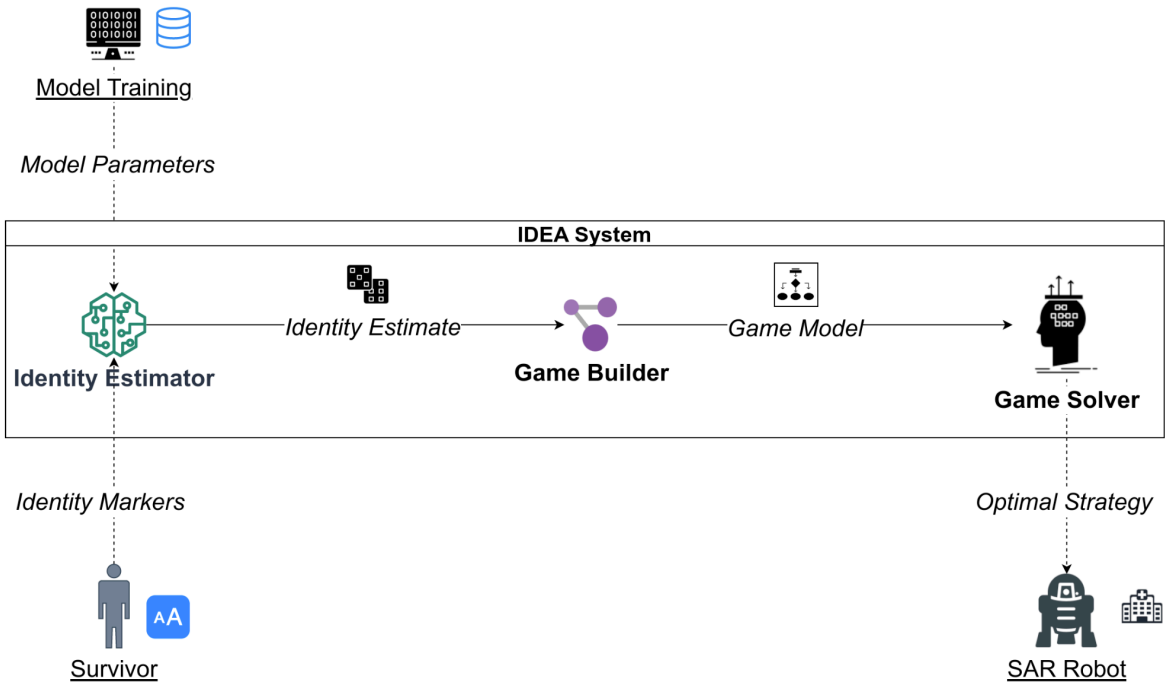
Towards a Formally Verified Identity-Aware Architecture for Autonomous Systems

The IDEA Framework [1]



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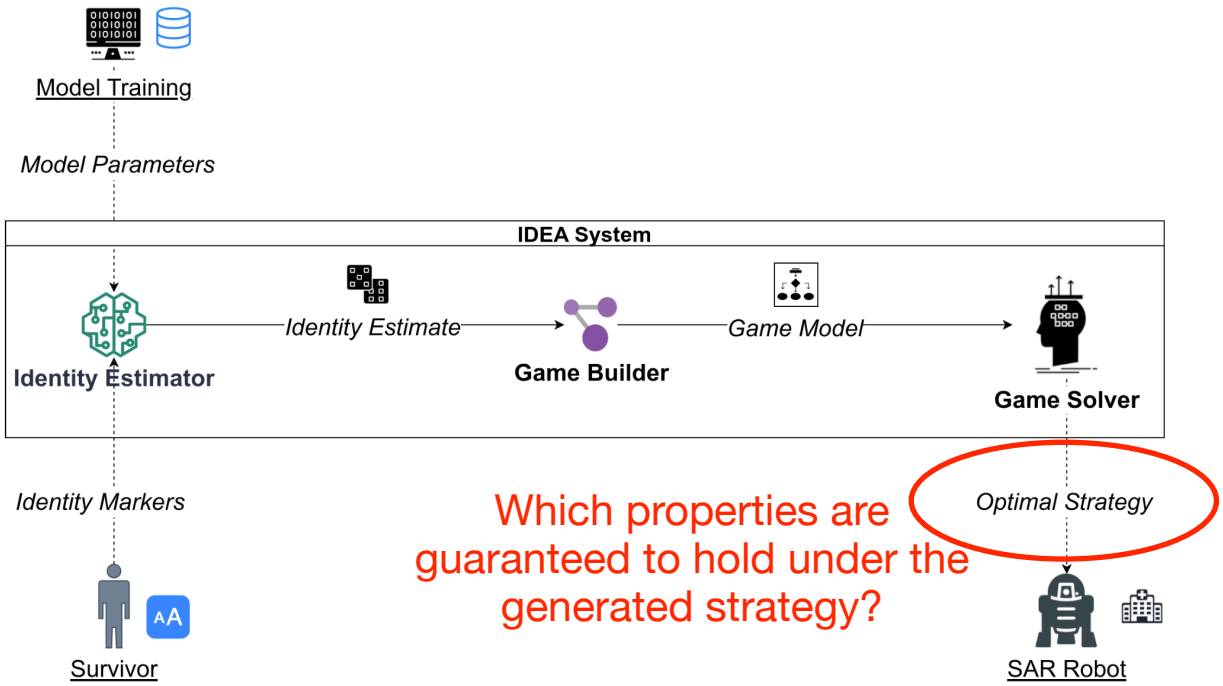

