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Utilization of Multi-Criteria Influence Diagrams in Simulation Metamodeling

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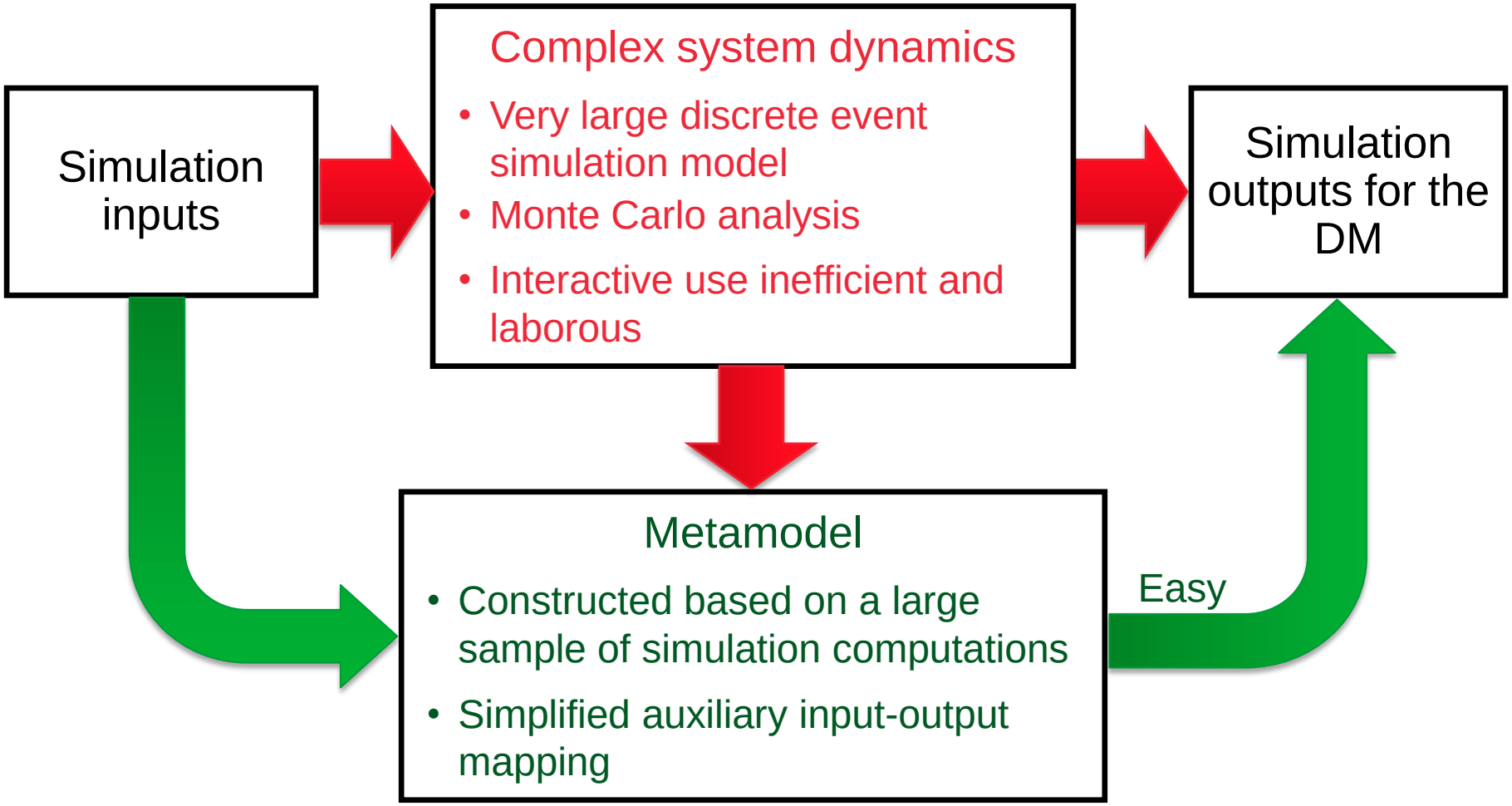
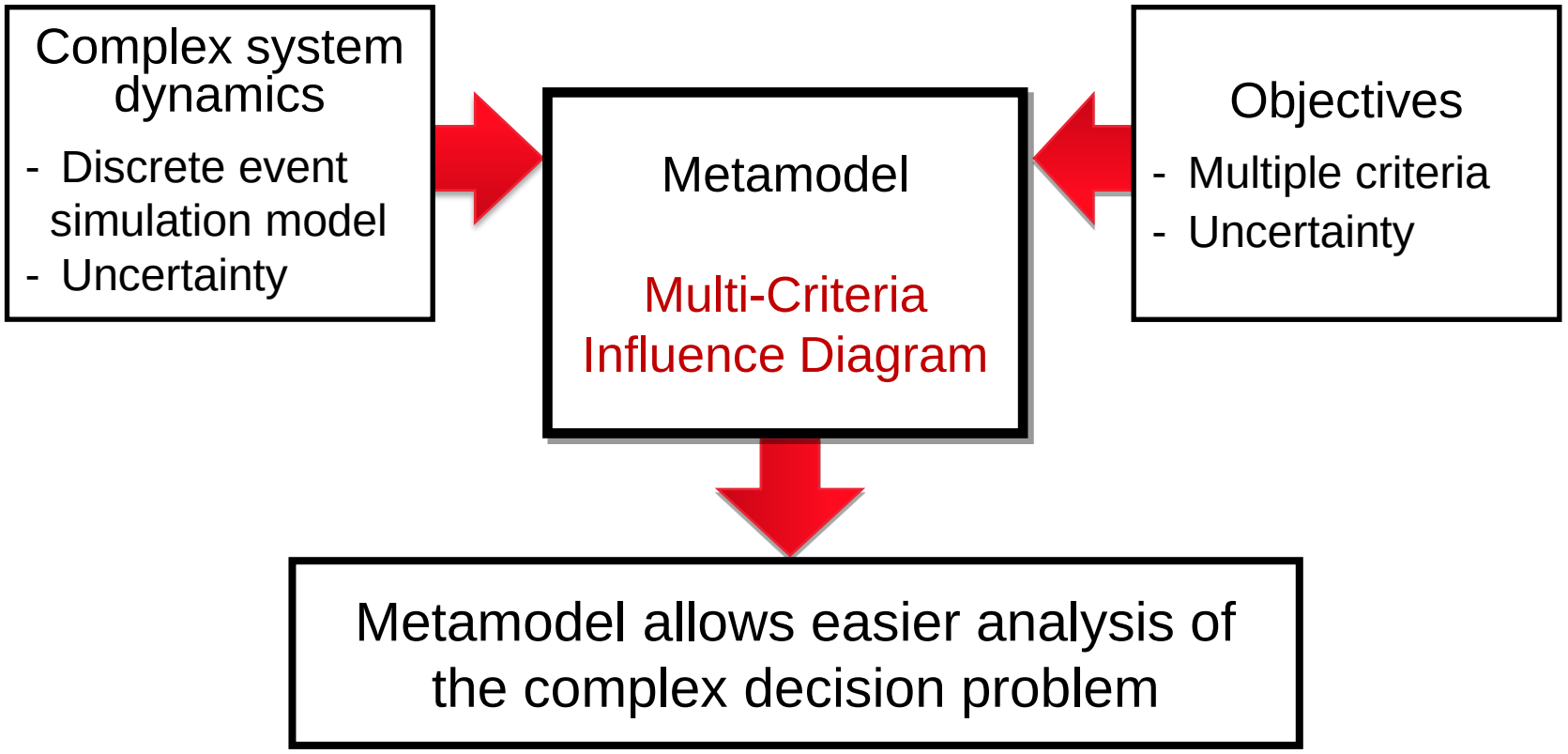
Introduction of Multiple Criteria Decision Making (MCDM) perspective to simulation metamodeling



