Adversarial Risk Analysis: The Somali Pirates Case

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Outline

- Adversarial Risk Analysis
- The sequential Defend-Attack-Defend Model
- The Somali Pirates Case
- Discussion

Adversarial Risk Analysis

- A framework to manage risks from actions of intelligent adversaries

- One-sided prescriptive support
  - Use a SEU model
  - Treat the adversary's decision as uncertainties

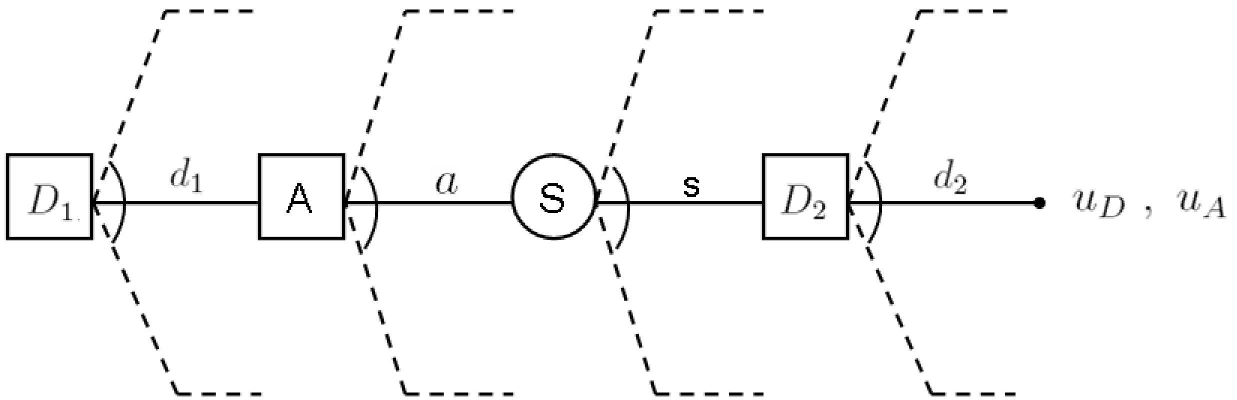
- New method to predict adversary's actions
  - We assume the adversary is a *expected utility maximizer*
    - Model his decision problem
    - Assess his probabilities and utilities
    - Find his action of maximum expected utility
  - But other *descriptive* models are possible

- Uncertainty in the Attacker's decision stems from
  - *our* uncertainty about his probabilities and utilities

The Defend–Attack–Defend model

- Two intelligent players
  - Defender and Attacker

- Sequential moves
  - First, Defender moves
  - Afterwards, Attacker knowing Defender's move
  - Afterwards, Defender again responding to attack

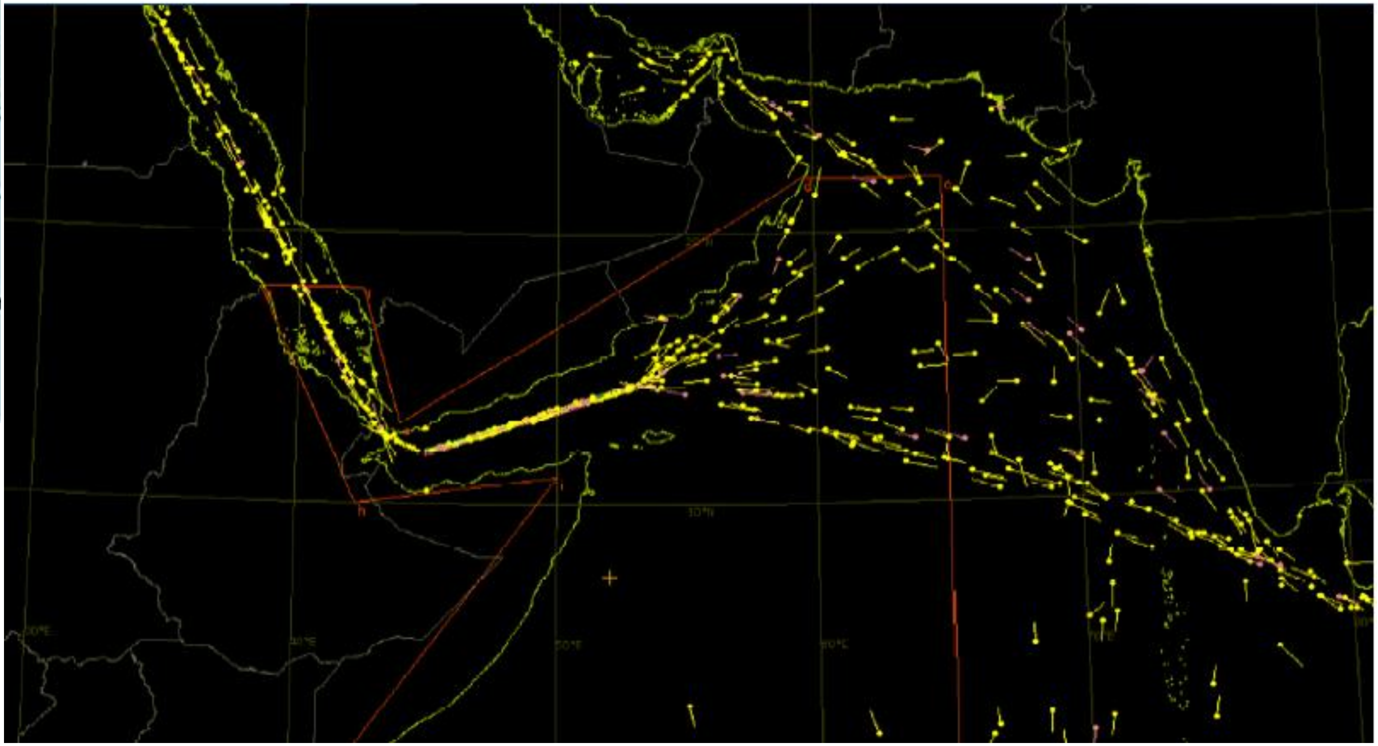


The Somali Pirates case

- An Illustrative application of the ARA framework
- We support the owner of a Spanish fishing ship managing risks from piracy
- Modeled as a Defend-Attack-Defend decision problem
- Develop predictive models of Pirates' behaviour
  - By thinking about their decision problem

