Adversarial Risk Analysis Models for Urban Security Resource Allocation

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ARA for Urban Security Resource Allocation

- Security
- Urban security from a modelling perspective
- Adversarial Risk Analysis
- ARA for Urban Security Resource Allocation
- Discussion

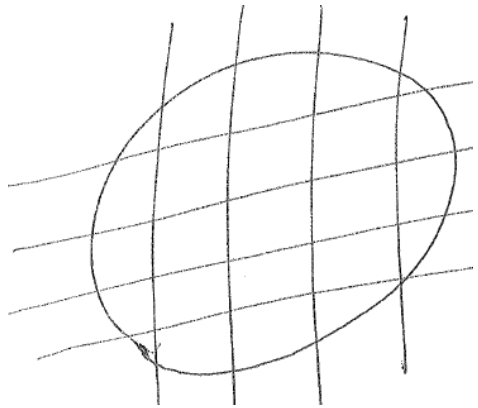
Security

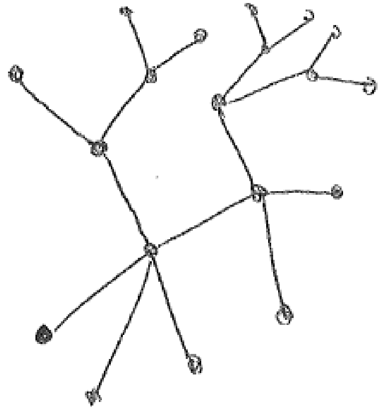
- One of ‘The World’s (23) Biggest Problems´ (Lomborg, 2008)
  - Arms proliferation
  - Conflicts
  - Corruption
  - Terrorism
  - Drugs
  - Money laundering

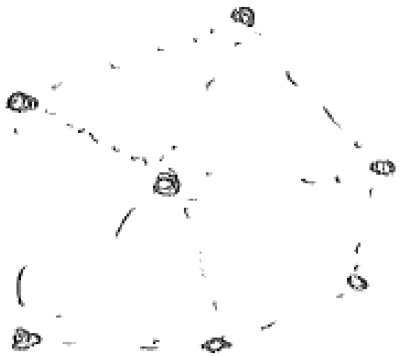
Security

- One of FP7 priorities
- SECONOMICS (2012-2015)
  - Anadulu Airport
  - Barcelona underground
  - National Grid, UK

Security







Urban Security from a modelling perspective

- Criminology
- Becker (1968) Economic theory of delict
- Clarke and Cornish (1986) Situational crime prevention. The reasoning criminal
  - Rational Choice in criminology
  - Routine activities theory
  - Delictive pattern theory
  - Problem-oriented policing
- Displacement theory
- Policing performance measures

Urban Security from a modelling perspective

- COMPSTAT (1994)
- Crime Mapping
- Patrol Car Allocation Models (Tongo, 2010)
- Police Patrol Area Covering Models (Curtin et al, 2007)
- Police Patrol Routes Models (Chawathe, 2007)
- ARMOR at LAX (CREATE, 2007, 2009, 2011)

- The Numbers behind NUMB3RS (Devlin, Lorden, 2007)

Adversarial Risk Analysis

- S-11, M-11 lead to large security investments globally, some of them criticised
- Many modelling efforts to efficiently allocate such resources
- Parnell et al (2008) NAS review
  - Game theoretic approaches. Common knowledge assumption…
  - Decision analytic approaches. Forecasting the adversary action…
- Merrick, Parnell (2011) review approaches commenting favourably on Adversarial Risk Analysis

Adversarial Risk Analysis

- A framework to manage risks from actions of intelligent adversaries (DRI, Rios, Banks, JASA 2009)

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

- 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
  - but this leads to a hierarchy of nested decision problems

(noninformative, heuristic, mirroring argument) vs (common knowledge)

Adversarial Risk Analysis

- ARA applications to counterterrorism models (Rios, DRI, 2009, 2012 Risk Analysis)
  - Sequential Defend-Attack
  - Simultaneous Defend-Attack
  - Sequential Defend-Attack-Defend
  - Sequential Defend-Attack with private information

- Somali pirates case (Sevillano, Rios, DRI, 2012 Decision Analysis)
- Routing games (anti IED war) (Wang, Banks, 2011)