Simulation metamodeling with MCDM



Increasing complexity of models increases the need for metamodeling

- Metamodel helps
  - Sensitivity and what-if analysis
  - Optimization of a simulation output
  - Model validation
- Several existing approaches, seminal book by Friedman 1996
  - Regression models, neural networks, splines, kriging models, games, dynamic Bayesian networks, ...

New features allowed by multi-criteria influence diagrams

- Inclusion of preferences of the decision maker (DM)
- Solving efficient decision alternatives
- Selection of the most preferred decision alternative
- Sensitivity with respect to preferences

Multi-Criteria Influence Diagram (MCID)

Influence diagram (Howard and Matheson, 1984)

- Modeling decision problems under uncertainty

Nodes:

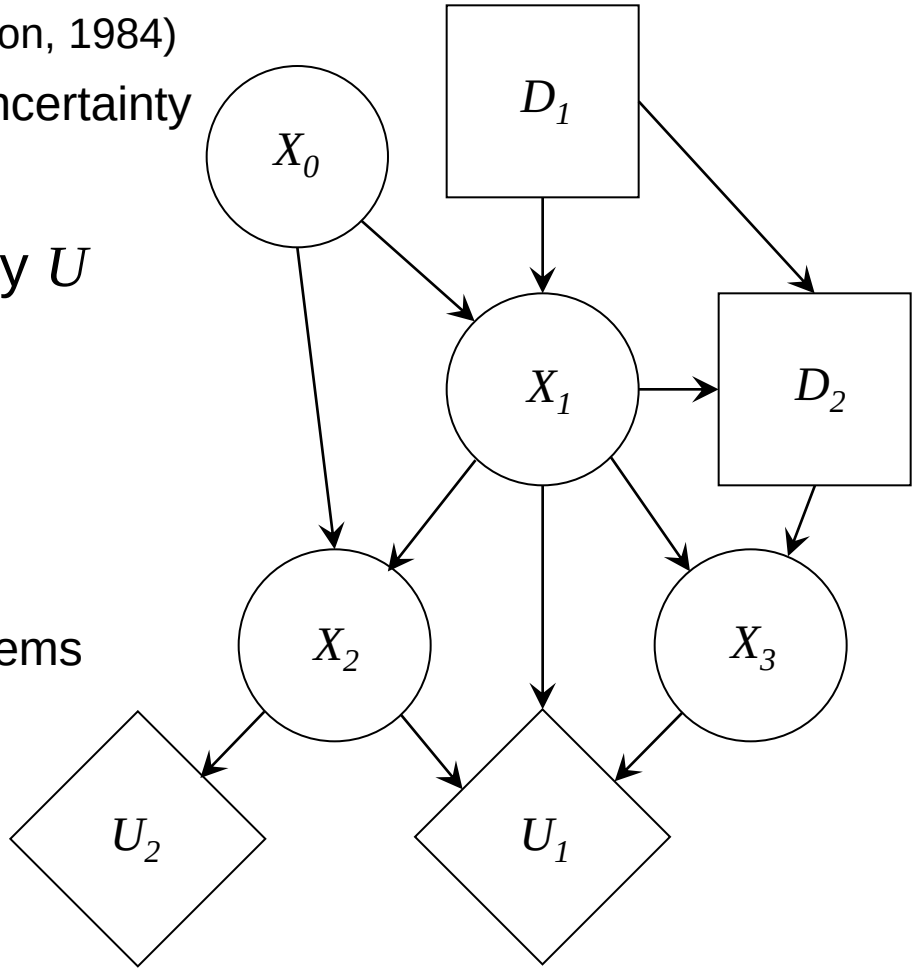
- Decision D, chance X, and utility U

Utility node: DM's utility function

- Preferences
- Scores on the objectives

MCID (Diehl and Haimes, 2004)

- Modeling multi-criteria decision problems under uncertainty
- Multiple utility nodes U_i



MCID in simulation metamodeling

Simulation inputs described by:

- Decision or chance nodes

Simulation state described by:

- Chance nodes

Simulation outputs described by:

