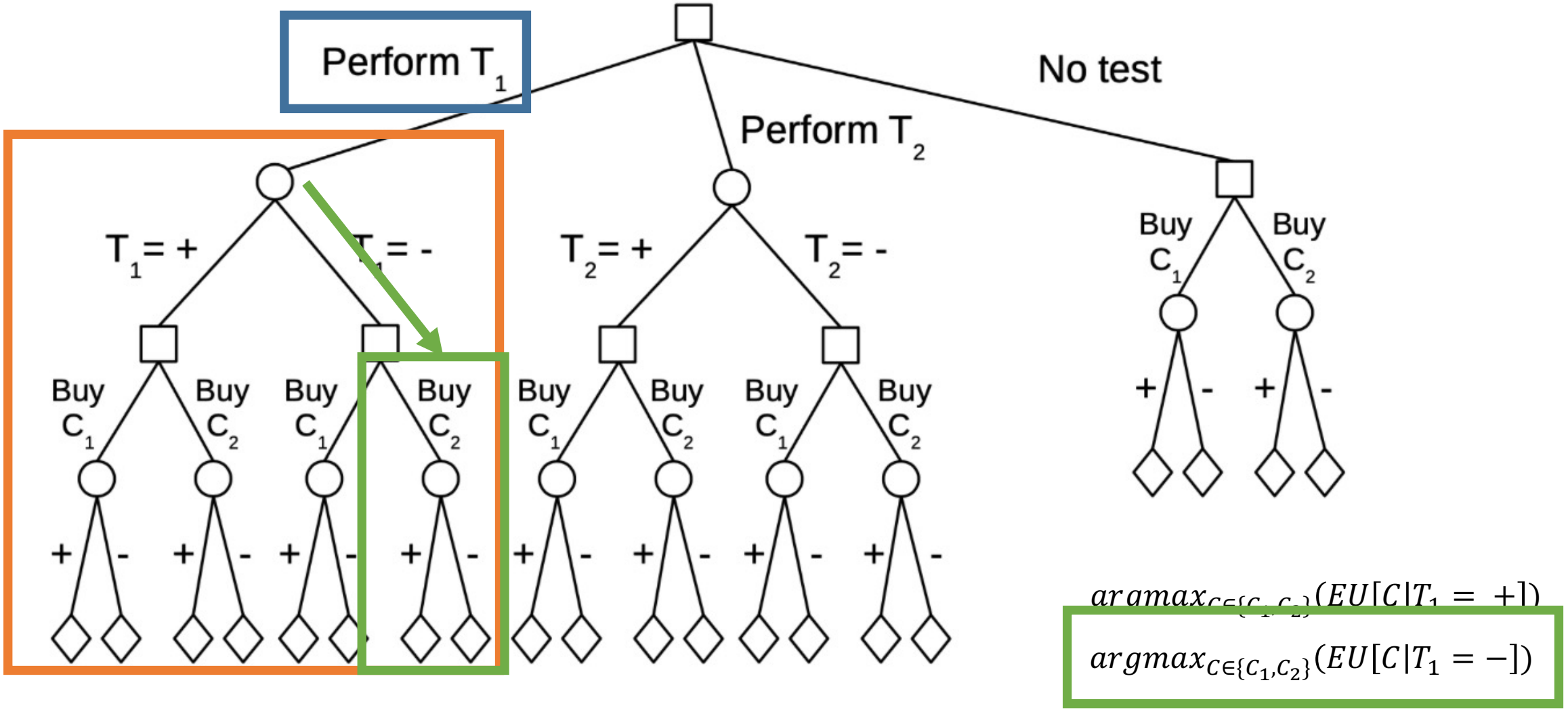


$argmax_{C \in \{C_1, C_2\}}(EU[C|T_1 = +])$

$argmax_{C \in \{C_1, C_2\}}(EU[C|T_1 = -])$

$$EU[T_1] = P(T_1 = +)EU(C_1|T_1 = +) + P(T_1 = -)U(T_1 = -)$$

If we deterministically choose C_2 when T_1 = -, …

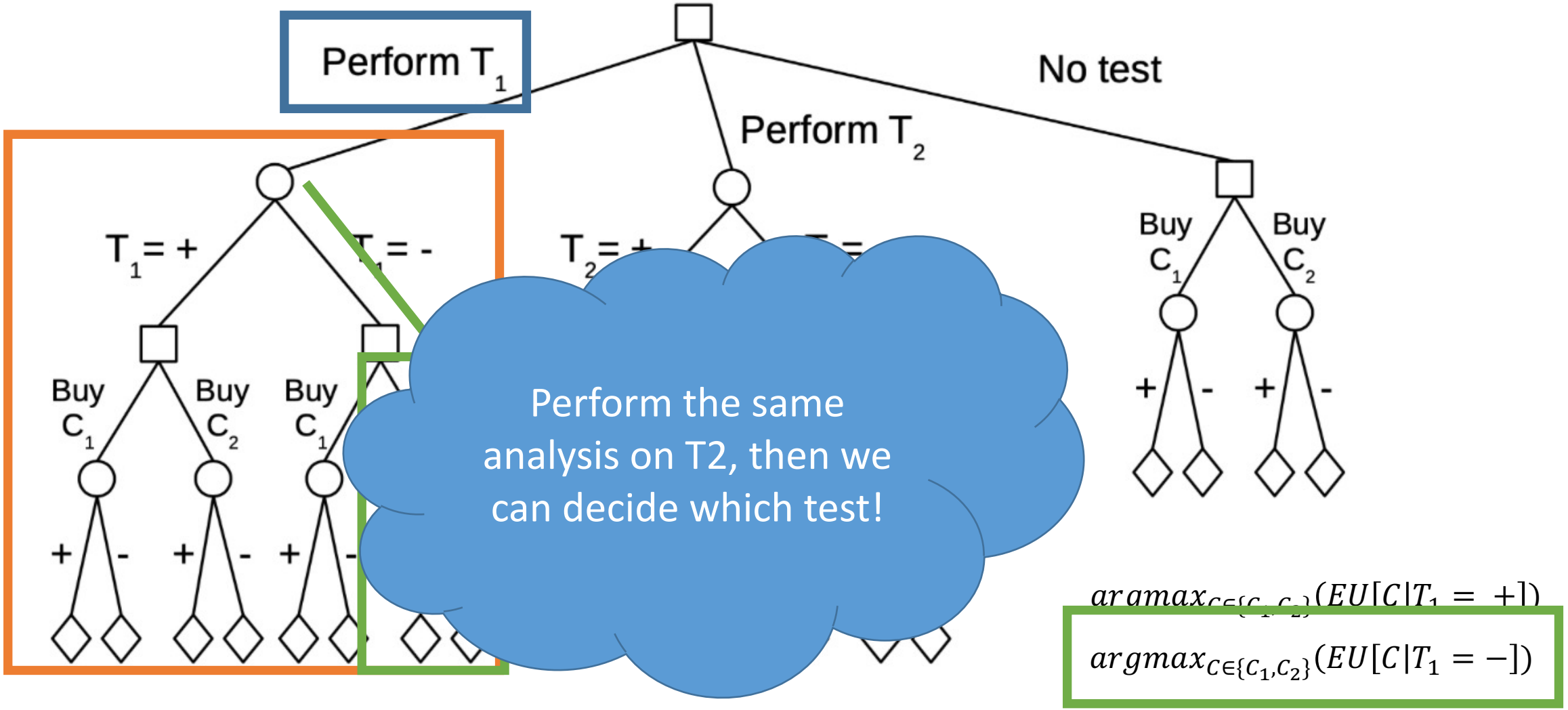


$argmax_{C \in \{C_1, C_2\}}(EU[C|T_1 = +])$

$argmax_{C \in \{C_1, C_2\}}(EU[C|T_1 = -])$

$$EU[T_1] = P(T_1 = +)EU(C_1|T_1 = +) + P(T_1 = -)U(T_1 = -)$$

If we deterministically choose C_2 when T_1 = -, …



$argmax_{C\in\{C_1,C_2\}}(EU[C|T_1 = +])$

$argmax_{C\in\{C_1,C_2\}}(EU[C|T_1 = -])$

$$EU[T_1] = P(T_1 = +)EU(C_1|T_1 = +) + P(T_1 = -)EU(C_2|T_1 = -)$$

If we deterministically choose C_2 when T_1 = -, …

When uncertainty comes from another agent's actions

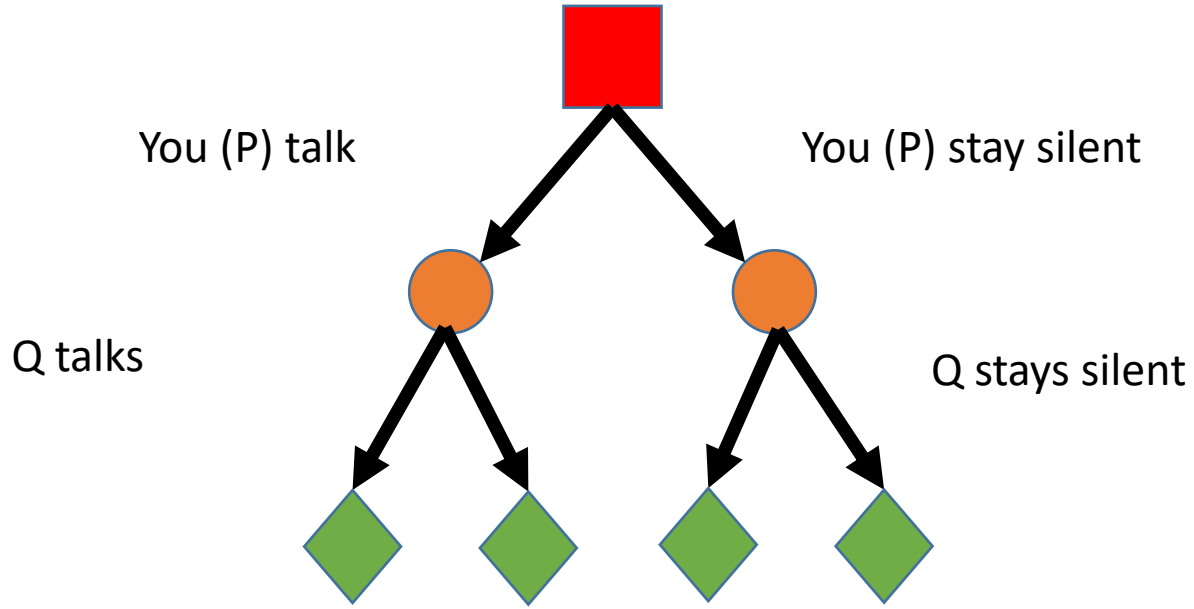
Car example: taking an action in one branch closes off possibilities in another

- Randomness comes from
    - Epistemic uncertainty about effects of past actions (e.g., accuracy of test results)