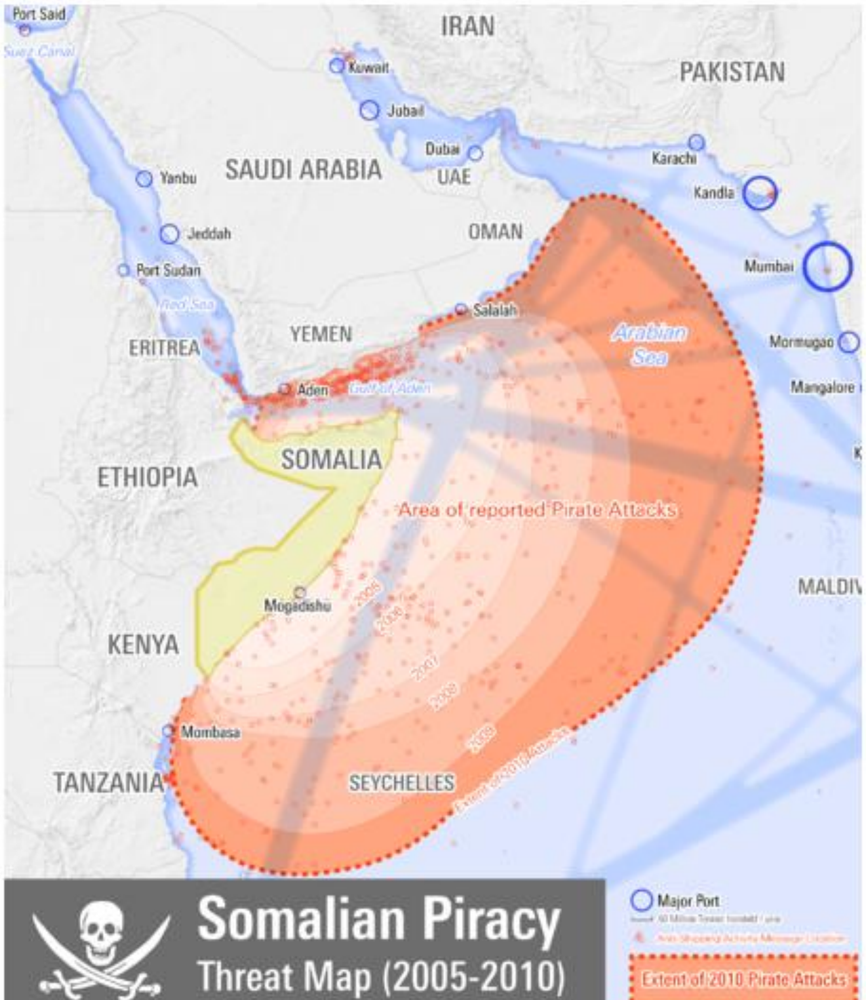
Why sail through Somali waters?