- Borel games (Banks, Petralia, Wang, 2011)
- Auctions (DRI, Rios, Banks, 2009; Rothkopf, 2007)

- Kadane, Larkey (1982), Raiffa (1982), Lippman, McCardle (2012)
- Stahl and Wilson (1994,1995) D. Wolpert (2012)

ARA for Urban Security. Basics

- City divided into cells (i,j)
- Each cell has a value v_{ij}
- Actors
  1. Defender, D, Police. Aims at maintaining value
  2. Attacker, A, Mob. Aims at gaining value

- D allocates resources to prevent $\sum_{ij} d_{ij}^1 \leq D_1$
- A performs attacks $\sum_{ij} a_{ij} \leq A$
- D allocates resources to recover $\sum_{ij} d_{ij}^2 \leq D_2$

  Plus other constraints

ARA for Urban Security. Basics

	1	2	3
1			
2			
3			

	1	2	3
1	1,0	0,8	0,6
2	0,4	0,2	0,5
3	0,7	0,9	1,0

$\sum_{ij} d^1_{ij} \leq 11$ y $d^1_{ij} \geq 0$, d^1_{ij} integer

	1	2	3
1	1	0	1
2	1	3	1
3	1	1	2

	1	2	3
1	11	0	0
2	0	0	0
3	0	0	0

	1	2	3
1	1	0	1
2	0	1	0
3	0	0	0

	1	2	3
1	0	0	0
2	0	0	0
3	0	0	3

$\sum_{ij} a_{ij} \leq 3$ y $a_{ij} \geq 0$, a_{ij} integer

$\sum_{ij} d^2_{ij} \leq 11$, $d^2_{ij} \geq 0$, d^2_{ij} integer

$$\sum_{ij} d^2_{ij} \leq \sum_{(k,h) \in (i,j)_m} d^1_{kh}$$

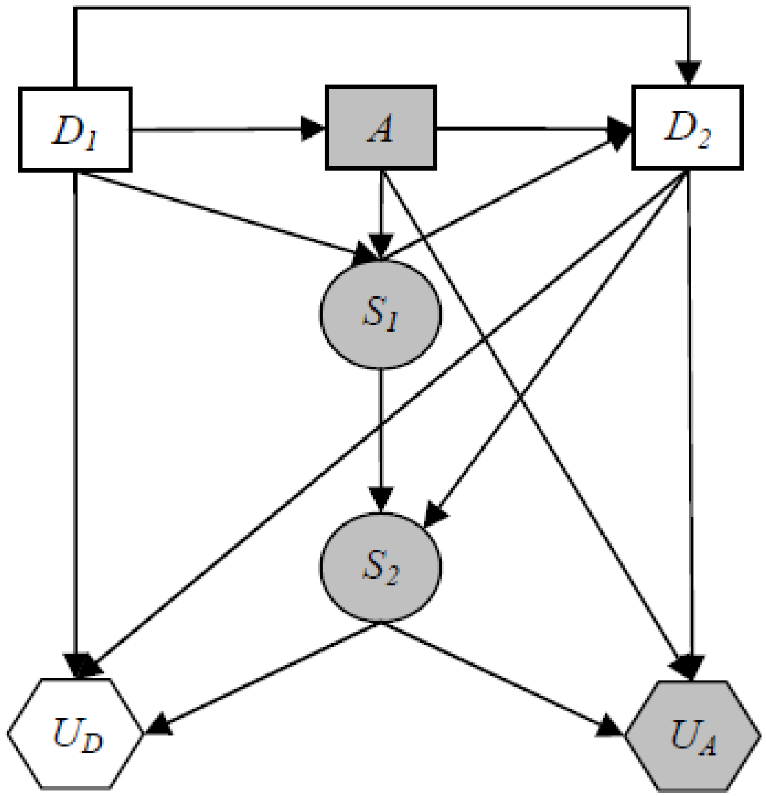
	1	2	3
1	d^1_{11}	d^1_{12}	d^1_{13}
2	d^1_{21}	d^1_{22}	d^1_{23}
3	d^1_{31}	d^1_{32}	d^1_{33}