    - Epistemic uncertainty about future state (e.g., quality of car)

Consider the case when randomness comes from another agent's actions…

Example: Prisoner's Dilemma

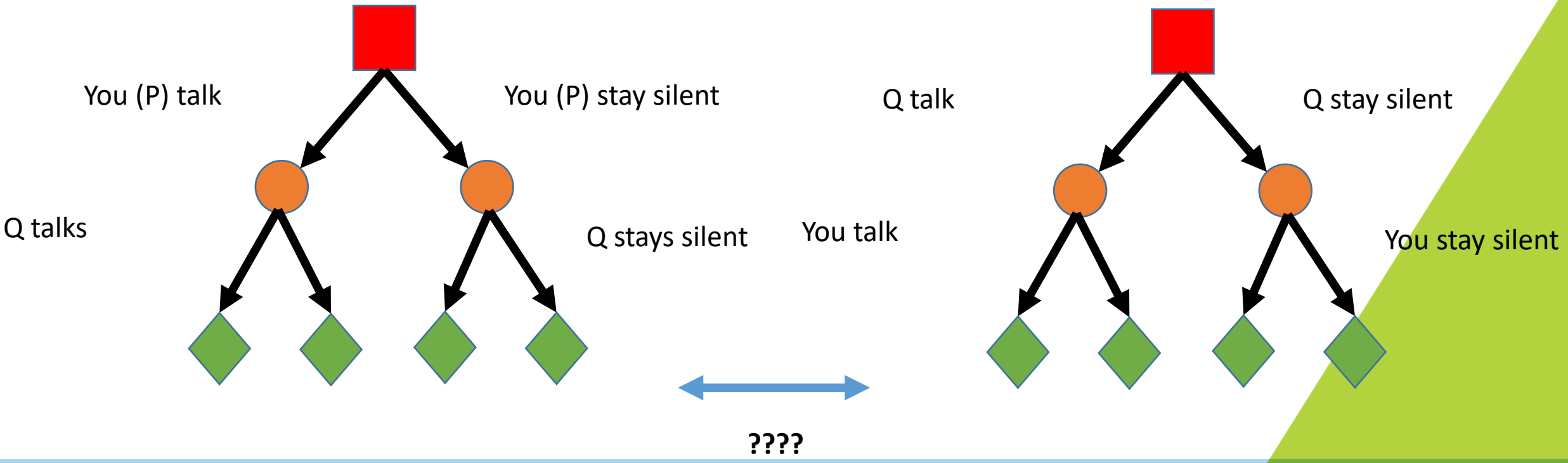
You (agent P) and an accomplice (agent Q) have been arrested for a crime…



But Q also knows all this and must make the same choices…

Example: Prisoner's Dilemma

You (agent P) and an accomplice (agent Q) have been arrested for a crime…



Both parties know this

Example: Prisoner's Dilemma

P and Q have been arrested for a crime and separated for in
the choice of whether or not to confess and each action is ass
You don't know how your accomplice will act. What do you do?

Utility function:
Collective cost?

	P silent	P talks
Q silent	(0, 0)	(-2, -5)
Q talks	(-5, -2)	(-10, -10)

Both parties know this matrix

Weak case

Example: Prisoner's Dilemma

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You don't know how your accomplice will act. What do you do?

Utility function:
Collective cost?