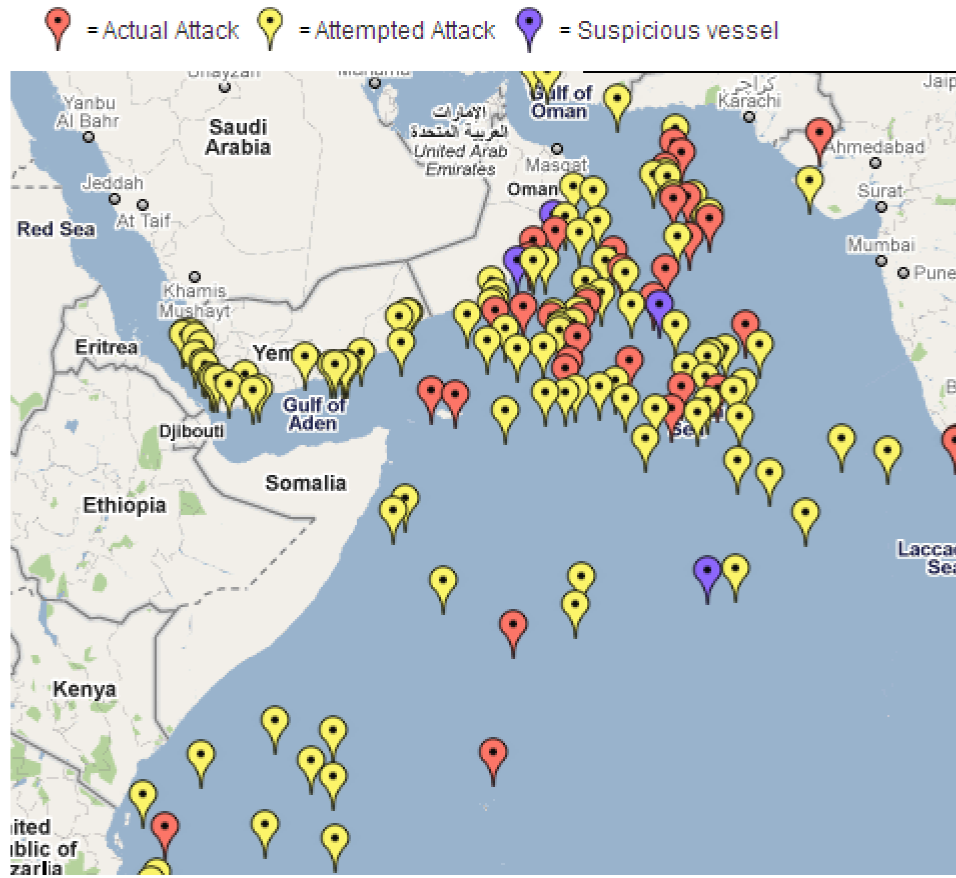
Best route between Europe and Asia



More than 20,000 ships/year passing through the Suez Canal

Increase in piracy acts around the cost of Somalia





Piracy and armed robbery incidents reported to the IMB Piracy Reporting Centre 2011

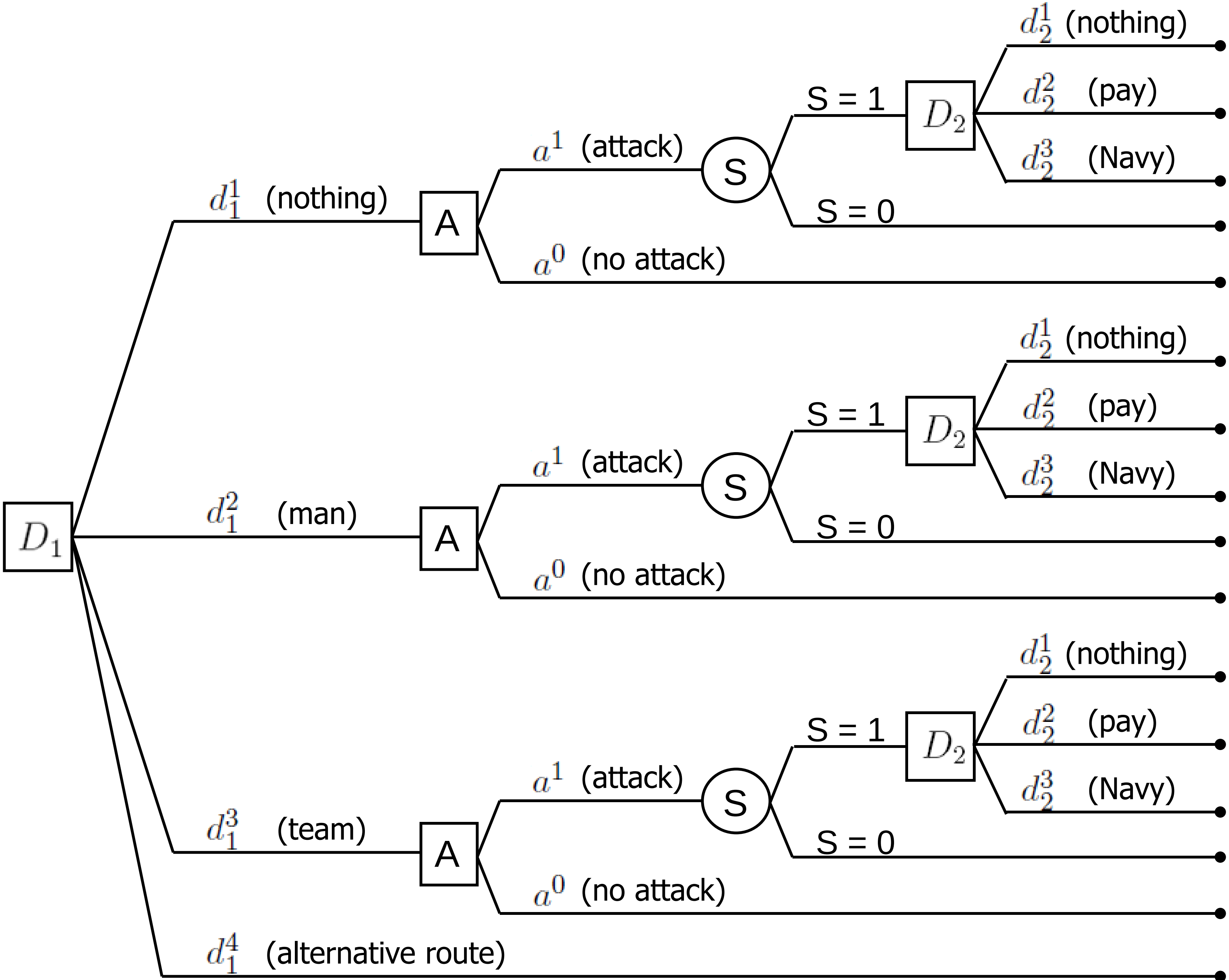
Some statistics

- Piracy and armed robbery incidents in 2011
  - IMB Piracy Reporting Centre (updated on 23 May 2011)
- Worldwide
  - Total Attacks: 211
  - Total Hijackings: 24
- Somalia
  - Total Incidents: 139
  - Total Hijackings:21
  - Total Hostages: 362
  - Total Killed: 7
- Currently
  - Vessels held by Somali pirates: 26
  - Hostages: 522