	1	2	3
1	d^2_{11}	d^2_{12}	d^2_{13}
2	d^2_{21}	d^2_{22}	d^2_{23}
3	d^2_{31}	d^2_{32}	d^2_{33}

ARA for Urban Security. Basics

At each cell, a
coupled
influence diagram

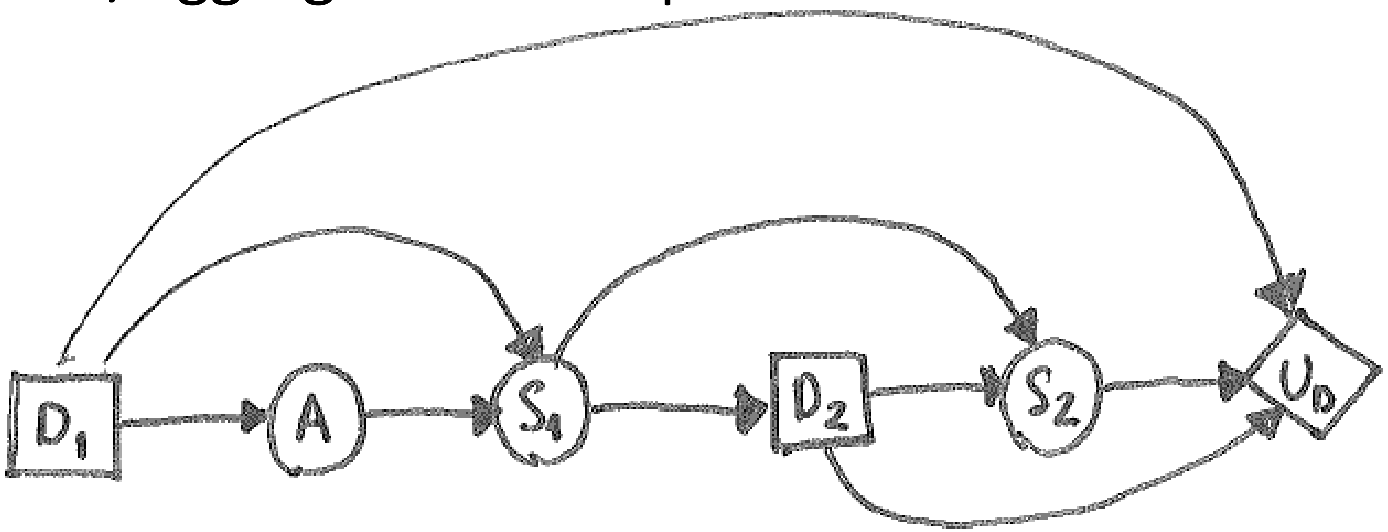
Cell decision making
coordinated by
constraints on
resources



ARA for Urban Security. Police dynamics

At each cell:

- Makes resource allocation d_{ij}^{1}
- Faces a level of delinquency a_{ij}, with impact s_{ij}^{1}
- Recovers as much as she can with resources d_{ij}^{2} with a level of success s_{ij}^{2}
- Gets a consequence
- Aggregates utilities/Aggregates consequences



ARA for Urban Security. Police dynamics

The assessments required from the defender are

- $p_D(a|d_1)$

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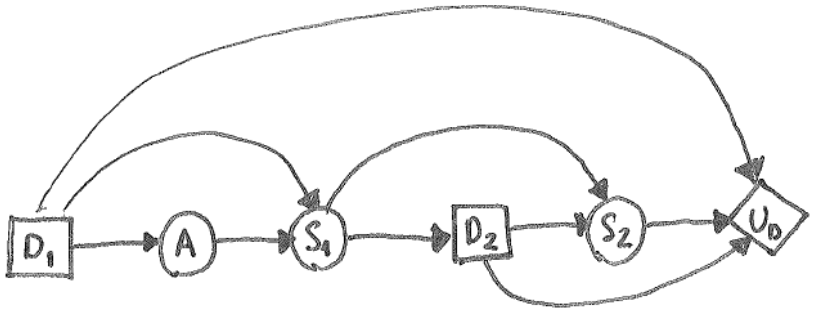
- $p_D(s_1|a, d_1)$
- $p_D(s_2|s_1, d_2)$
- $u_D(d_1, s_2, d_2, v)$