	P silent	P talks
Q silent	0	-7
Q talks	-7	-20

Both choose silent if both are using the same utility function

Both parties know this matrix

Weak case

Example: Prisoner's Dilemma

P and Q have been arrested for a crime and separated for in
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You don't know how your accomplice will act. What do you do?

Utility function:
Collective cost?

	P silent	P talks
Q silent	0	-7
Q talks	-7	-20

What if one uses a different utility function?

Both parties know this matrix

Weak case

Example: Prisoner's Dilemma

Utility function:
Individual Cost?

You and an accomplice have been arrested for a crime and [illegible] interrogation. You have the choice of whether or not to confe[illegible] associated with a cost. You don't know how your accomplice will [illegible] you do?

	P silent	P talks
Q silent	(0, 0)	(-2, -5)
Q talks	(-5, -2)	(-10, -10)

Both parties know this matrix

Weak case

Example: Prisoner's Dilemma

You and an accomplice have been arrested for a crime and [illegible] interrogation. You have the choice of whether or not to confe[illegible] associated with a cost. You don't know how your accomplice will [illegible] you do?

Utility function: Individual cost?

	P silent	P talks
Q silent	0	-2
Q talks	-5	-10

Both parties know this matrix

Weak case

Example: Prisoner's Dilemma

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Utility function:
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Both parties know this matrix

Weak case

Example: Prisoner's Dilemma

Utility function:
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Both parties know this matrix

Weak case

Example: Prisoner's Dilemma

You and an accomplice have been arrested for a crime and
interrogation. You have the choice of whether or not to confe
associated with a cost. You don't know how your accomplice will
do?

Local reasoning, rather than global

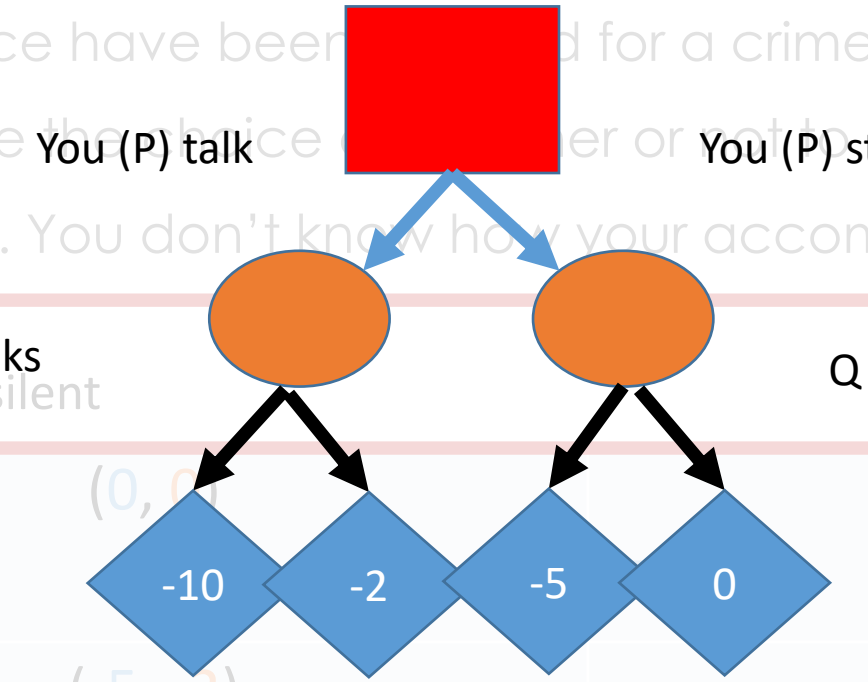
Decision/action

Uncertainty	P silent	P talks
Q silent	(0, 0)	(-2, -5)
Q talks	(-5, -2)	(-10, -10)

Weak case

Example: Prisoner's Dilemma

You and an accomplice have been [illegible] for a crime and [illegible] interrogation. You have the choice [illegible] or both confess, associated with a cost. You don't know how your accomplice will [illegible] you do?



Local reasoning, rather than global

Decision/action

Uncertainty

Q silent

Q talks

P silent

P talks

(0, 0)

(-2, -5)

(-5, -2)

(-10, -10)

Example: Prisoner's Dilemma

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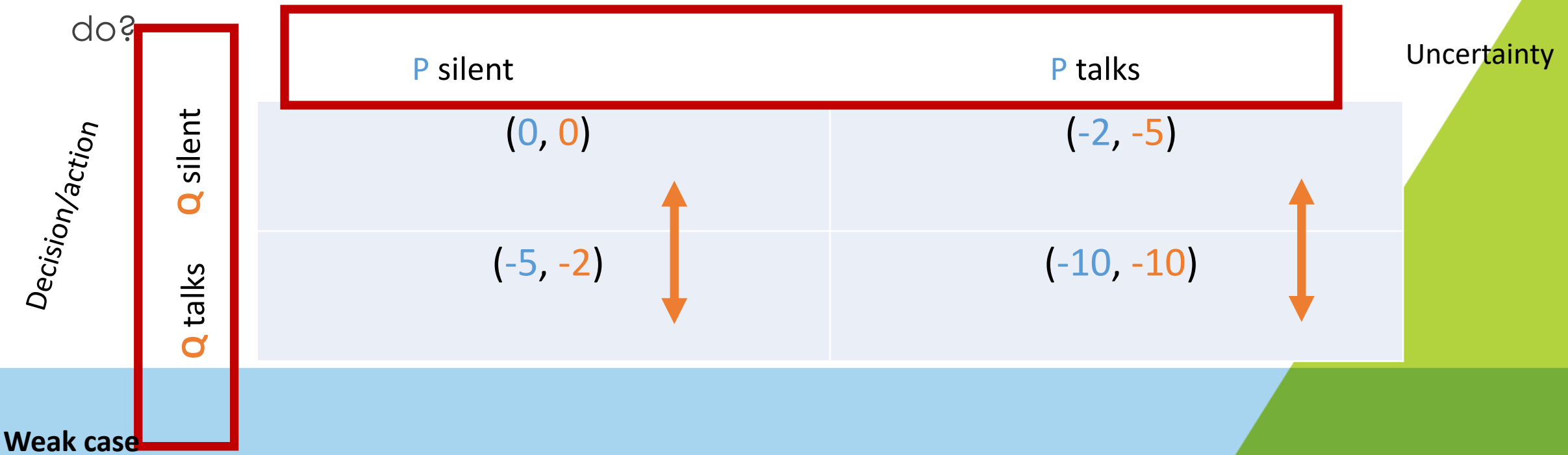
Weak case

Example: Prisoner's Dilemma

You and an accomplice have been arrested for a crime and separated for interrogation. You have the choice of whether or not to confess and each action is associated with a cost. You don't know how your accomplice will act. What do you do?