The Pirates

Problem formulation

- Two players
  - Defender: Ship owner
  - Attacker: Pirates
- Defender first move
  - Do nothing
  - Private protection with an armed person
  - Private protection with a team of two armed persons
  - Go through the Cape of Good Hope avoiding the Somali coast
- Attacker’s move
  - Attack or not to attack the Defender’s ship
- Defender response to an eventual kidnapping
  - Do nothing
  - Pay the ransom
  - Ask the Navy for support to release the boat and crew


D_1
d_1^1 (nothing)
d_1^2 (man)
d_1^3 (team)
d_1^4 (alternative route)
A
a^1 (attack)
a^0 (no attack)
S
S = 1
S = 0
D_2
d_2^1 (nothing)
d_2^2 (pay)
d_2^3 (Navy)

Defender's own preferences and beliefs

- Assessments from the Defender
  - Multi-attribute consequences
  - Preferences over consequences
  - Beliefs about $S \mid d_1, a^1$
  - Beliefs about $A \mid d_1$
- Defender's relevant consequences
  - Loss of the boat
  - Costs of protecting and responding to an eventual attack
  - Number of deaths on her crew
- Defender's monetary values of
  - a Spanish life: 2.04M Euros
  - the ship: 7M Euros

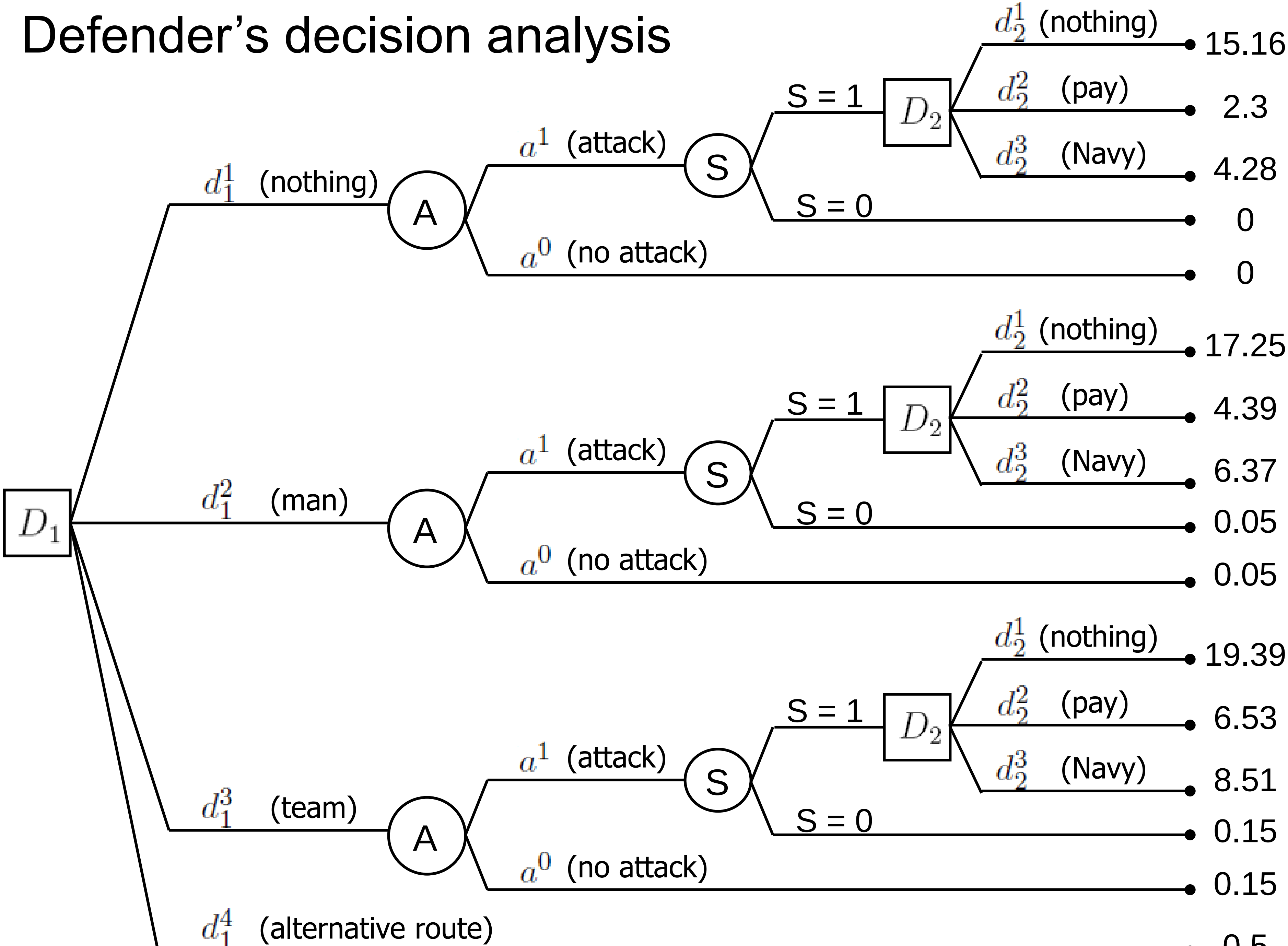
Defender's own preferences and beliefs

- Consequences of the tree paths for the Defender

D_1	S	D_2	Boat loss	Action costs	Lives lost	Aggregate cost
d_1^1 (nothing)	$S = 1$	d_2^1 (nothing)	1	0 + 0	0 + 4	15.16
d_1^1 (nothing)	$S = 1$	d_2^2 (pay)	0	0 + 2.3M	0 + 0	2.3