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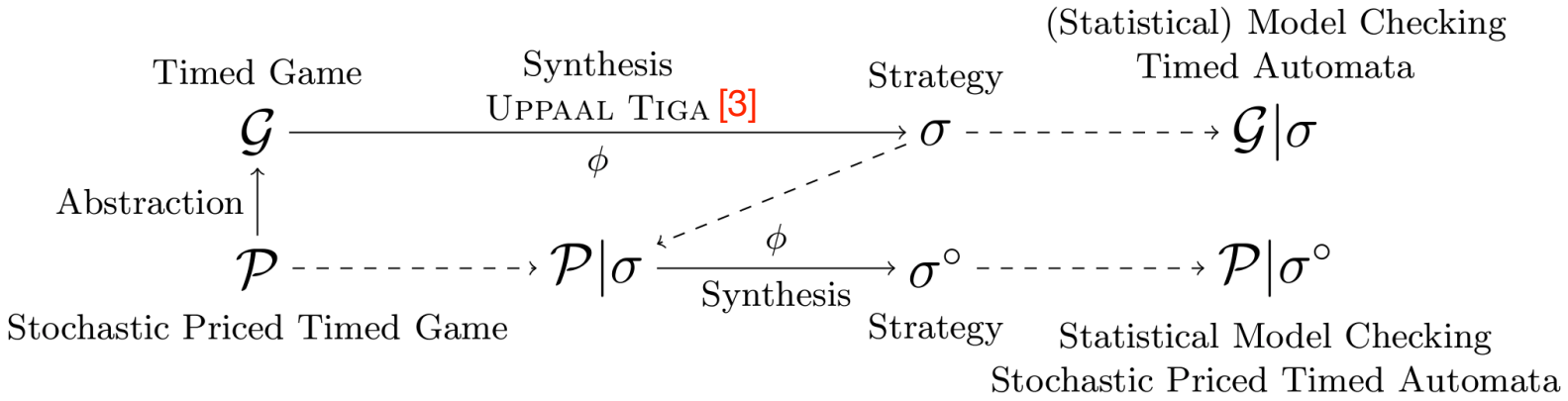
Uppaal Stratego [2]



[2] David, A., Jensen, P. G., Larsen, K. G., Mikučionis, M., & Taankvist, J. H. (2015). Uppaal stratego. In TACAS 2015, Proceedings 21 (pp. 206-211). Springer Berlin Heidelberg.

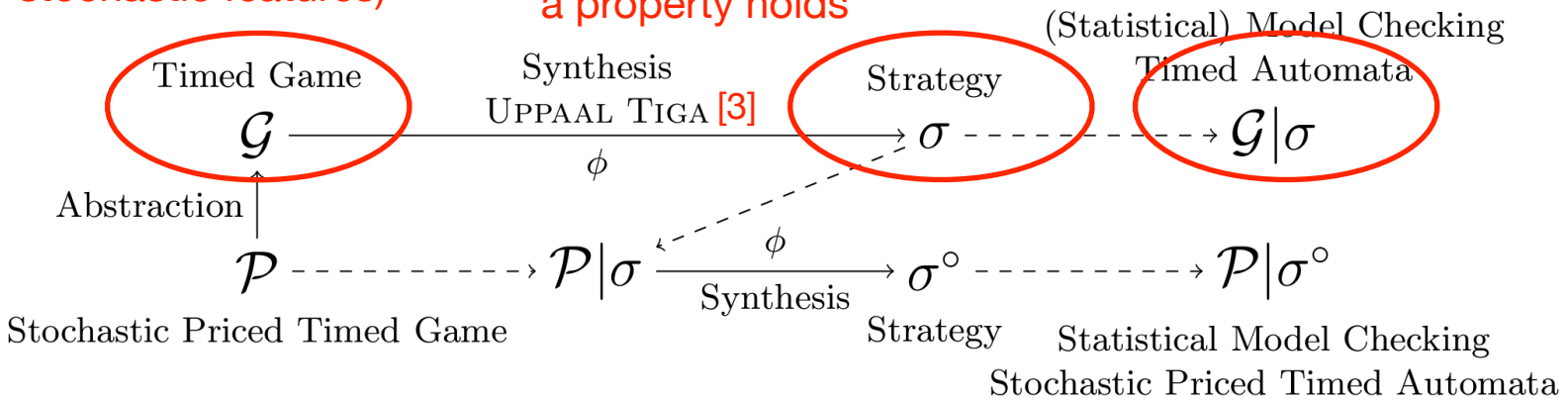
[3] Behrmann, G., Cougnard, A., David, A., Fleury, E., Larsen, K. G., & Lime, D. (2007). UPPAAL-Tiga: Time for Playing Games! (Tool Paper). In CAV 2007. Proceedings 19 (pp. 121-125). Springer Berlin Heidelberg.

Uppaal Stratego [2]

Timed Game Automata (TGA) Network (i.e., no stochastic features)

Strategy guaranteeing that a property holds

Model Checking under the generated (verified) strategy



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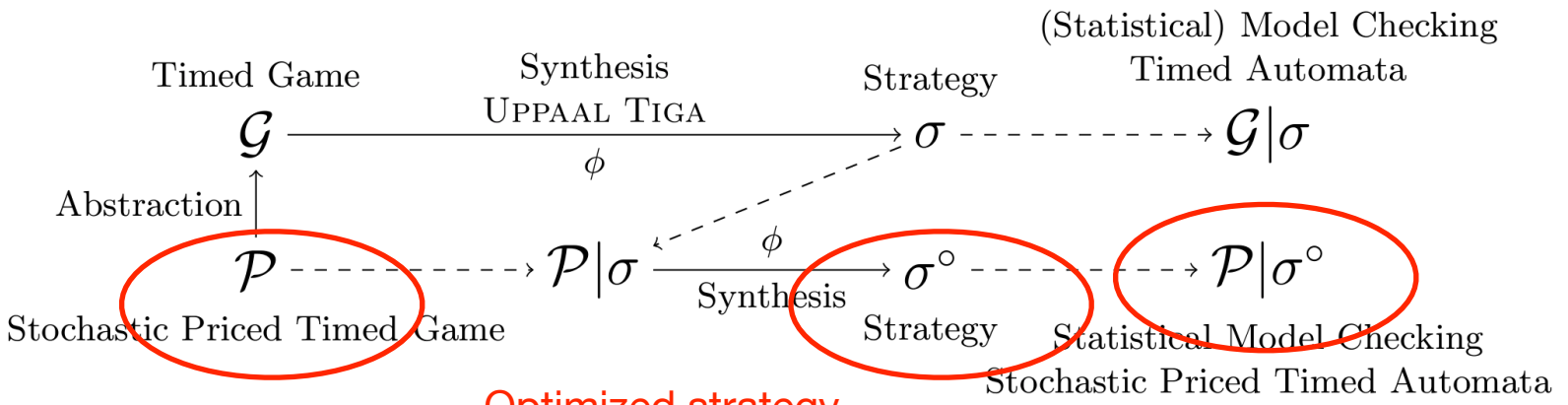
Uppaal Stratego [2]