ARA for Urban Security. Police dynamics

The Police solves sequentially



- At node U_D, $u_D(d_1, s_2, d_2, v)$.
- At node S_2, compute $\psi_D(d_1, s_1, d_2, v) = \int u_D(d_1, s_2, d_2, v) p_D(s_2|s_1, d_2) ds_2$.
- At node D_2, compute $\psi_D(d_1, s_1, v) = \max_{\sum d_2^{ij} \leq D_2} \psi_D(d_1, s_1, d_2, v)$ and store optimal allocation.
- At node S_1, compute $\psi_D(d_1, v, a) = \int \psi_D(d_1, s_1, v) p_D(s_1|a, d_1) ds_1$.
- At node A, compute $\psi_D(d_1, v) = \int \psi_D(d_1, v, a) p_D(a|d_1) da$
- At node D, compute $\psi_D(v) = \max_{\sum d_1^{ij} \leq D_1} \psi_D(d_1, v)$ and store optimal allocation.

$$\max_{\sum d_1^{ij} \leq D_1} \max_{\sum d_2^{ij} \leq D_2} \int \int \int u_D(d_1, s_2, d_2, v) p_D(s_2|s_1, d_2) p_D(s_1|a, d_1) p_D(a|d_1) ds_2 ds_1 da$$

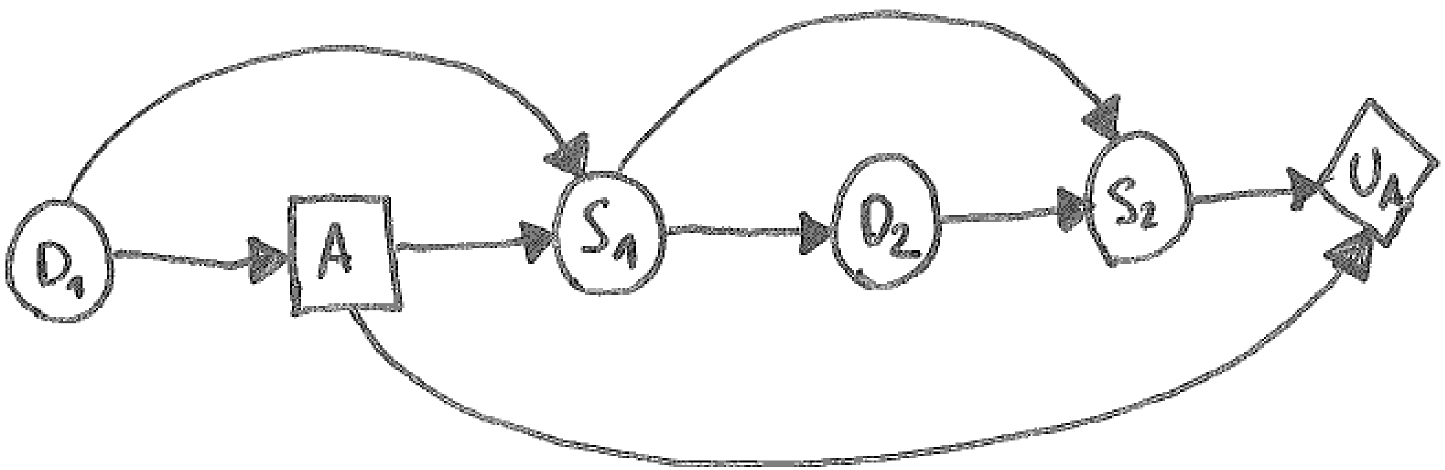
Augmented probability simulation (Bielza, Muller, DRI, 1999 Mansci)

$$p_D(a|d_1)$$

ARA for Urban Security. Mob dynamics

At each cell:

- Observes resource allocation d_{ij}^{1}
- Undertakes attack a_{ij} , with impact s_{ij}^{1}
- Observes recovery with resources d_{ij}^{2} with a level of success s_{ij}^{2}
- Gets a consequence
- Aggregates utilities/Aggregates consequences