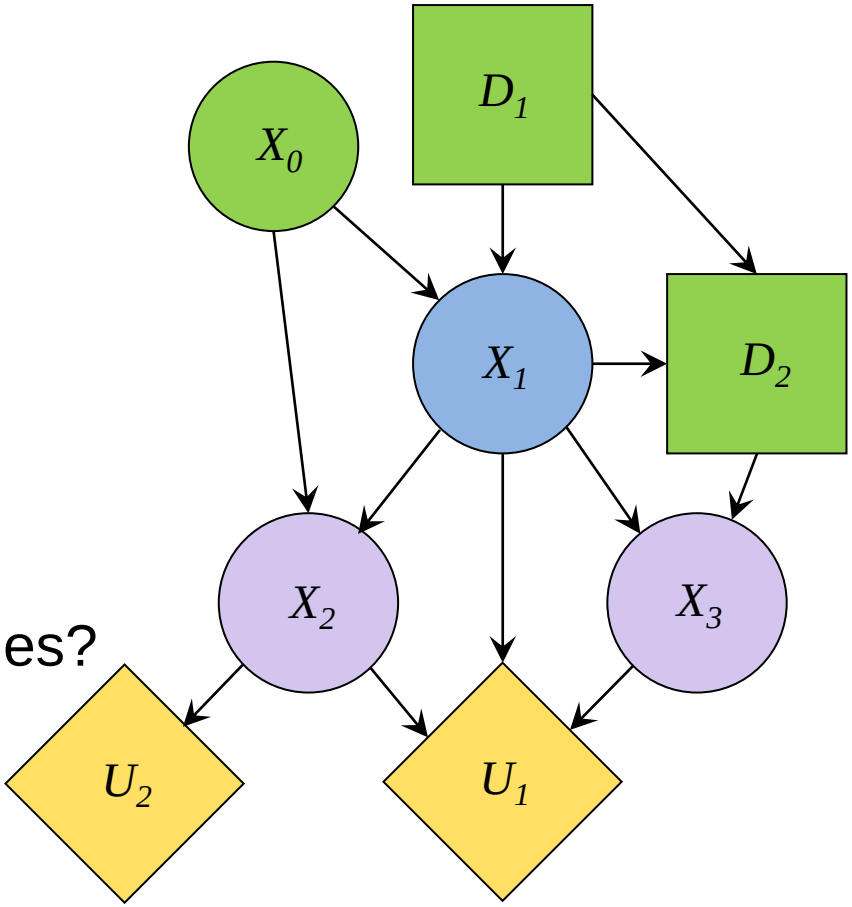
- Chance nodes

Objectives and preferences of DM:

- Utility nodes and functions

Estimation of structure and probabilities?

- **From raw simulation data**
- Expert knowledge
- Available software:
  - GeNIe (free), Hugin, ...

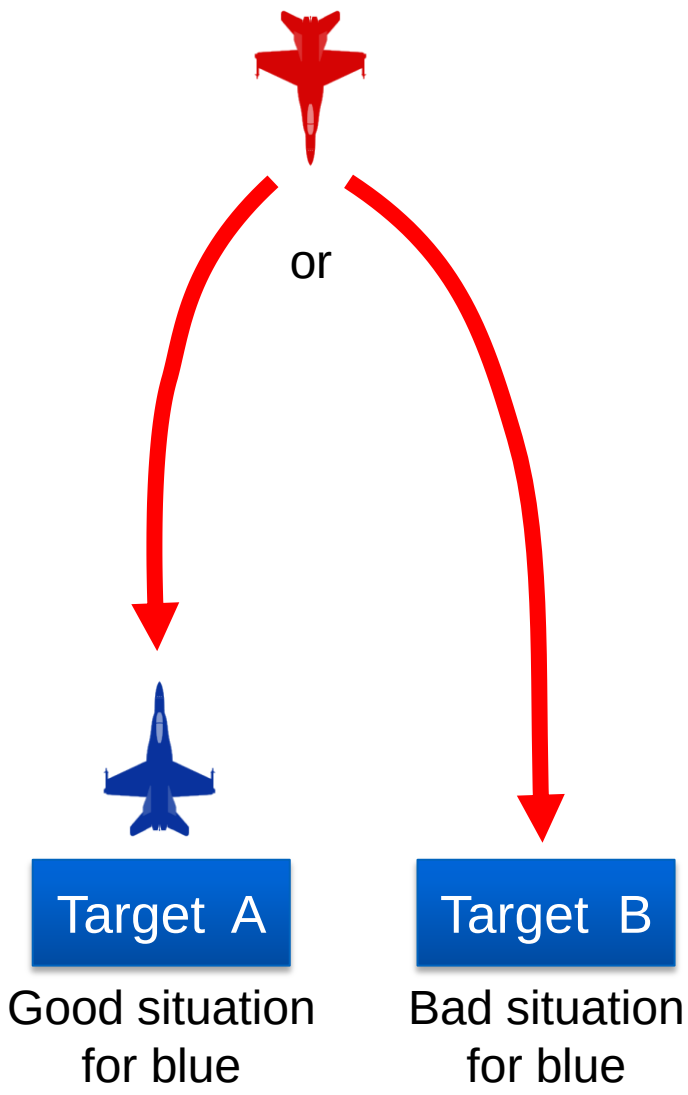


Use of MCID in metamodeling

- Generation of efficient decision alternatives
  - Probability distributions of utilities for each decision alternative
  - E.g. expected utilities of decision alternatives
  - Identification of the most preferred solution
- Time evolution of probability distributions in simulation
- What-if analysis – the impact of evidence
  - Probability distributions of chance nodes for fixed values (evidence) of other nodes
  - Efficient decision alternatives for fixed values (evidence) of other nodes
- Sensitivity analysis
  - Effect of the changes in the probability distributions on the set of efficient decision alternatives

Air combat example

- Blue DM decides on
  - Target to defend (blue target)
    - Target A or target B
  - Air combat tactics (blue tactics)
    - Tactic 1 or tactic 2
- Uncertain strategy of Red DM
  - Target to attack (red target)
    - Target A or target B
  - Air combat tactics (red tactics)
    - Tactic 1 or tactic 2
- Bad situation for blue if decides to defend wrong target