d_1^1 (nothing)	$S = 1$	d_2^3 (army)	0	0 + 0.2M	0 + 2	4.28
d_1^1 (nothing)	$S = 0$		0	0	0	0
d_1^2 (man)	$S = 1$	d_2^1 (nothing)	1	0.05M + 0	1 + 4	17.25
d_1^2 (man)	$S = 1$	d_2^2 (pay)	0	0.05M + 2.3M	1 + 0	4.39
d_1^2 (man)	$S = 1$	d_2^3 (army)	0	0.05M + 0.2M	1 + 2	6.37
d_1^2 (man)	$S = 0$		0	0.05M	0	0.05
d_1^3 (team)	$S = 1$	d_2^1 (nothing)	1	0.15M + 0	2 + 4	19.39
d_1^3 (team)	$S = 1$	d_2^2 (pay)	0	0.15M + 2.3M	2 + 0	6.53
d_1^3 (team)	$S = 1$	d_2^3 (army)	0	0.15M + 0.2M	2 + 2	8.51
d_1^3 (team)	$S = 0$		0	0.15M	0	0.15
d_1^4 (alternative route)			0	0.5 M	0	0.5

Costs in Million Euros

Defender's decision analysis



Defender's own preferences and beliefs

- The Defender is constant risk adverse to monetary costs
  - Defender's utility function strategy equivalent to

$$u_D(c_D) = -\exp(c \times c_D), \text{ with } c > 0$$

- We perform sensitivity analysis on "*c*"

- Defender's beliefs about $S|a^1,d_1$

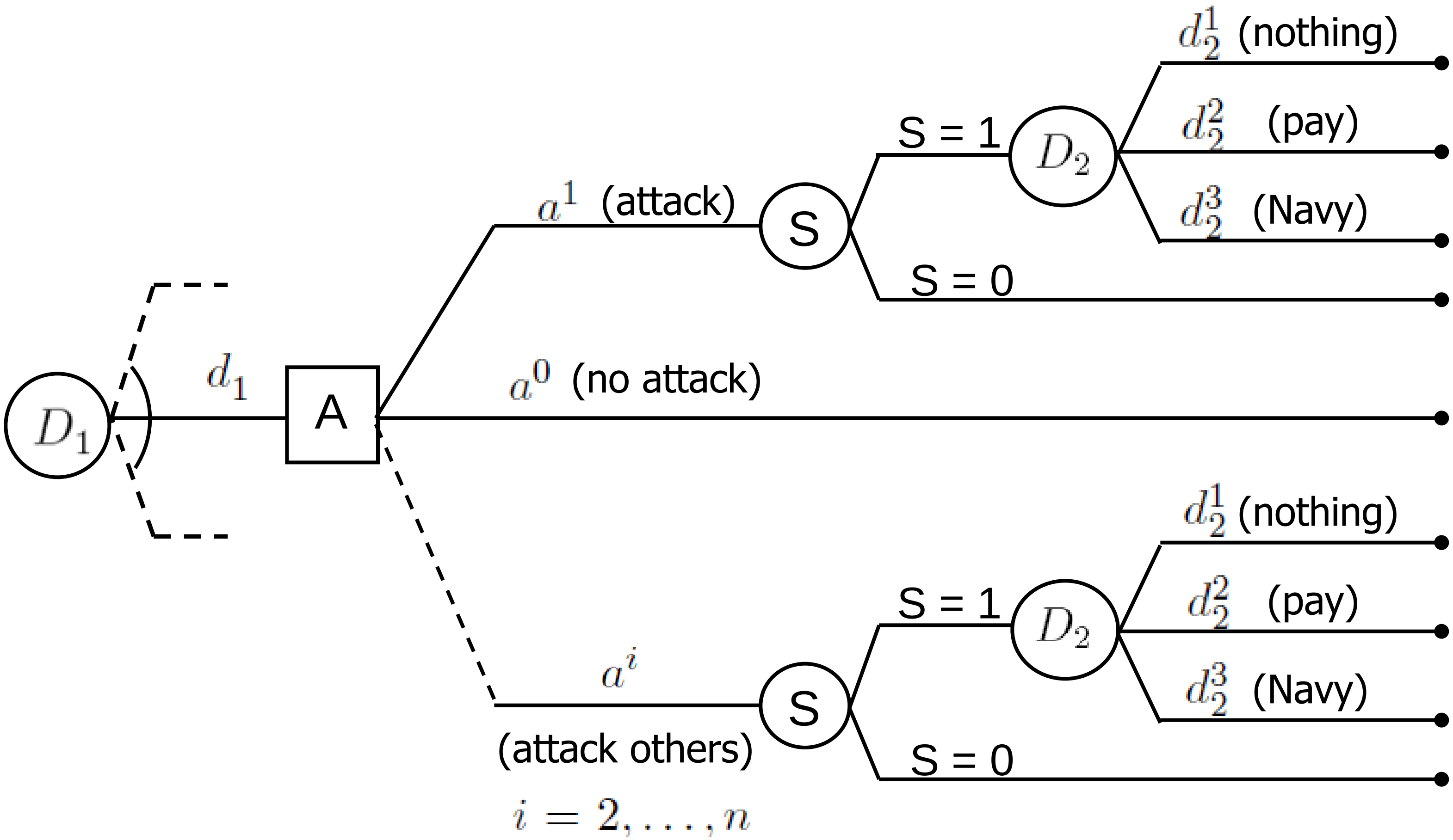
$$p_D(S = 1|a^1, d_1^1) = 0.40$$

$$p_D(S = 1|a^1, d_1^2) = 0.10$$

$$p_D(S = 1|a^1, d_1^3) = 0.05$$

Predicting Attacker's behavior

- The objective is to assess $p_D(A = a^1 | d_1)$
- Attacker's decision problem as seen by the Defender



Defender's beliefs over the Attacker's beliefs and preferences

- Assess from the Defender the Pirates' preferences $U_A(a, s, d_2)$
- Perceived relevant consequences for the Pirates
  - Whether they keep the boat
  - Money earned.
  - Number of Pirates' lives lost.