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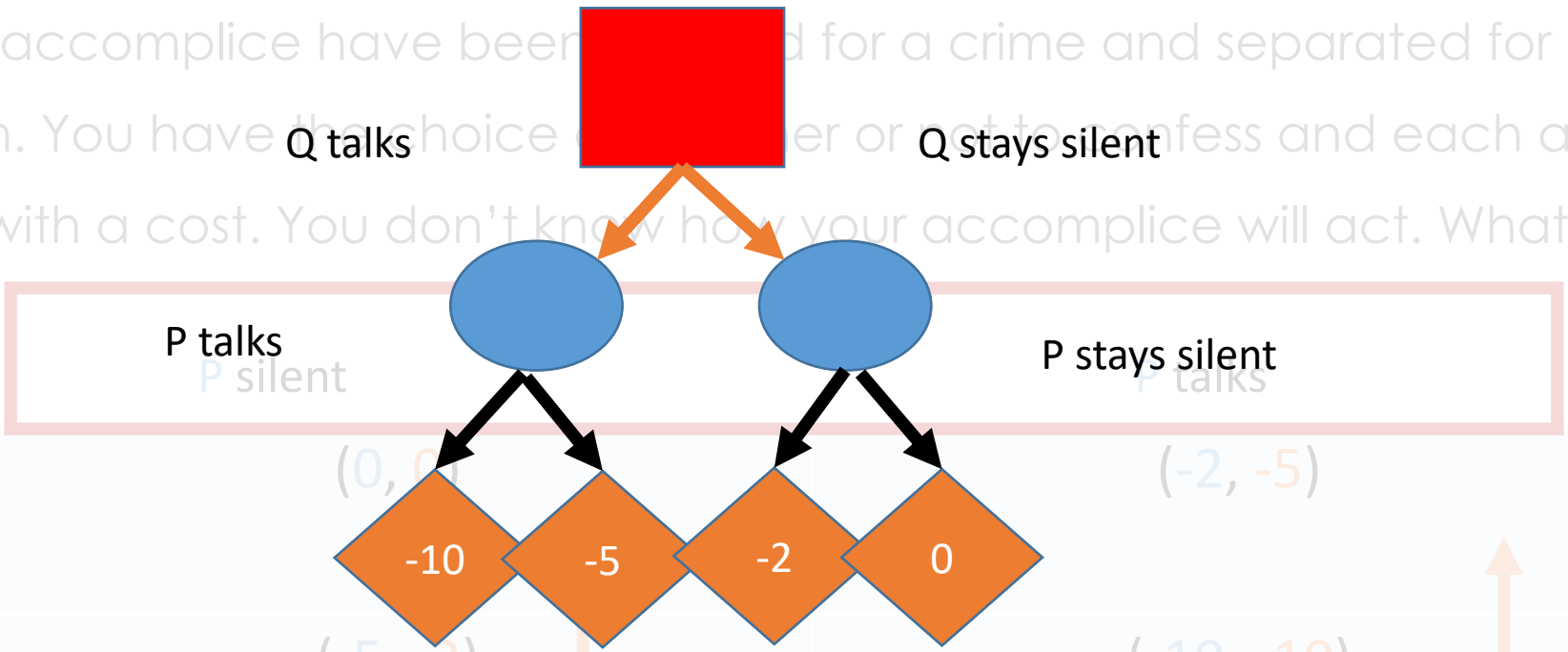

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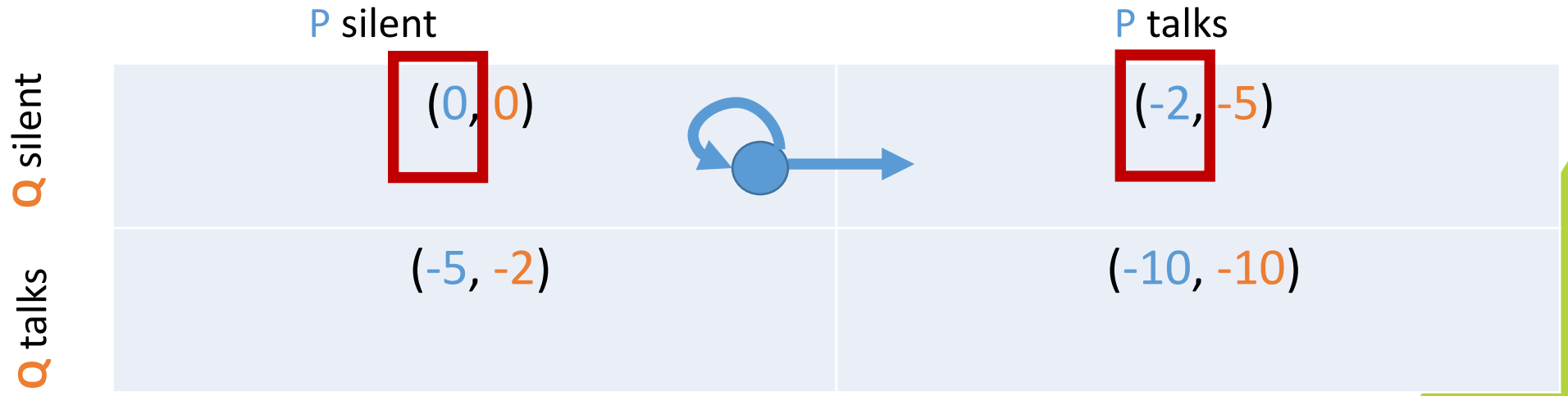

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Weak case

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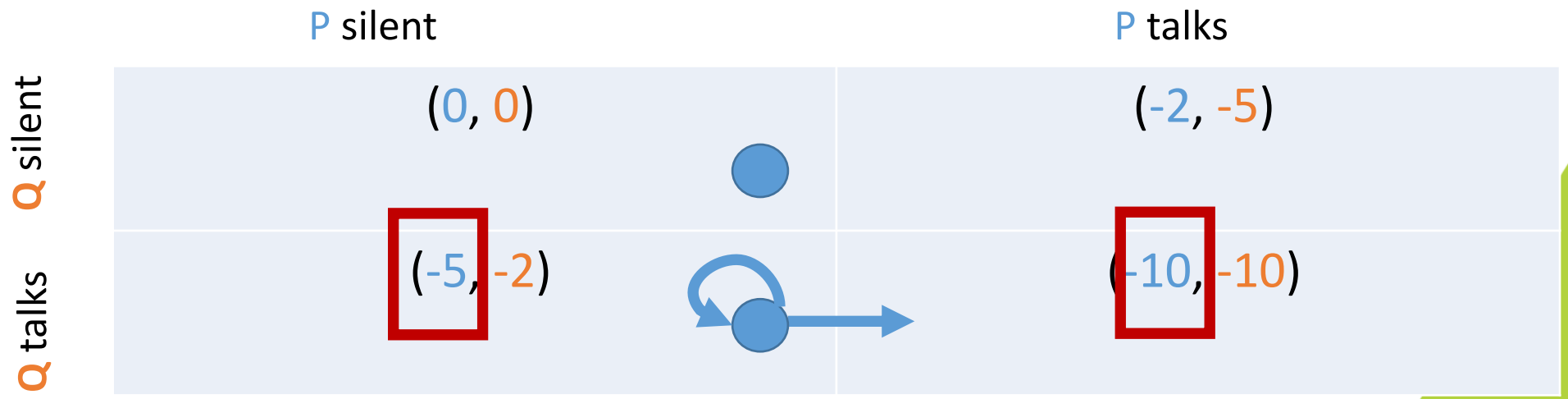