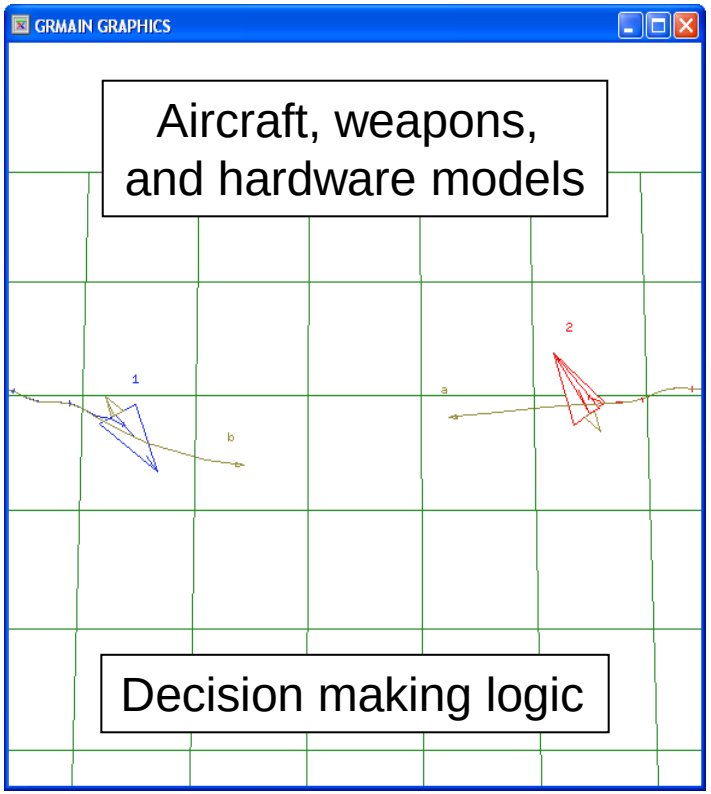


Generation of data by stochastic simulation

Multiple simulation runs

Simulation input

- Blue tactics
- Blue target
- Red tactics
- Red target



Simulation output

- Number of blue aircraft killed
- Number of red aircraft killed
- Target A survives?
- Target B survives?