$c_A(a, s, d_2)$

A	S	D_2	Boat kept	Profit	Lives lost	Aggregate profit
a^0 (no attack)			0	0	0	0
a^i (attack)	$S = 1$	d_2^1 (nothing)	1	-0.03M	0	0.97
a^i (attack)	$S = 1$	d_2^2 (pay rescue)	0	2.27M	0	2.27
a^i (attack)	$S = 1$	d_2^3 (Navy sent)	0	-0.03M	5	-1.28
a^i (attack)	$S = 0$		0	-0.03M	2	-0.53

→ $i = 1,\ldots,n$ (no difference in consequences of attacking the Defender's and other boats)

- The Defender thinks the Pirates are increasing constant risk prone for money
  - Pirates' utility function strategically equivalent to

$$U_A(c_A) = \exp(c \times c_A), \text{ with } c \sim \mathcal{U}(0, 20)$$

- Defender assessment of Pirates' beliefs on
  - $S \mid a, d_1$

$$P_A(S = 1 | a^1, d_1^1) \sim \mathcal{B}e(40, 60)$$

$$P_A(S = 1 | a^1, d_1^2) \sim \mathcal{B}e(10, 90)$$

$$P_A(S = 1 | a^1, d_1^3) \sim \mathcal{B}e(50, 950)$$

$$P_A(S = 1 | a^i \quad) \sim \mathcal{B}e(1, 1) \quad \text{for boat } i = 2, \ldots, n$$

  - $D_2 \mid d_1, a^1, S=1$

$$P_A(D_2 \mid d_1^1, a^1, S = 1) \sim Dir(1, 1, 1)$$

$$P_A(D_2 \mid d_1^2, a^1, S = 1) \sim Dir(0.1, 4, 6)$$

$$P_A(D_2 \mid d_1^3, a^1, S = 1) \sim Dir(0.1, 1, 10)$$

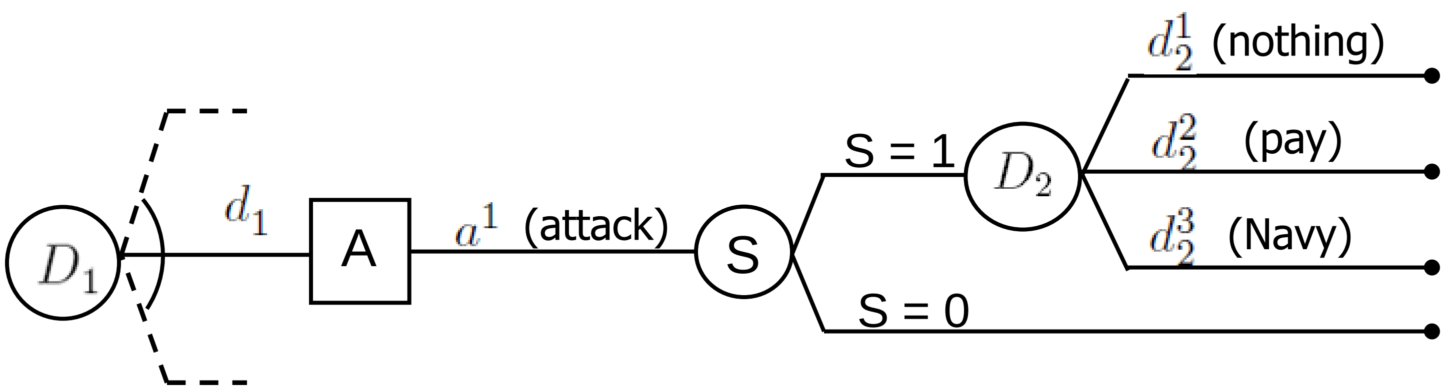
  - $D_2 \mid a^i, S=1$

$$P_A(D_2 \mid a^i, S = 1) \sim Dir(1, 1, 1) \text{ for } i = 2, \ldots, n$$

Predicting Pirates' uncertain behavior

- Based on the above assessments,
  the Defender solve the Pirates' decision problem

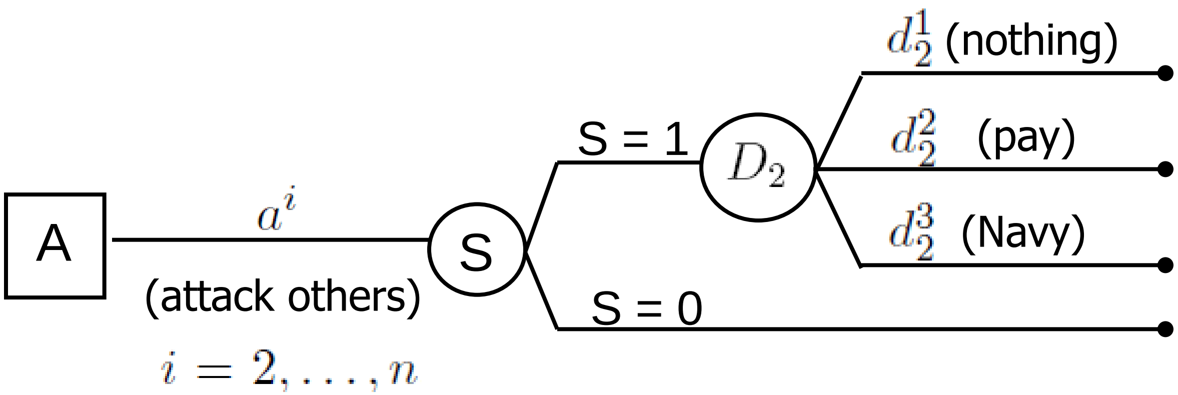
- Random Pirates' EU of a^1 given $d_1 \in \mathcal{D}_1 \setminus \{d_1^4\}$