Weak case

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Weak case

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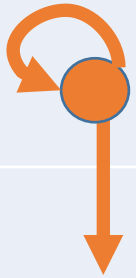

Weak case

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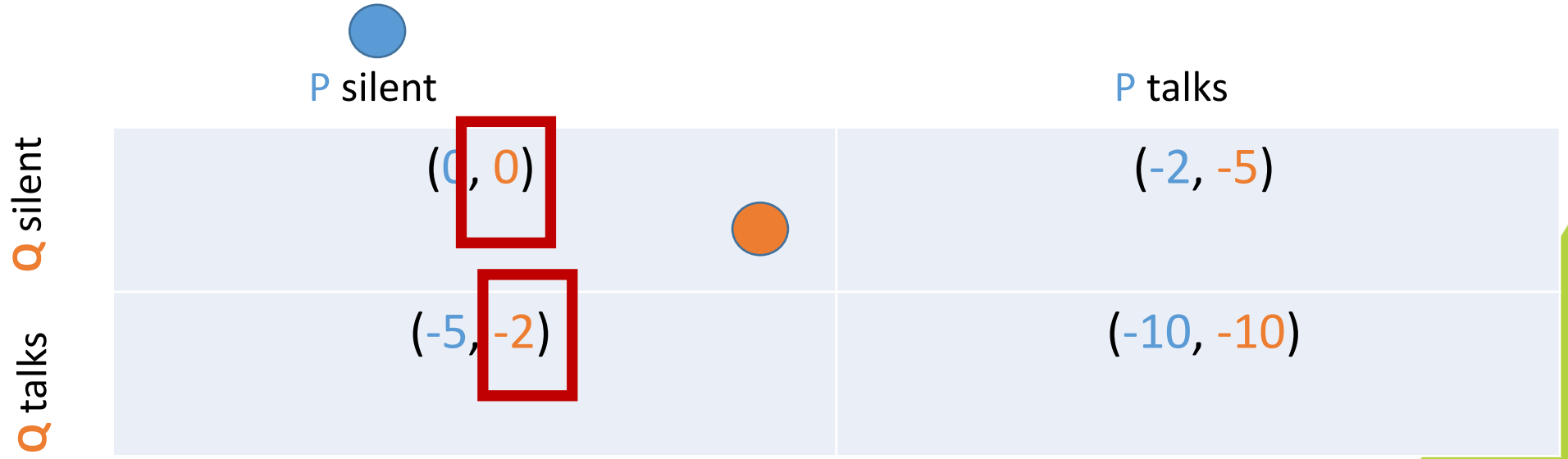

Weak case

Example: Prisoner's Dilemma

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Weak case

Example: Prisoner's Dilemma

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Weak case

Example: Prisoner's Dilemma

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	P silent	P talks
Q silent	(0, 0)	(-2, -5)
Q talks	(-5, -2)	(-10, -10)

Weak case

Same as globally optimal case for both utility functions

Example: Prisoner's Dilemma

Consider a different payoff matrix

You and an accomplice have been arrested for a crime and se
interrogation. You have the choice of whether or not to confess
associated with a cost. You don't know how your accomplice will a
do you do?

	P silent	P talks
Q silent	(-2, -2)	(0, -15)
Q talks	(-15, 0)	(-10, -10)

Still globally optimal for collective utility?

Incentivize talking

Example: Prisoner's Dilemma

You and an accomplice have been arrested for a crime and separated for interrogation. You have the choice of whether or not to confess and each action is associated with a cost. You don't know how your accomplice will act. What do you do?

	P silent	P talks
Q silent	-4	-15
Q talks	-15	-20

Incentivize talking

Still globally optimal for collective utility?

Example: Prisoner's Dilemma

Assume Q uses collective utility, but P uses individual utility…

You and an accomplice have been arrested for a crime and se
interrogation. You have the choice of whether or not to confess
associated with a cost. You don't know how your accomplice will
do you do?

	P silent	P talks
Q silent	-2	0
Q talks	-15	-10

Still globally optimal for individual utility for P?

Incentivize talking

Example: Prisoner's Dilemma

What if Q knows P's utility function and decides to mimic?

You and an accomplice have been arrested for a crime and se
interrogation. You have the choice of whether or not to confess
associated with a cost. You don't know how your accomplice will act. What do you do?

	P silent	P talks
Q silent	-2	-15
Q talks	0	-10

Incentivize talking

Still globally optimal for individual utility?

Example: Prisoner's Dilemma

What if Q knows P's utility function and decides to mimic?

You and an accomplice have been arrested for a crime and se
interrogation. You have the choice of whether or not to confess
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Incentivize talking

Still globally optimal for individual utility?

Example: Prisoner's Dilemma

You and an accomplice have been arrested for a crime and separated for interrogation. You have the choice of whether or not to confess and each action is associated with a cost. You don't know how your accomplice will act. What do you do?

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	P silent	P talks
Q silent	-4	-15
Q talks	-15	-20

Worst possible global outcome!

Incentivize talking

Example: Prisoner's Dilemma

You and an accomplice have been arrested for a crime and [illegible] interrogation. You have the choice of whether or not to confe[illegible] associated with a cost. You don't know how your accomplice will [illegible] you do?

Local reasoning, rather than global

	P silent	P talks
Q silent	(-2, -2)	(0, -15)
Q talks	(-15, 0)	(-10, -10)

Incentivize talking

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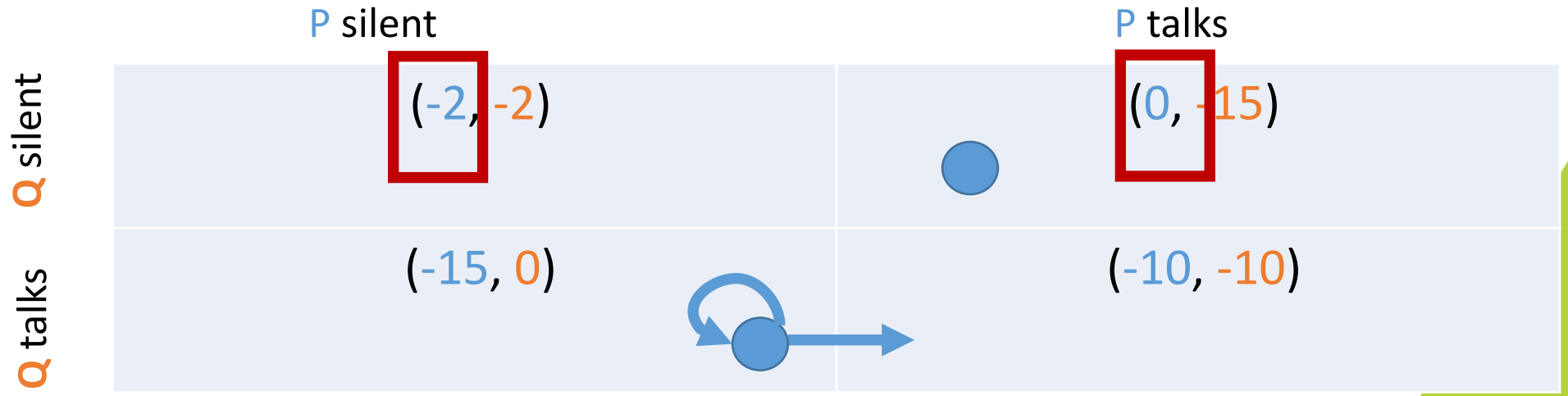