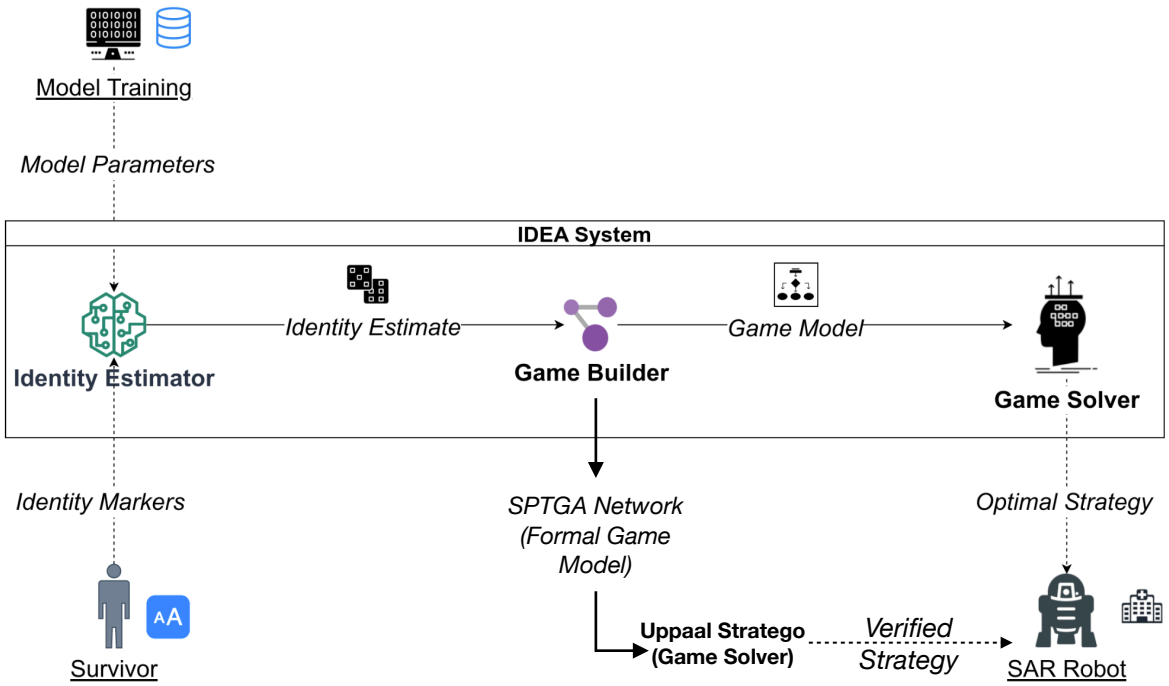
Stochastic Priced Timed Game Automata (SPTGA) Network (i.e., including the stochastic part)

Optimized strategy guaranteeing that a property holds AND maximizing (minimizing) a certain quantity

Statistical Model Checking under the optimized strategy

[2] David, A., Jensen, P. G., Larsen, K. G., Mikučionis, M., & Taankvist, J. H. (2015). Uppaal stratego. In TACAS 2015, Proceedings 21 (pp. 206-211). Springer Berlin Heidelberg.

The IDEA Framework [1] + Formal Verification



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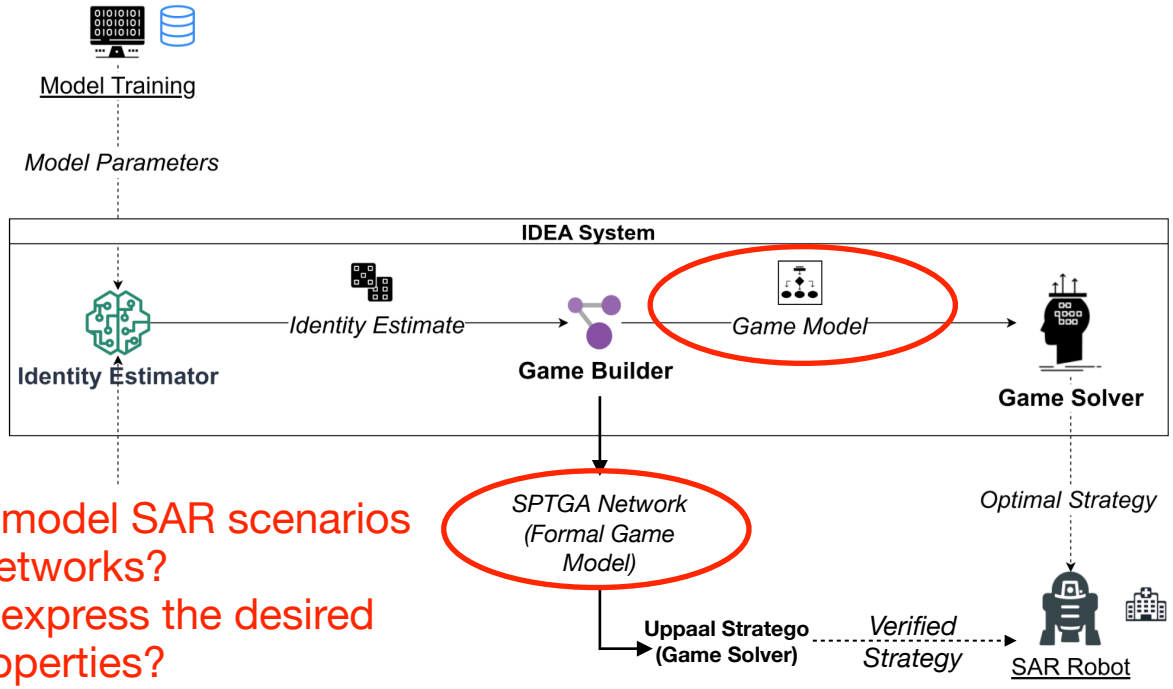

- How to model SAR scenarios as TGA networks?
- How to express the desired formal properties?
- Are the two models equivalent?