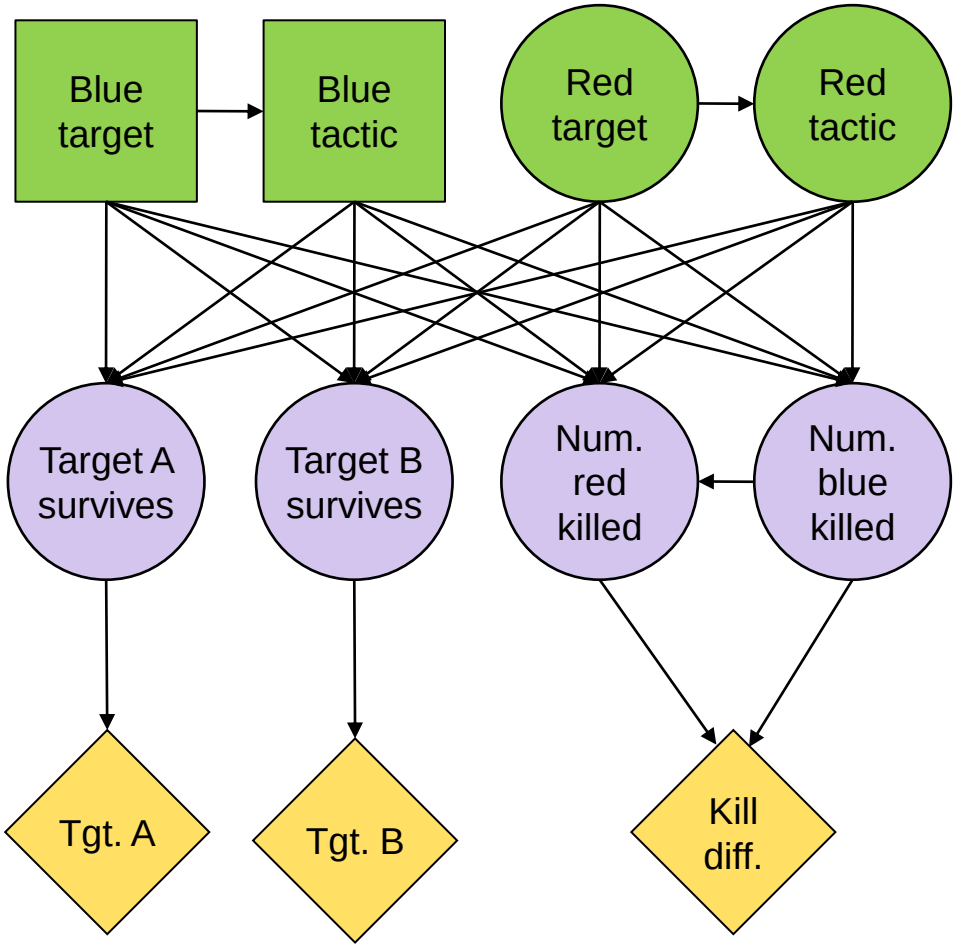
Introducing objectives to the MCID

Simulation inputs

Simulation outputs

Objectives of DM

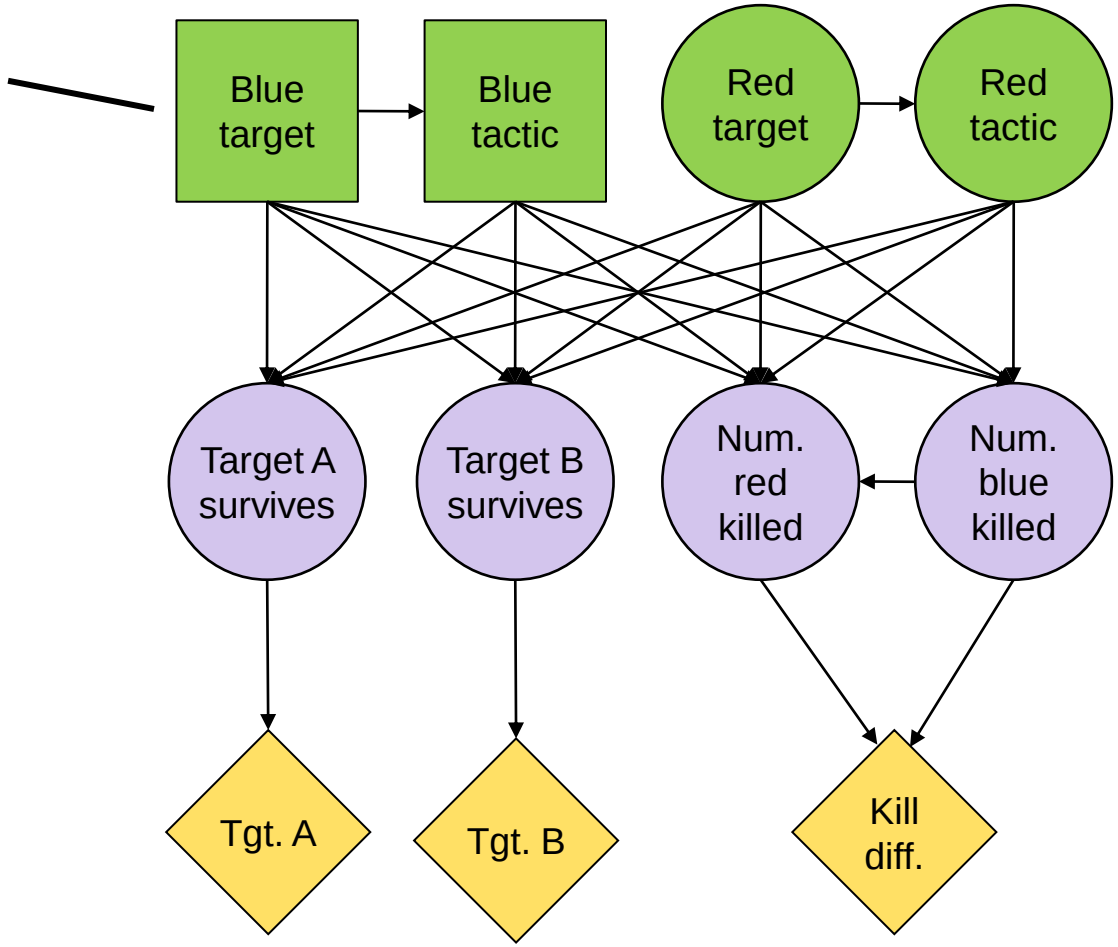
- Maximize probability that target A survives (Tgt. A)
- Maximize probability that target B survives (Tgt. B)
- Maximize kills-losses (Kill diff.)



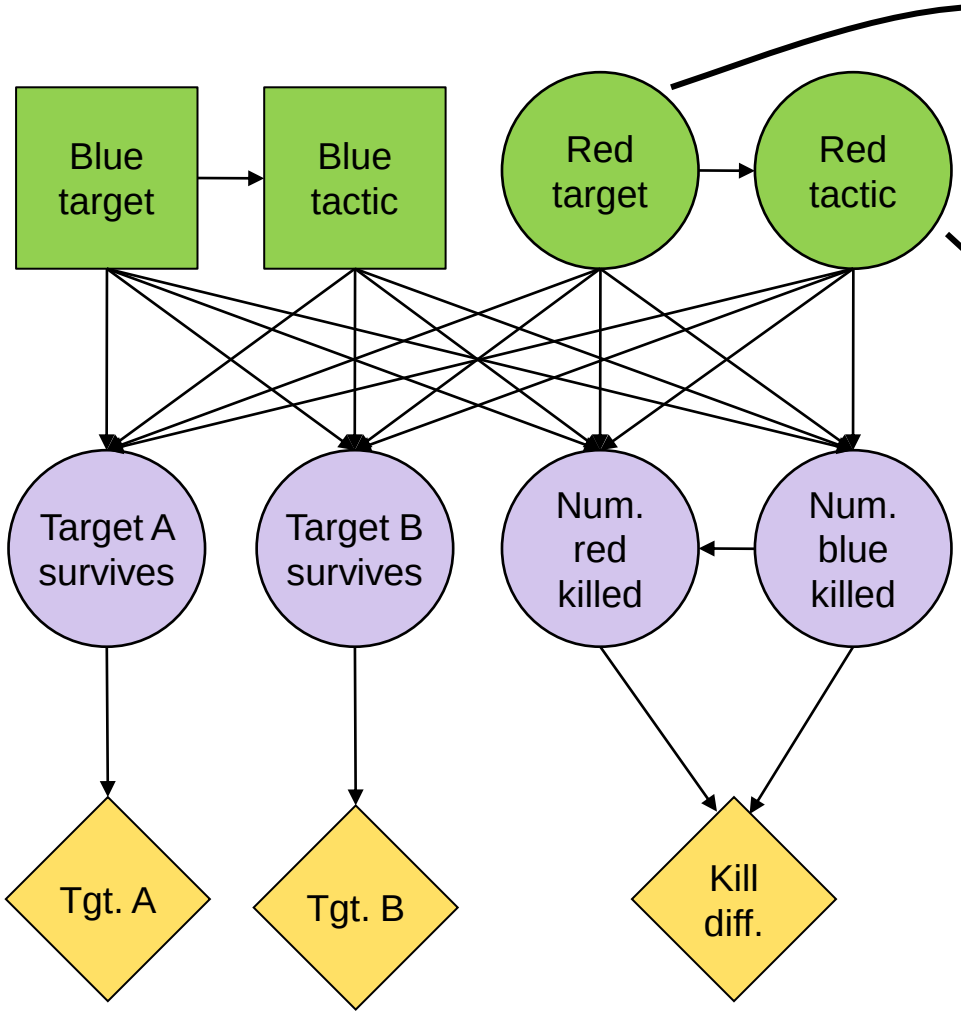
Simulation inputs in the MCID: decisions