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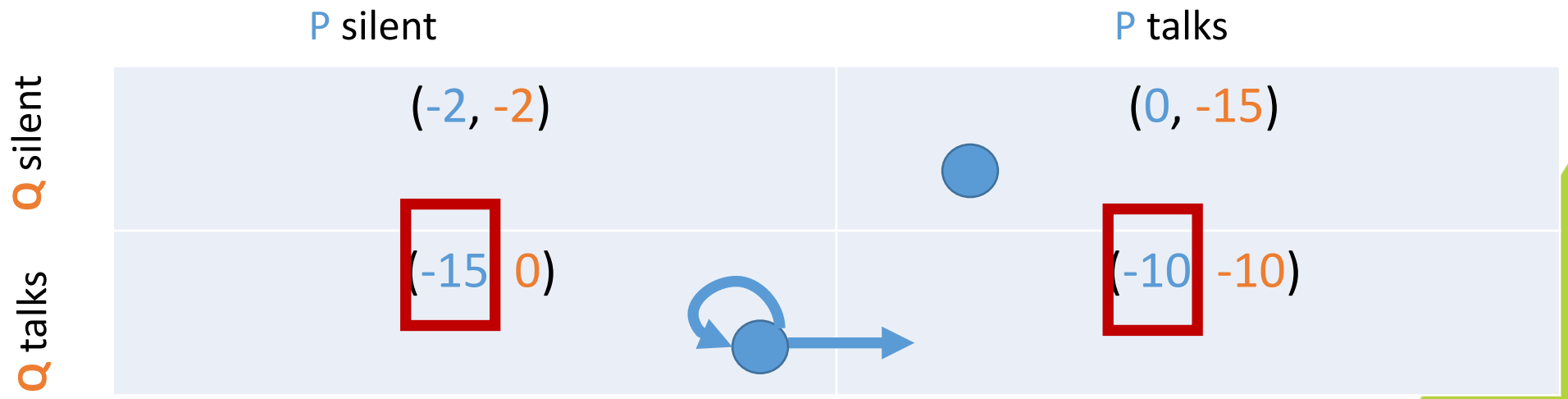

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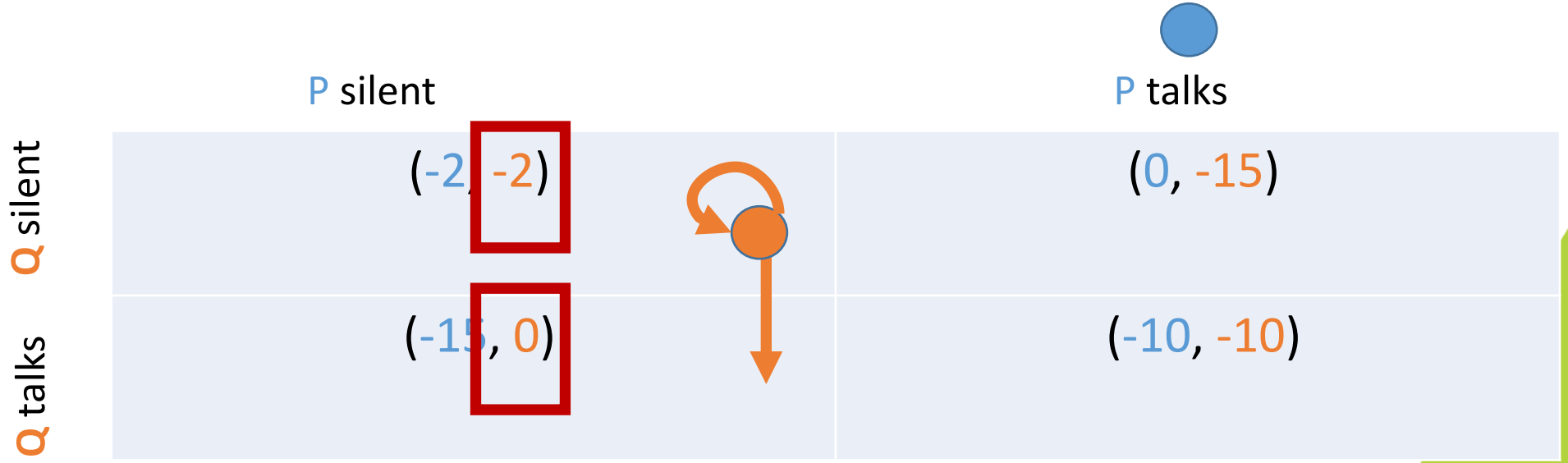

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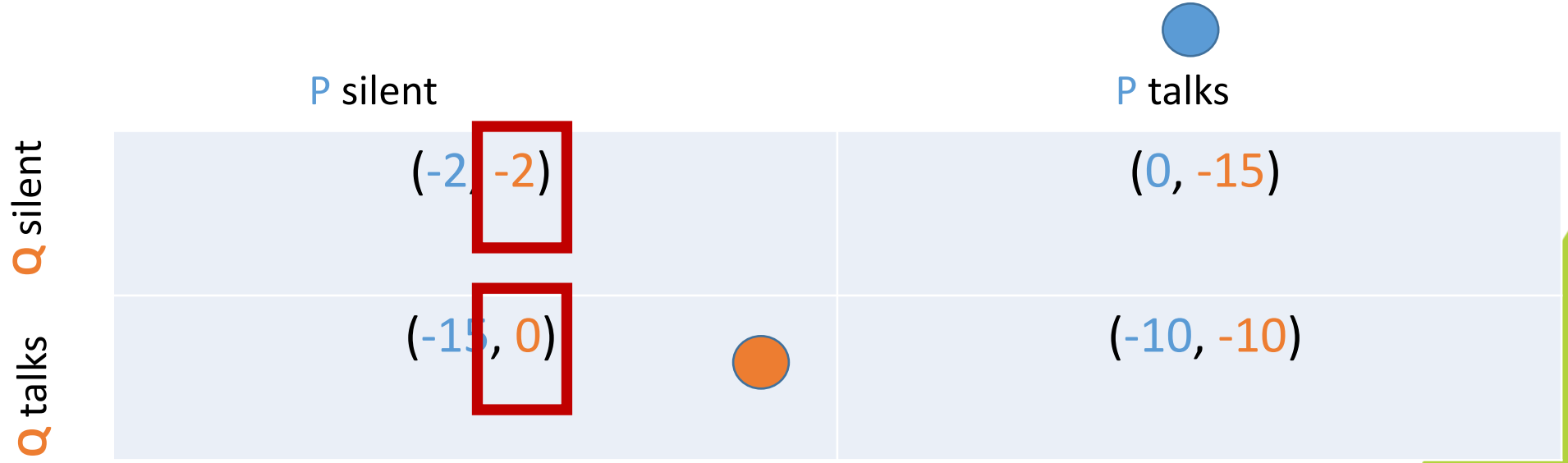