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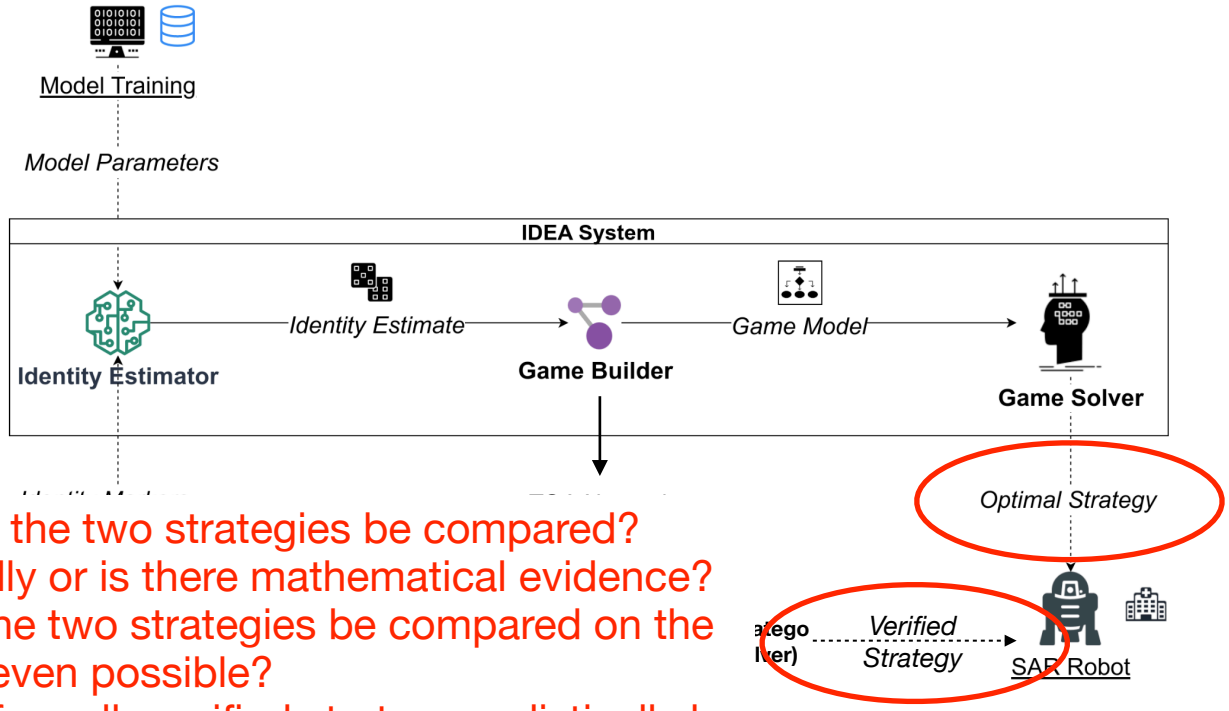

- How can the two strategies be compared? Empirically or is there mathematical evidence?
- Should the two strategies be compared on the fly? Is it even possible?
- Can the formally verified strategy realistically be computed at runtime?

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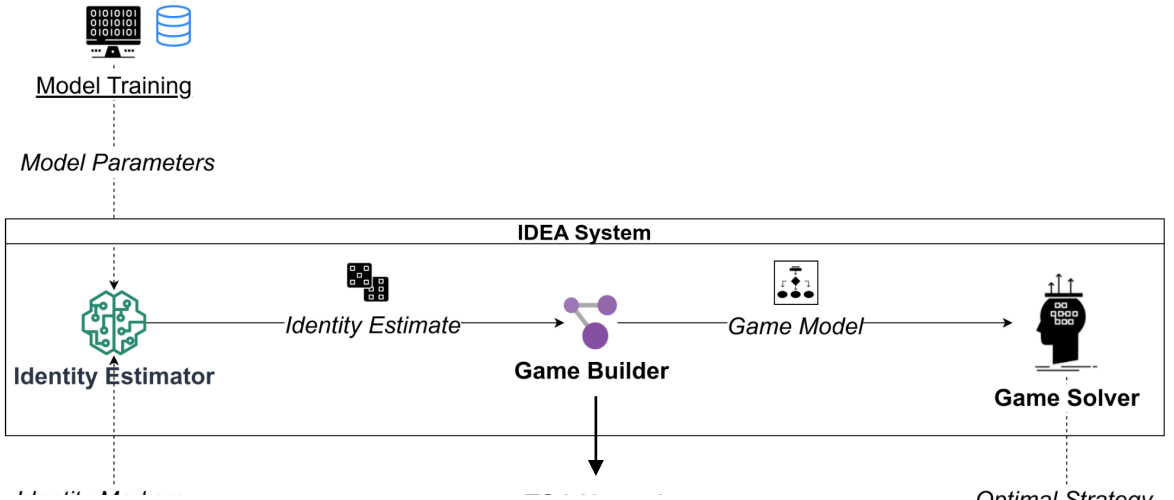

- Does the robot take into account both strategies?
- Do specific criteria exist to choose when one is preferable over the other? (E.g., the verified strategy overperforms the optimal one if >10 First-responders are in close proximity)