Blue target	
Target A	Target B

Decision nodes contain DM's decision alternatives



Simulation inputs in the MCID: chance nodes

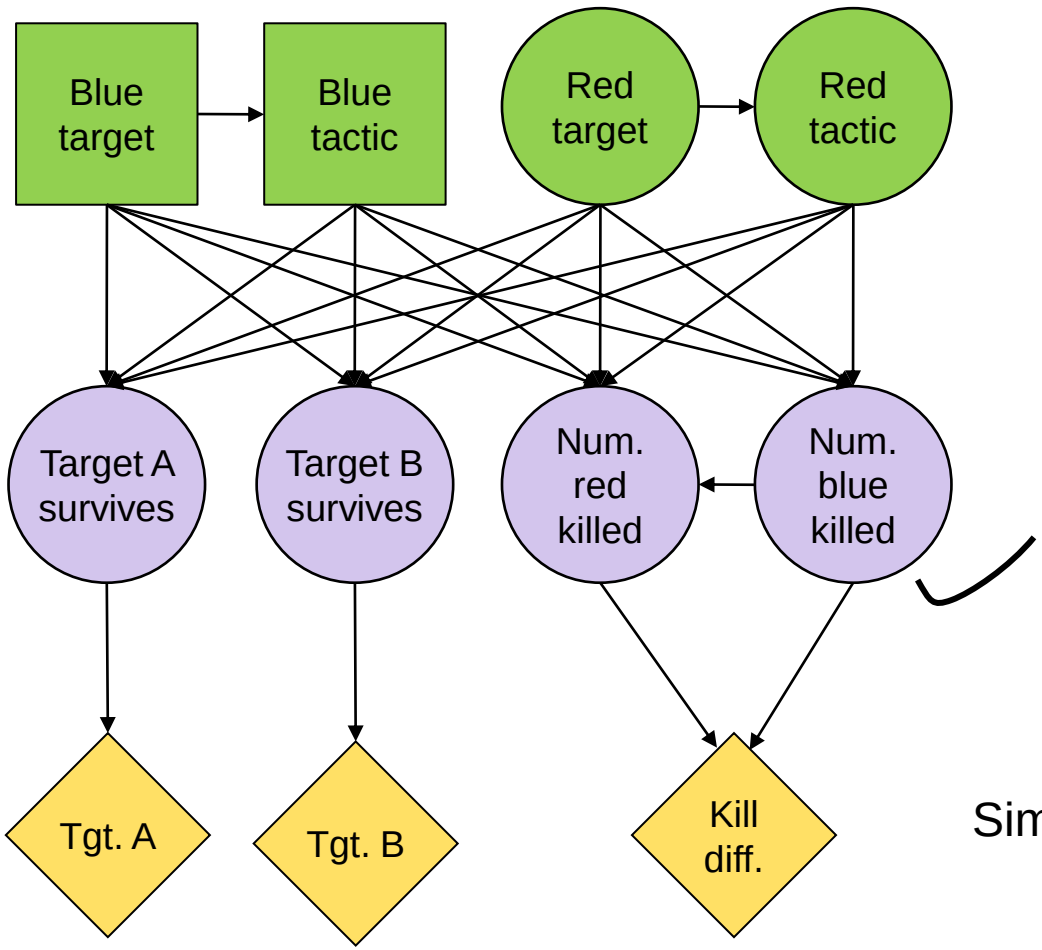


Red target	
Target A	0.7
Target B	0.3

Red tactic		
Red target	**A**	**B**
Tactic 1	0.2	0.8
Tactic 2	0.8	0.2

Uncertain strategy of red DM represented by probability distributions

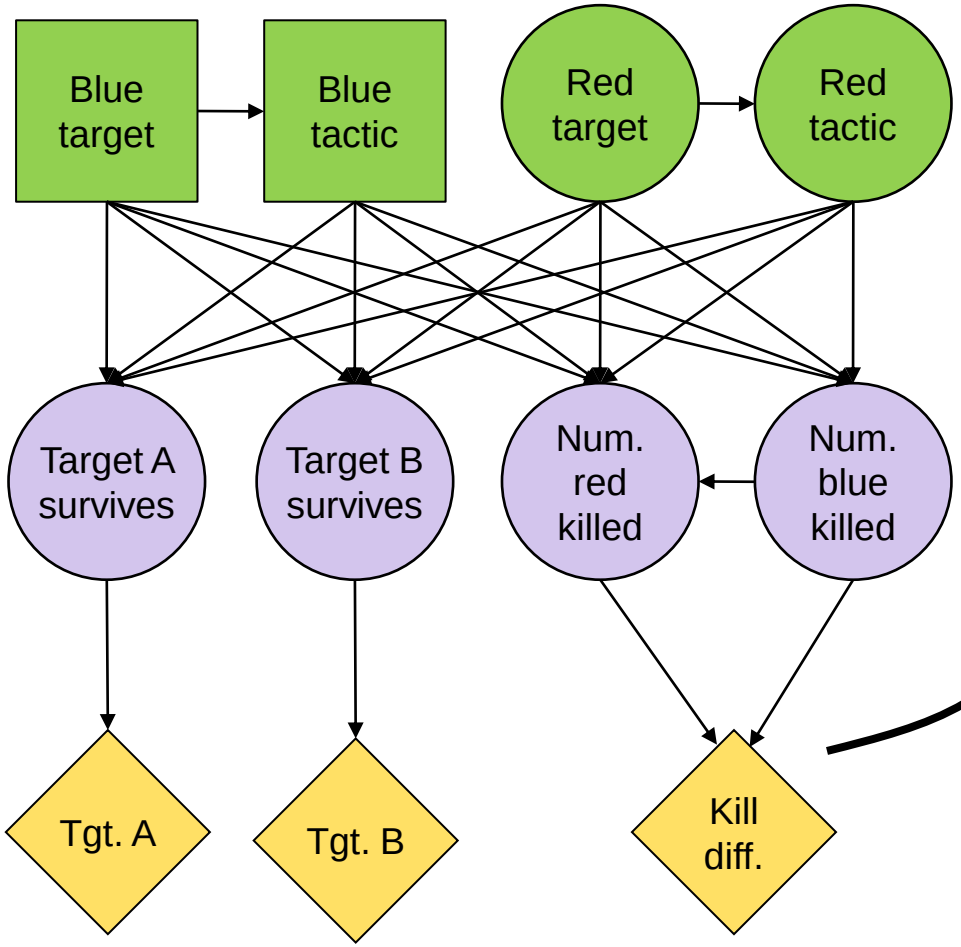
Simulation outputs in the MCID



Num. blue killed					
Blue target	**A**				…
Red target	**A**				…
Blue tactic	**1**		**2**		…
Red tactic	**1**	**2**	**1**	**2**	…
0	0.075	0.471	0.329	0.773	…
1	0.157	0.231	0.215	0.148	…
2	0.127	0.153	0.155	0.041	…
3	0.238	0.095	0.108	0.033	…
4	0.403	0.05	0.193	0.005	…