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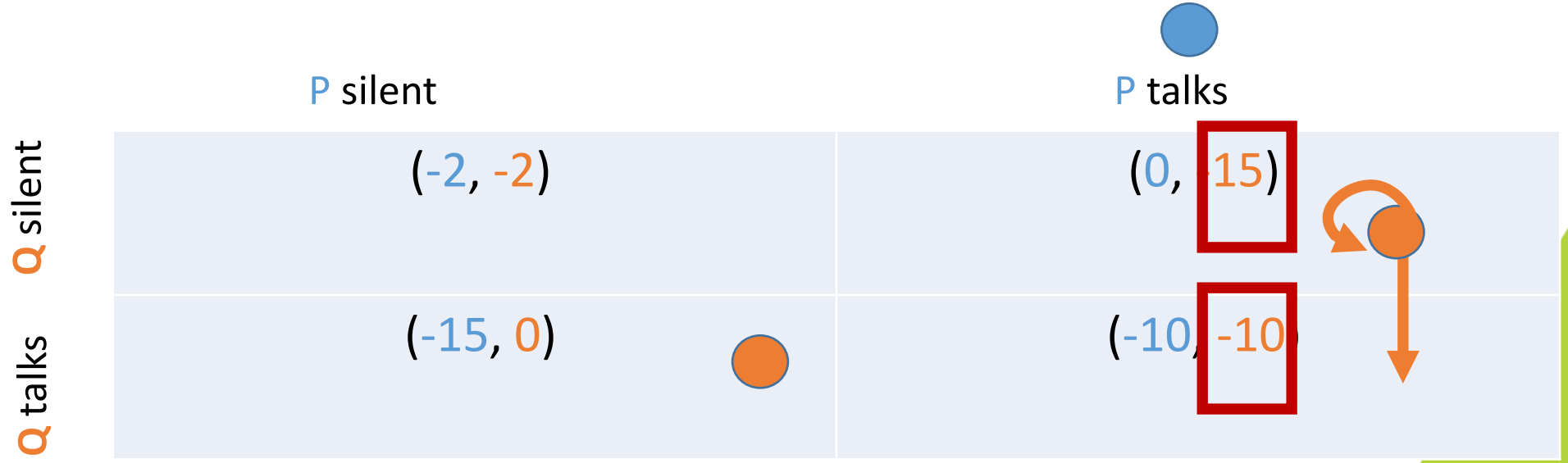

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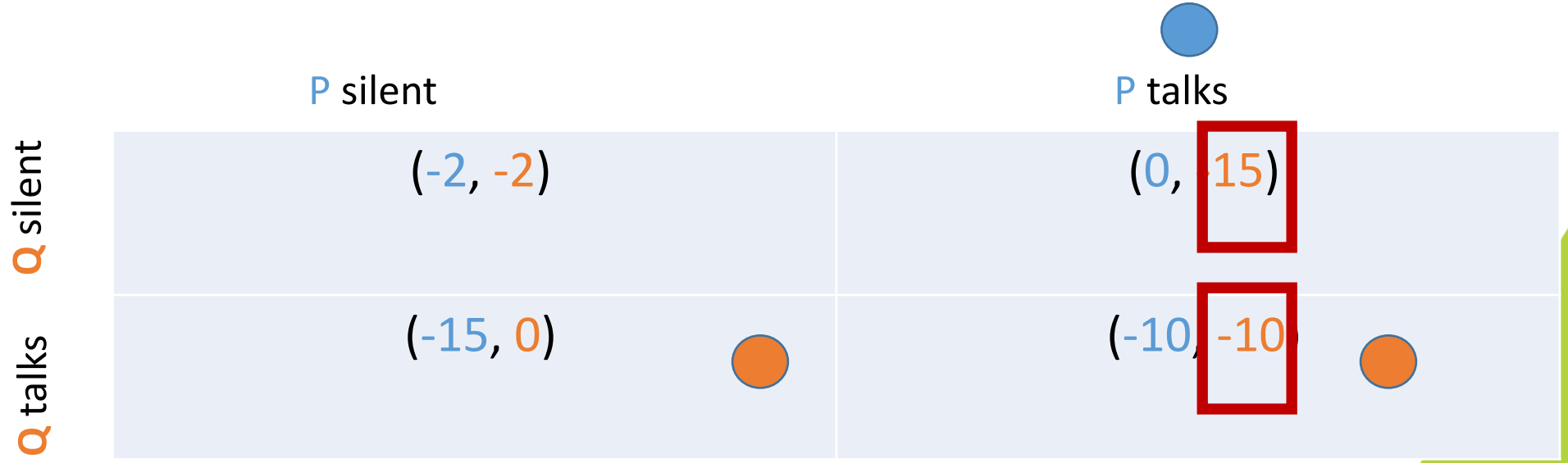

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Same result!

Incentivize talking

Example: 2-finger Morra

Choose between 1 and 2 fingers. P wins if sum is even. Q wins if sum is odd. Loser pays the winner.

	P plays 1	P plays 2
Q plays 1	(+2, -2)	(-3, +3)
Q plays 2	(-3, +3)	(+4, -4)

Example: 2-finger Morra

Choose between 1 and 2 fingers. P wins if sum is even. Q wins if sum is odd. Loser pays the winner.

Q plays 1 \ P plays 1	P plays 2
Q plays 2	0	0
	0	0

Example: 2-finger Morra

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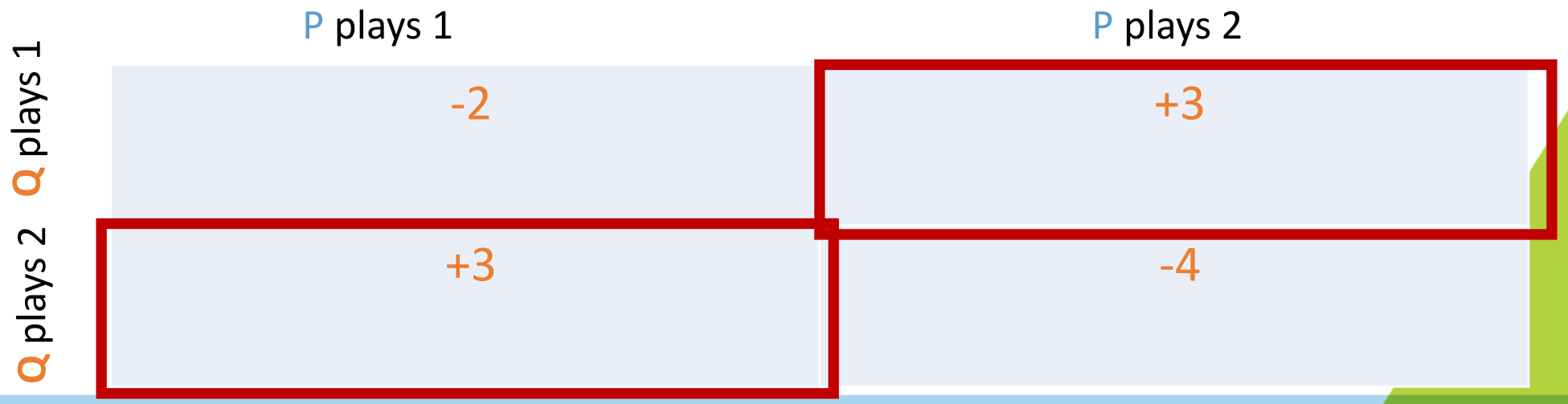

Example: 2-finger Morra

Choose between 1 and 2 fingers. P wins if sum is even. Q wins if pays the winner.