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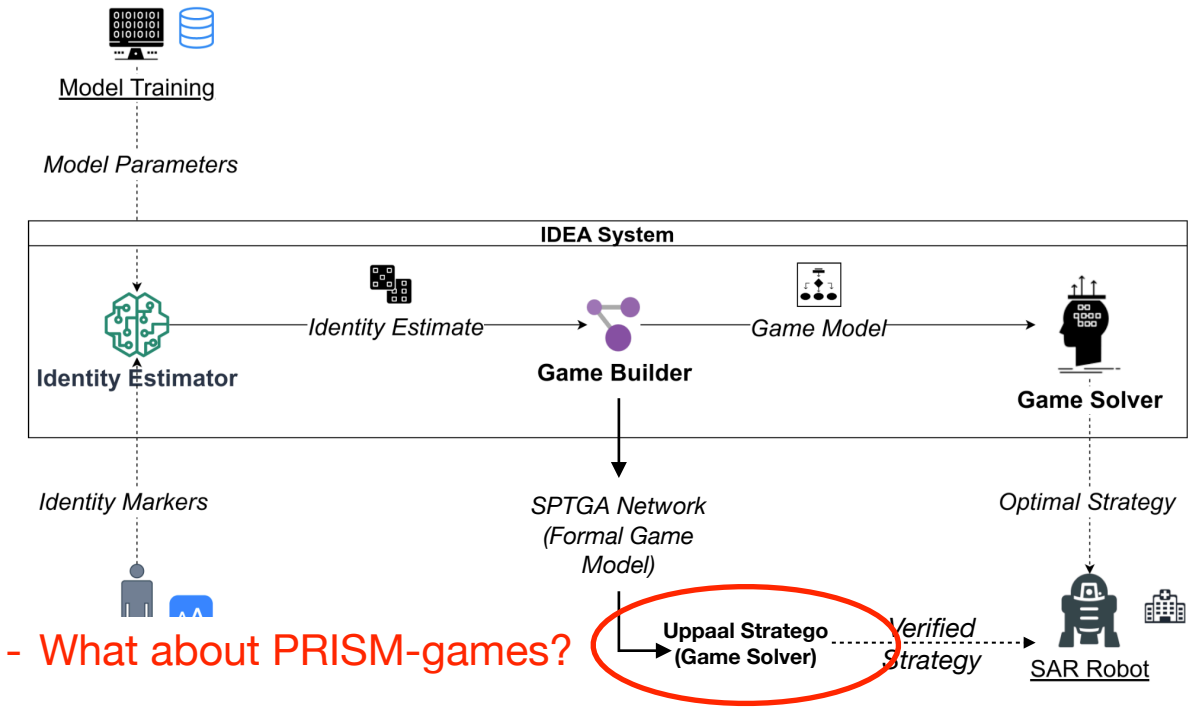

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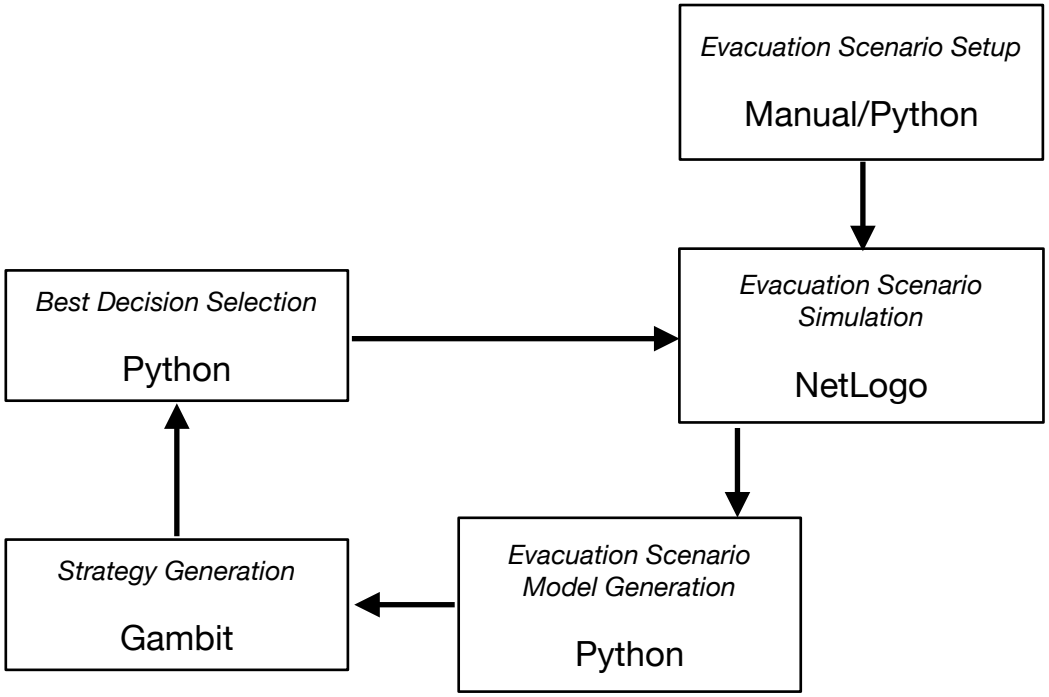
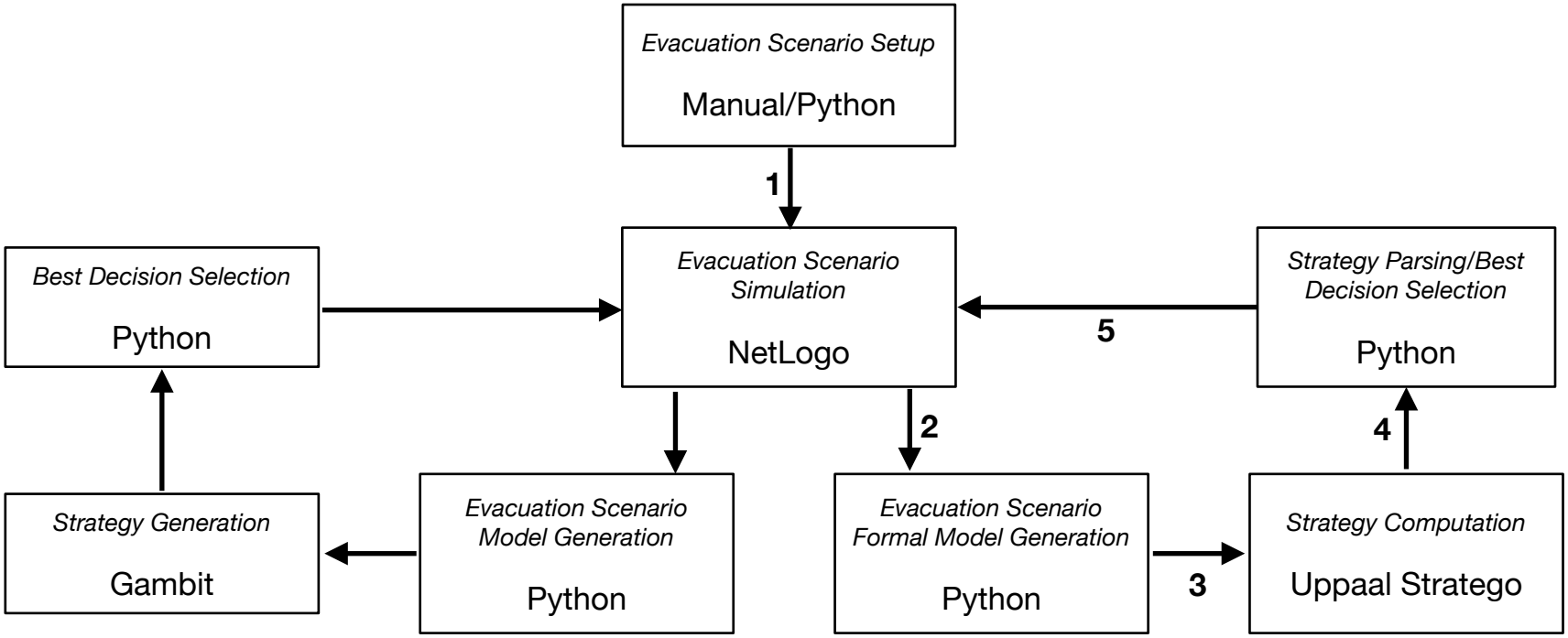
Livia Lestingi
DEIB, DeepSE Group
https://www.deepse.deib.polimi.it