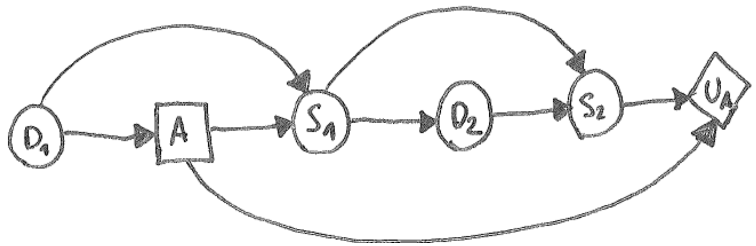
ARA for Urban Security. Mob Dynamics

- The assessments for the Mob are
  - $p_A(d_2|s_1)$
  - $p_A(s_1|a, d_1)$
  - $p_A(s_2|s_1, d_2)$
  - $u_A(a, s_2, v)$

- We model our uncertainty about them through
  - $P_A(d_2|s_1)$
  - $P_A(s_1|a, d_1)$
  - $P_A(s_2|s_1, d_2)$
  - $U_A(a, s_2, v)$

ARA for Urban Security. Mob dynamics

- We propagate such uncertainty through the scheme



- At node U_A, $U_A(a, s_2, v)$.
- At node S_2, compute $\Psi_D(a, s_1, d_2, v) = \int U_A(a, s_2, v) P_A(s_2 | s_1, d_2) ds_2$.
- At node D_2, compute $\Psi_D(a, s_1, v) = \int \Psi_D(a, s_1, d_2, v) P_A(d_2 | s_1) dd_2$
- At node S_1, compute $\Psi_D(d_1, v, a) = \int \Psi_D(a, s_1, v) P_A(s_1 | a, d_1) ds_1$.
- At node A, compute $\Psi_D(d_1, v) = \max_{\sum a^{ij} \leq A} \Psi_D(d_1, v, a)$ and stores optimal random allocation $A^*(d_1, v)$.

$$\int_{\{x \leq a\}} p_D(A = x | d_1, v) dx = Pr(A^*(d_1, v) \leq a)$$

ARA for Urban Security. Mob dynamics

- We can estimate it by Monte Carlo

- Sample from

$$F = \{U_A(a, s_2, v), P_A(s_1 \mid a, d_1), P_A(d_2 \mid s_1), P_A(s_2 \mid s_1, d_2)\}$$

- Solve for maximum expected utility attack

(EU computed in one step+ augmented prob. Simulation)

$$\hat{P}_D(A \leq a \mid d_1) = \frac{\#\{A_k^*(v, d_1) \leq a\}}{n}$$

ARA for Urban Security. Mob dynamics

```
Inicializamos parámetros v, k, ro, D1, D2, A,…
Generamos pA(d2|s1,a,d1)
Para d1's
  Para i's de 1 a n
    c <- U(1,10)
    Para a's
      Para s1's
        Generamos pA_i(s2_j|d2,s1)
        Nodo S2
        ψA_i(a,s1,d2,v) <- ∑_s2 uA_i(a,s2,v) * ∏_j pA_i(s2_j|d2,s1)
        Nodo D2
        ψA_i(d1,a,s1,v) <- ∑_d2 ψA_i(a,s1,d2,v) * pA(d2|s1,a,d1)
        Nodo S1
        Generamos pA_i(s1|a,d1)
        ψA_i(d1,a,v) <- ∑_s1 ψA_i(d1,a,s1,v) * ∏_j pA_i(s1_j|a,d1)
      Fin s1's
    Fin a's
    Nodo A
    a*_i(d1,v) <- argmax(ψA_i(a,d1,v))
    Actualizamos {# a*_i(d1,v) = a}
  Fin i's
  pD^(a|d1) <- {# a*_i(d1,v) = a} / n
Fin d1's
```

ARA for Urban Security. Mob dynamics

Very complex (De Werra’s talk)

Parallelise

Do the computations at a few d1’s and then some kind of response surface

Augmented simulation

Both problems in one shot??

Discussion

- Computational scheme
- Higher k-level
- Multiple Defenders to be coordinated (risk sharing).
- Private security
- Multiple Attackers possibly coordinated
- Various types of resources
- Various types of delinquency
- Multivalued cells. The perception of security (concern analysis)
- Multiperiod planning
- Time and space effects (Displacement of delicts)
- Insurance
- General coupled influence diagrams

- Networks with value only at nodes
- Networks with value at nodes and arcs