$$\Psi_A(d_1, a^1) = P_A(S = 1 \mid d_1, a^1) \sum_{d_2 \in \mathcal{D}_2} U_A(a^1, S = 1, d_2)\ P_A(D_2 = d_2 \mid d_1, a^1, S = 1) +$$
$$P_A(S = 0 \mid d_1, a^1)\ U_A(a^1, S = 0)$$

Predicting Pirates' uncertain behavior

- Random Pirates' EU of a^i for $i = 2, \ldots, n$



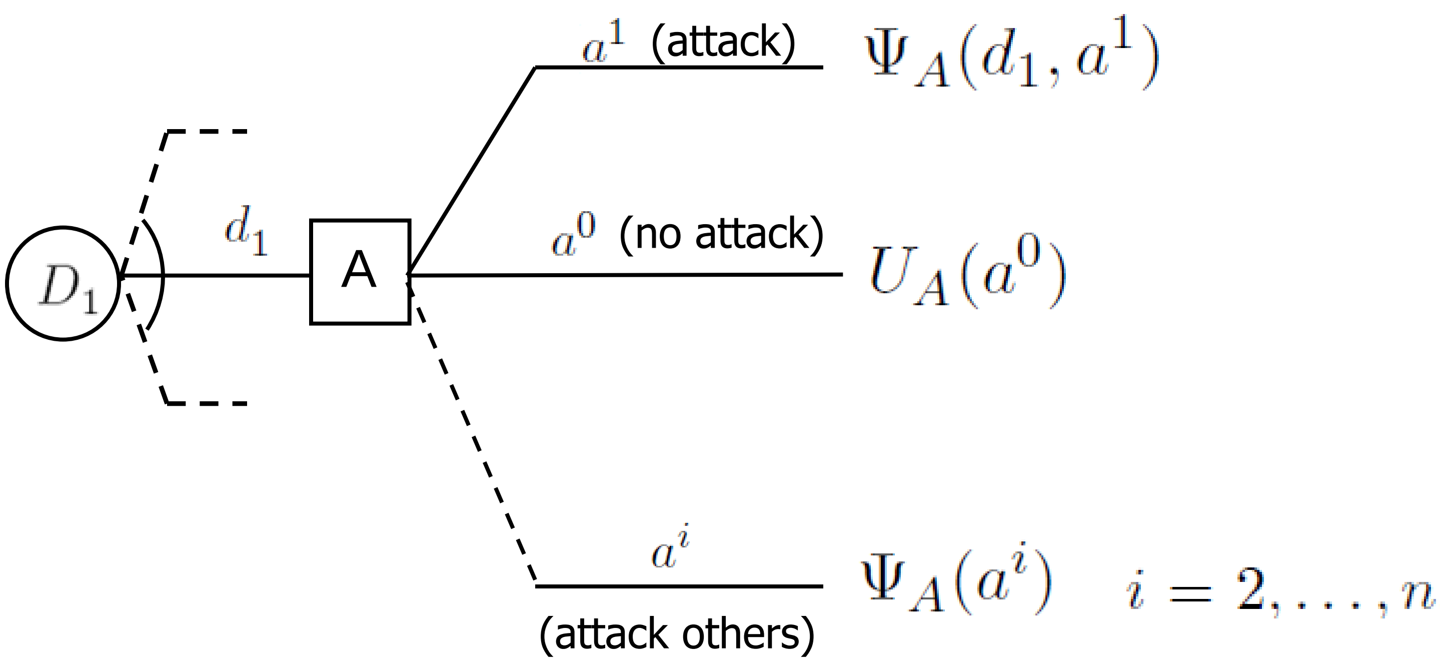
$$\Psi_A(a^i) = P_A(S=1 \mid a^i) \sum_{d_2 \in \mathcal{D}_2} U_A(a^i, S=1, d_2)\ P_A(D_2 = d_2 \mid a^i, S=1) +$$

$$P_A(S=0 \mid a^i)\ U_A(a^i, S=0)$$

Predicting Pirates' uncertain behavior

- Defender's predictive probs of being attacked $(A = a^1)$ given $d_1 \in \mathcal{D}_1 \setminus \{d_1^4\}$

$$p_D(A = a^1 \mid d_1) = \Pr(\ \Psi_A(d_1, a^1) > \max\{U_A(a^0),\ \Psi_A(a^2), \ldots, \Psi_A(a^n)\}\ )$$