The IDEA Framework



The IDEA Framework + Formal Verification: Option 1



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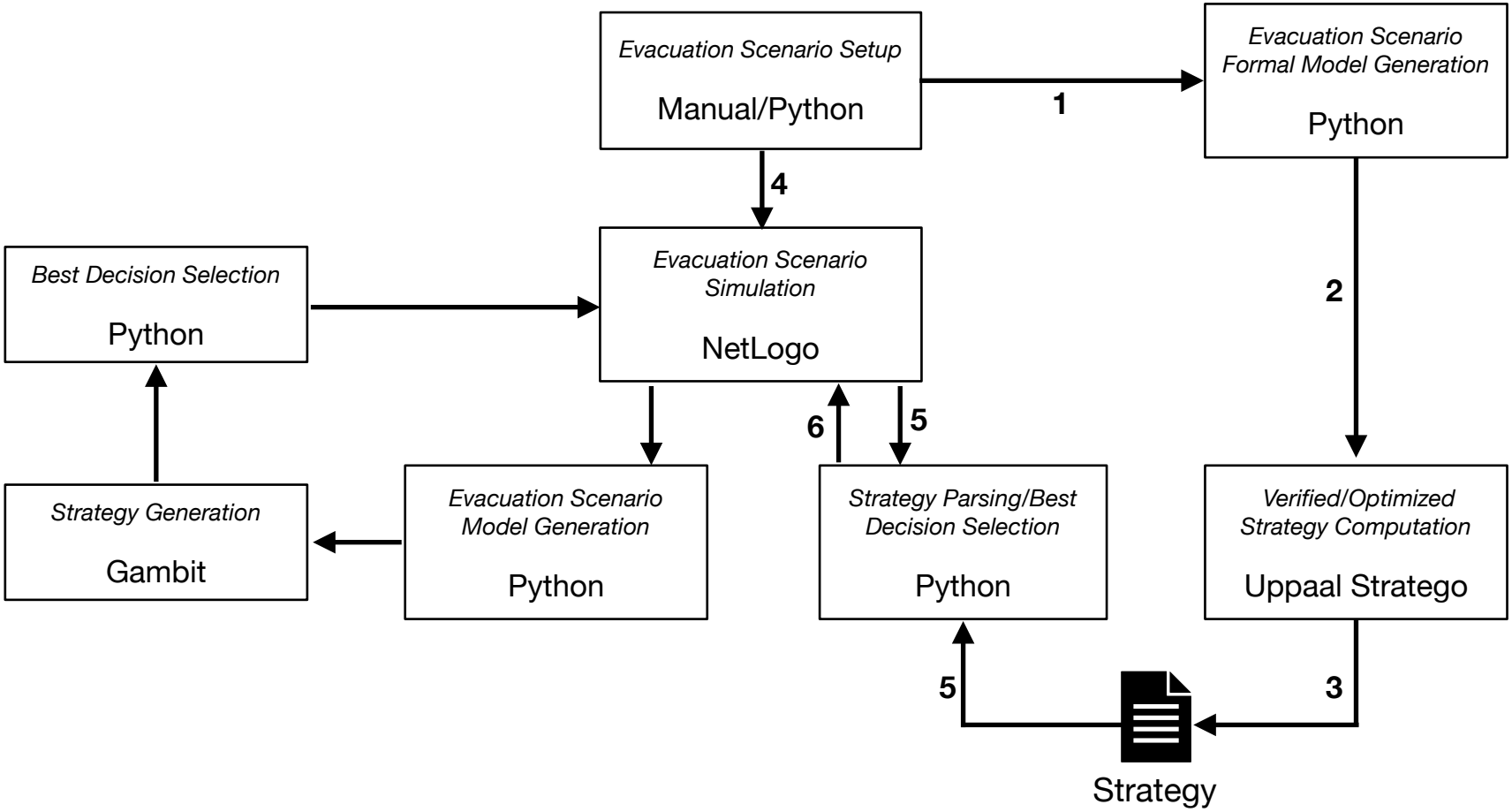
DEIB, DeepSE Group
https://www.deepse.deib.polimi.it