Choose probabilistically

Q plays 1 \ P plays 1	P plays 2
Q plays 1	(+2, -2)	(-3, +3)
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Example: Prisoner's Dilemma

You and an accomplice have been arrested for a crime and separated for interrogation. You have the choice of whether or not to confess and each action is associated with a cost. You don't know how your accomplice will act. What do you do?

	P silent	P talks
Q silent	(-4, -4)	(0, -6)
Q talks	(-5, -2)	(-10, -10)

No free ride for Q

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You and an accomplice have been arrested for a crime and separated for interrogation. You have the choice of whether or not to confess and each action is associated with a cost. You don't know how your accomplice will act. What do you do?

	P silent	P talks
Q silent	-8	-6
Q talks	-7	-20

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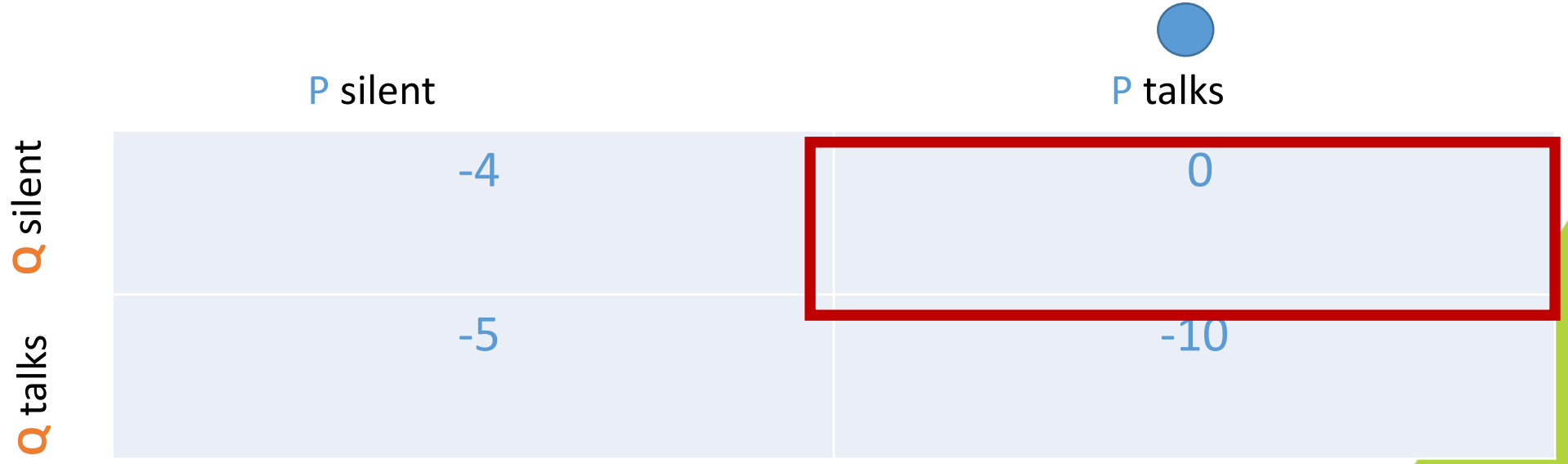

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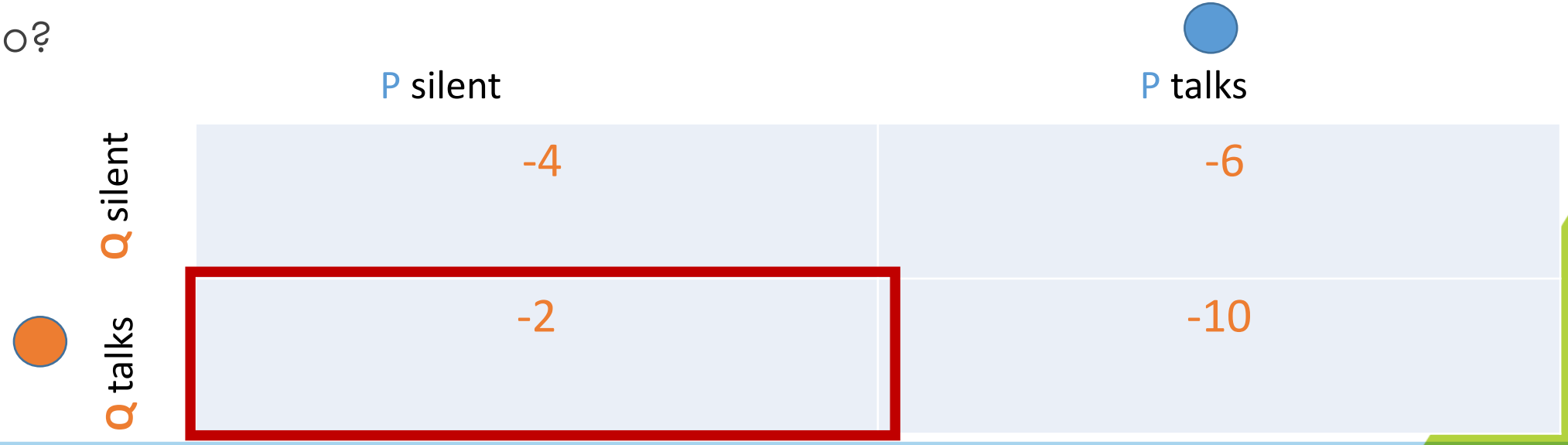

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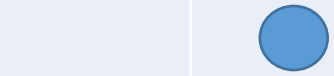

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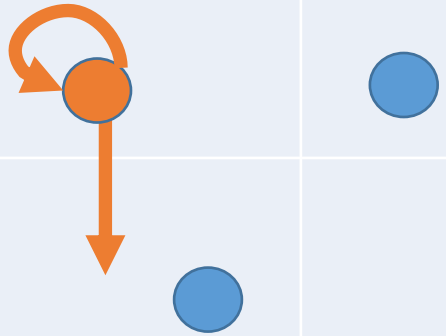

No free ride for Q

Example: Prisoner's Dilemma

Suppose we model Q's choice probabilistically…

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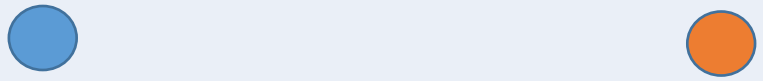

No free ride for Q

Do stuff on board

Vocabulary & Concepts

- Always assume local decision making (all players maximizing individual utility)
- **Zero sum** – every entry in global collective payoff is 0
- **Pure strategy** – always pick the same action no matter what
- **Mixed strategy** – pick an action probabilistically
- **Dominant strategy** – one action is strictly better no matter what the other plays does