Predicting Pirates' uncertain behavior

- We use MC simulation to approximate $p_D(A = a^1 \mid d_1)$ by

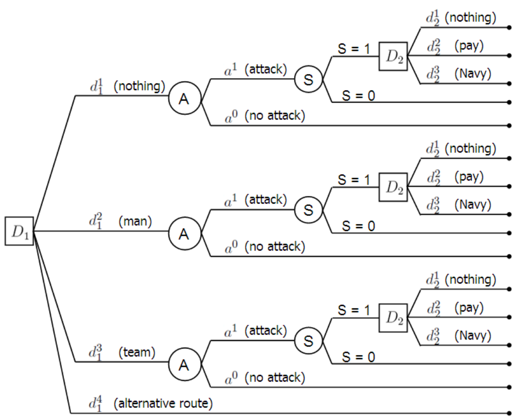
$$\frac{\#\{1 \leq k \leq N : \psi_A^k(d_1, a^1) > \max\{u_A^k(a^0),\ \psi_A^k(a^2), \ldots, \Psi_A^k(a^n)\}\}}{N}$$

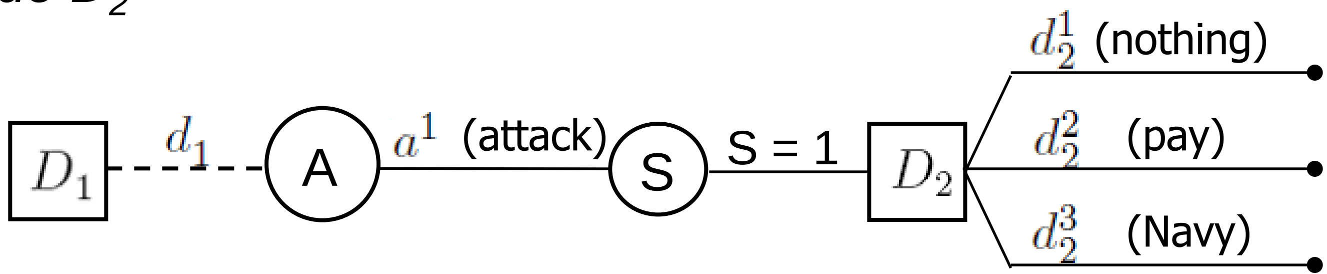
- For illustrative purposes, assume that *n = 4*
  - There will be 3 boats (of similar characteristics) at the time the Defender's boat sails through the Gulf of Aden

- *Based on 1000 MC iterations, we have*
  - $\hat{p}_D(A = a^1 \mid d_1^1) = 0.1931$
  - $\hat{p}_D(A = a^1 \mid d_1^2) = 0.0181$
  - $\hat{p}_D(A = a^1 \mid d_1^3) = 0.0002$

Max EU defense strategy

- *We solve the Defender's decision problem*
  - *At decision node D_2*





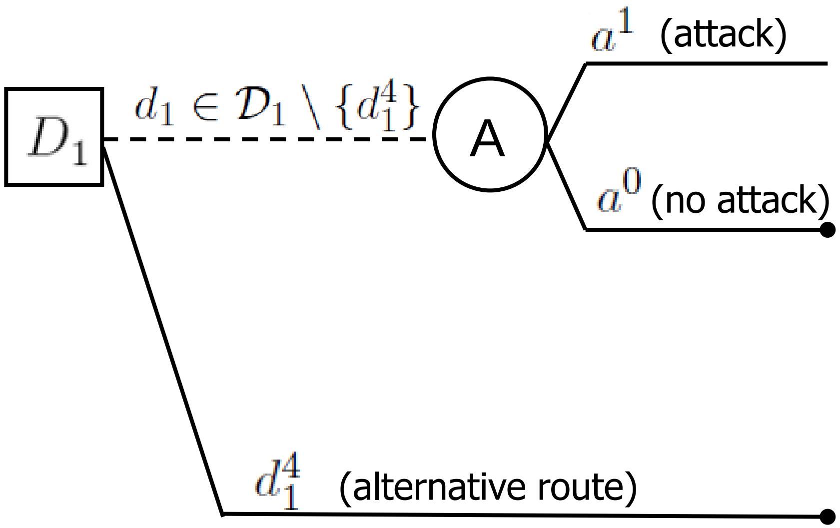
$$d_2^*(d_1, a^1, S = 1) = \text{argmax}_{d_2 \in \mathcal{D}_2} u_D(d_1, S = 1, d_2)$$

  - *At chance node S*

$$\psi_D(d_1, a^1) = p_D(S = 1 \mid d_1, a^1)\, u_D(d_1, S = 1, d_2^*(d_1, a^1, S = 1)) +$$
$$p_D(S = 0 \mid d_1, a^1)\, u_D(d_1, S = 0)$$

Max EU defense strategy

– *At chance node A*



$$\psi_D(d_1) = \psi_D(d_1, a^1)\ \hat{p}_D(A = a^1 \mid d_1)\ + u_D(d_1, S = 0)\ (1 - \hat{p}_D(A = a^1 \mid d_1))$$

$$\psi_D(d_1^4) = u_D(d_1^4)$$

– *At decision node D_1*

$$d_1^* = \text{argmax}_{d_1 \in \mathcal{D}_1} \psi_D(d_1)$$

Max EU defense strategy

- *For different risk aversion coefficients "c"*
  - *c = 0.1 and c = 0.4*

    $d_1^* = d_1^2$ (protect with an armed man) and
    if kidnapped ($S = 1$), pay the ransom ($d_2^* = d_2^2$)

  - *c = 2*

    $d_1^* = d_1^4$ (Going through GH Cape)

Discussion

- ARA vs. GT

- Incorporate more information about $a^i, i = 2, \ldots, n$

$$c_A(a^i, s, d_2)$$

$$P_A(S = 1 \mid a^i)$$

- Incorporate analysis modeling strategic decision behavior of other Defenders

$$P_A(D_2 \mid a^i, S = 1)$$