The IDEA Framework + Formal Verification: Option 2



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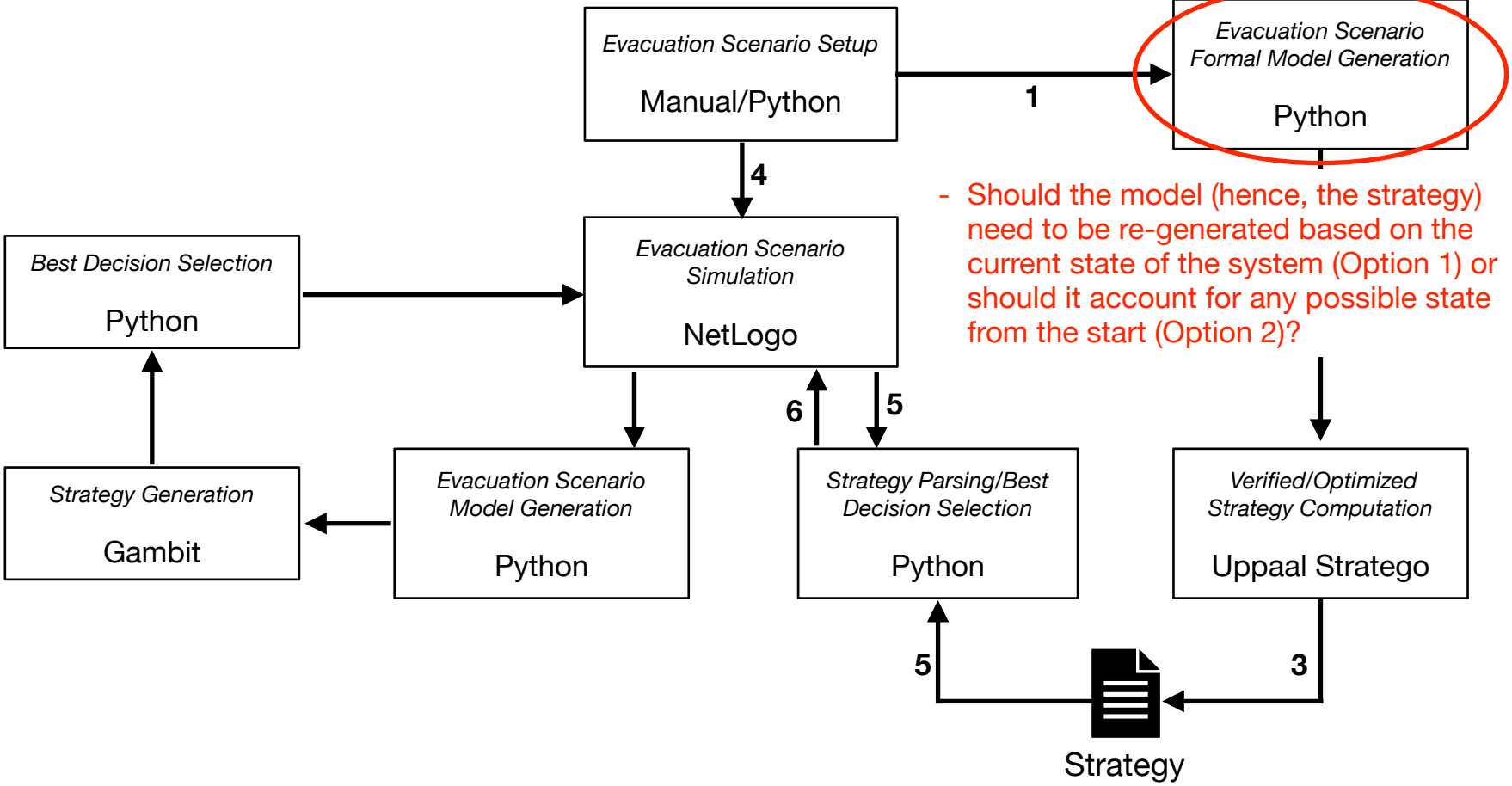
The IDEA Framework + Formal Verification: Option 2



- Should the model (hence, the strategy) need to be re-generated based on the current state of the system (Option 1) or should it account for any possible state from the start (Option 2)?