Simulation output probability distributions estimated from generated data

Utility functions in the MCID

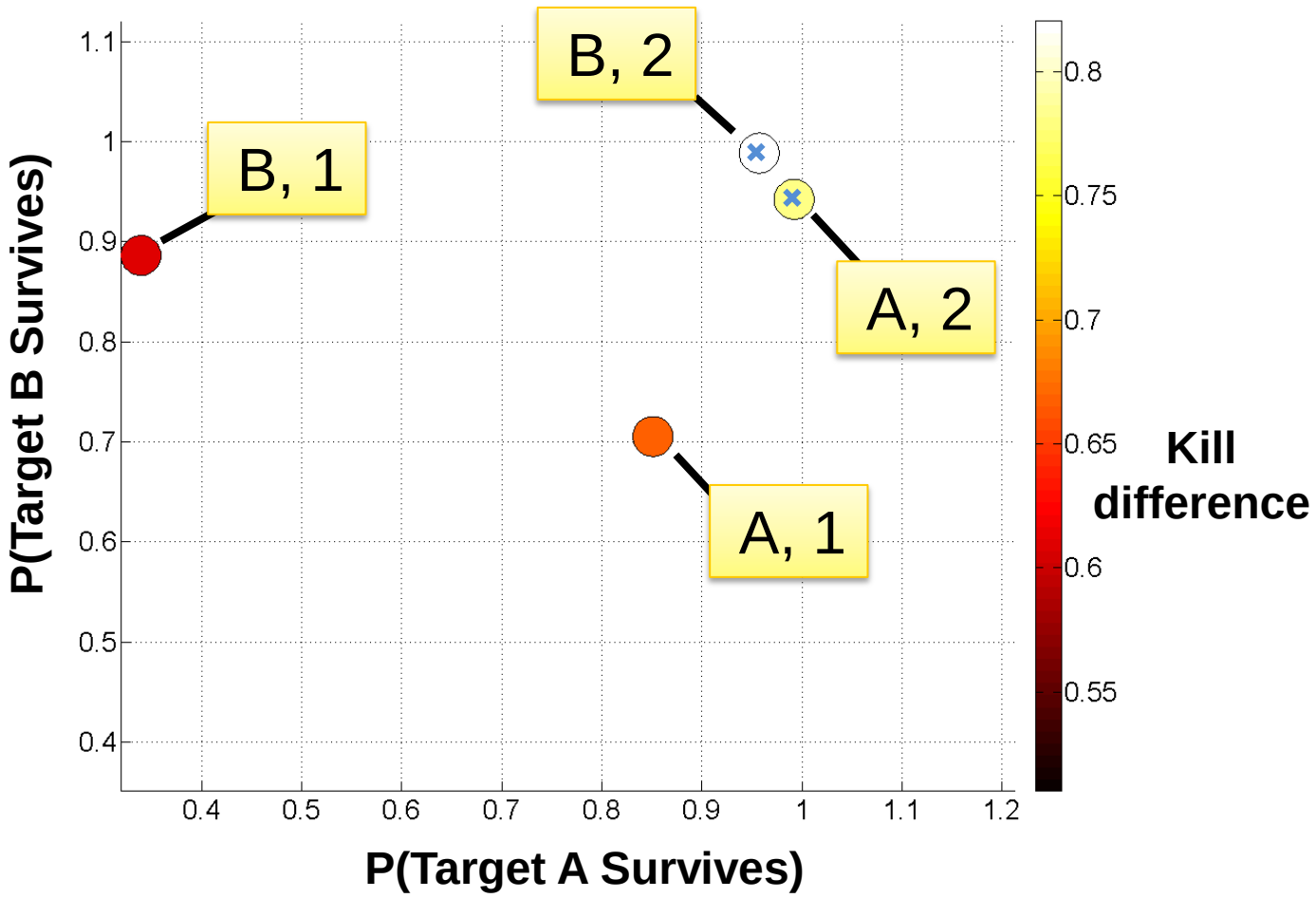


Kill diff.						
Num. blue killed	**0**					...
Num. red killed	**0**	**1**	**2**	**3**	**4**	...
Utility	0.500	0.625	0.750	0.875	1.000	...

Utilities of outcomes elicited from DM

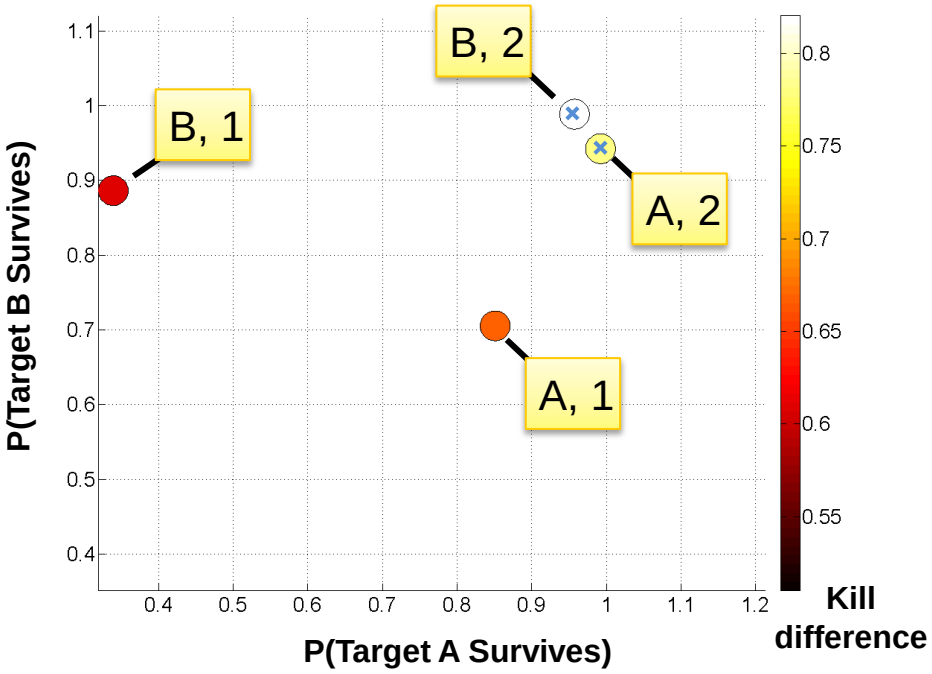
Efficient decision alternatives

Efficient decision alternatives marked with x

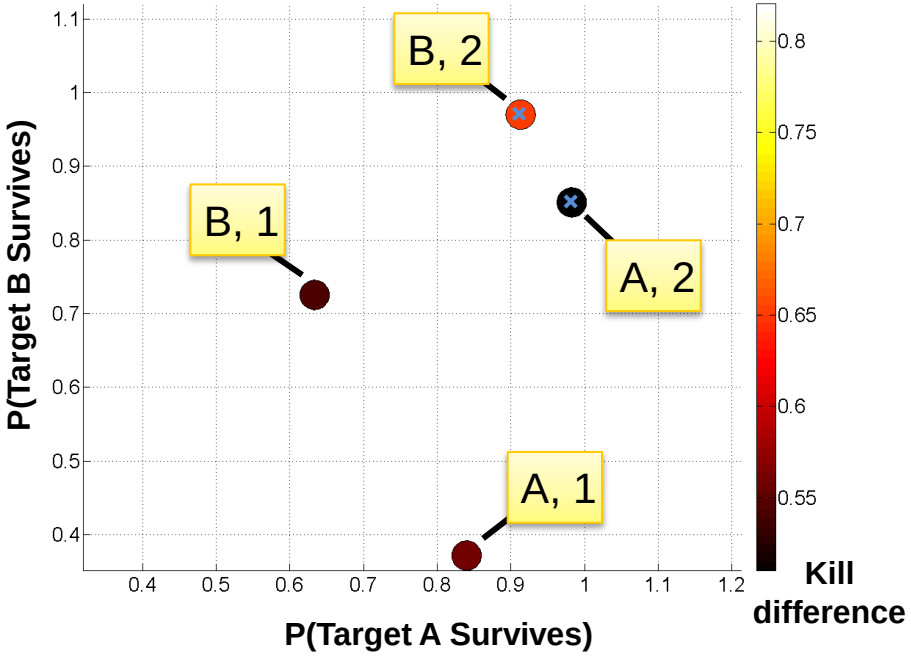


What-if analysis: red uses tactic 1

No evidence

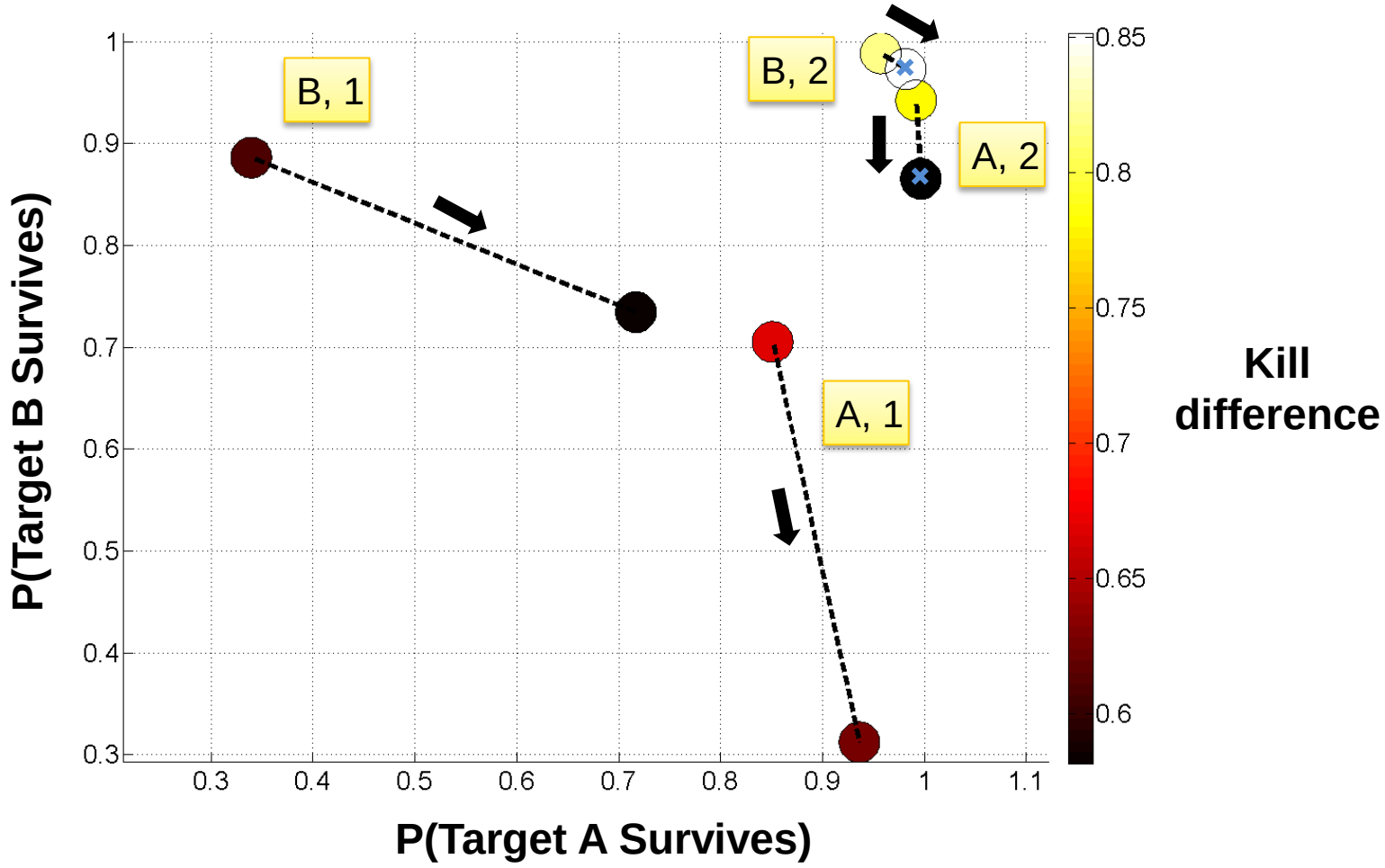


Evidence



Probability of red attacking target A decreases from 0.7 to 0.37

Sensitivity analysis: probability of red attacking target A decreases from 0.7 to 0.3



Conclusion: Simulation metamodeling benefits from new tools - MCDM and MCID

- MCDM provides
  - DM's preferences with respect to multiple criteria
- MCID provides
  - New analysis capabilities
  - Flexible and transparent modeling
- Efficient calculation: Easy-to-use software available
- Our case: Simulation analysis of air combat
- Future work
  - Dynamic decision making
  - Multiple DMs
  - Input modeling – the impact of correlated inputs

References

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