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DEIB, DeepSE Group
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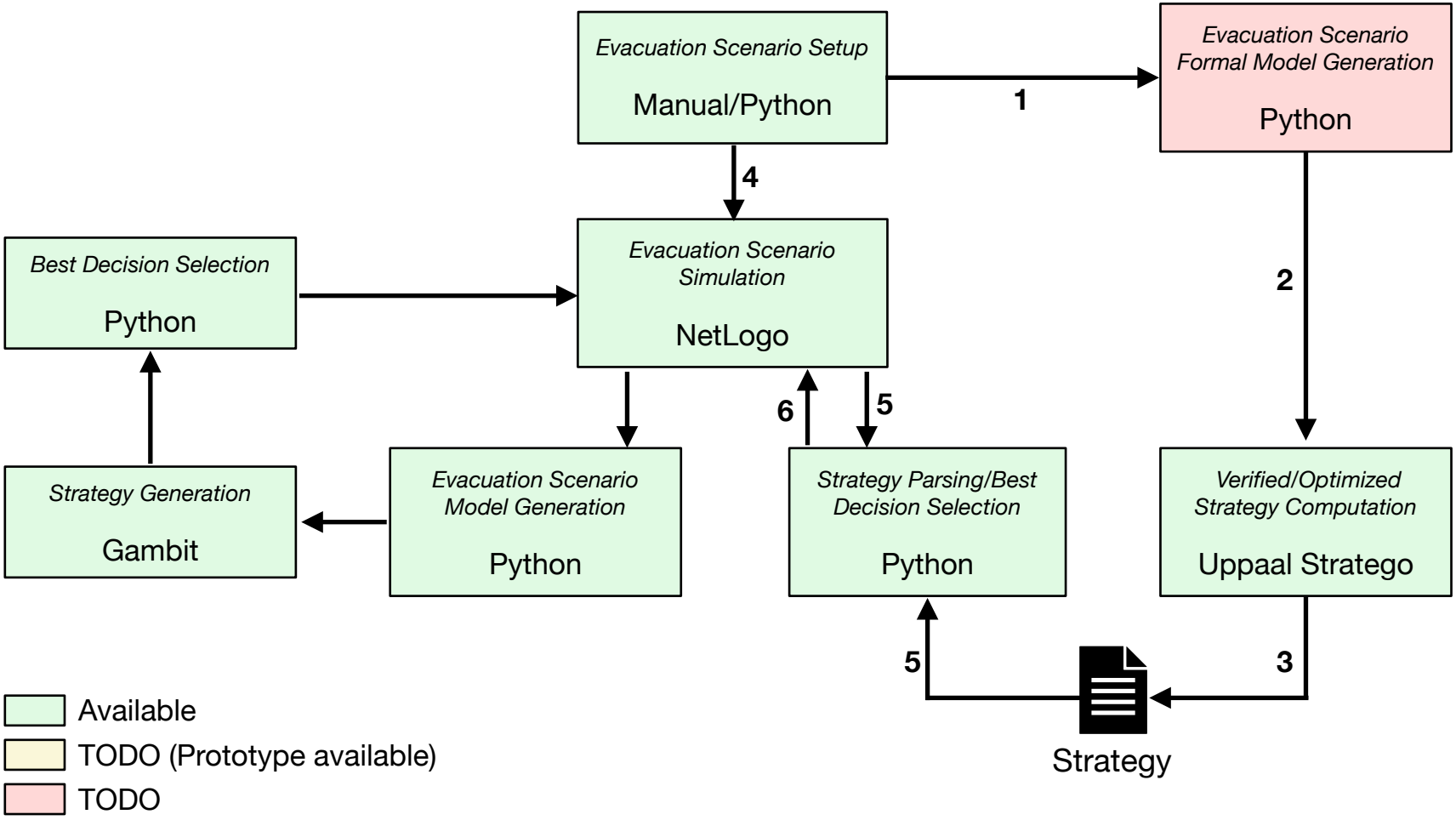
The IDEA Framework + Formal Verification: Current state w Option 2



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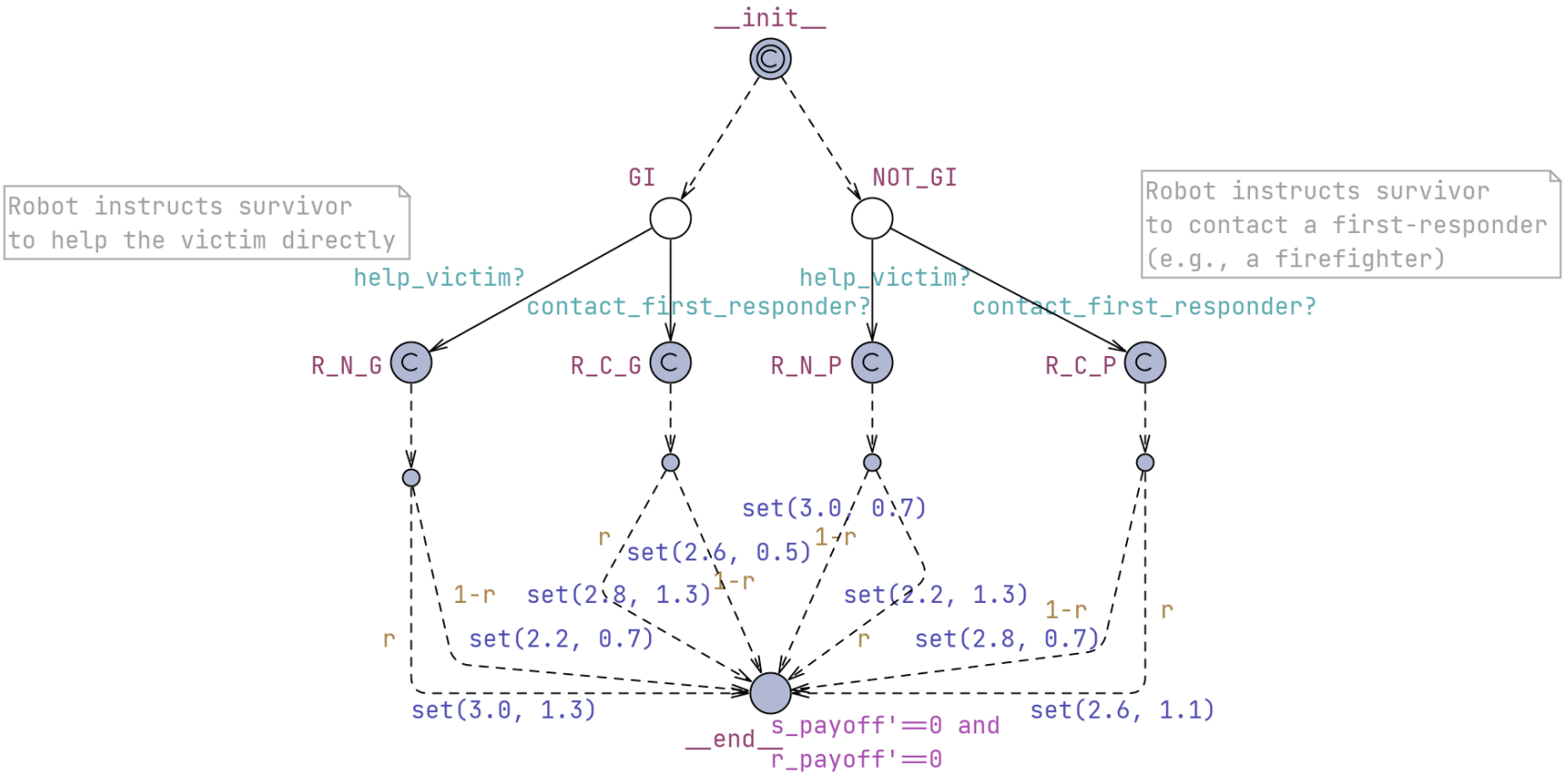
Formal Model



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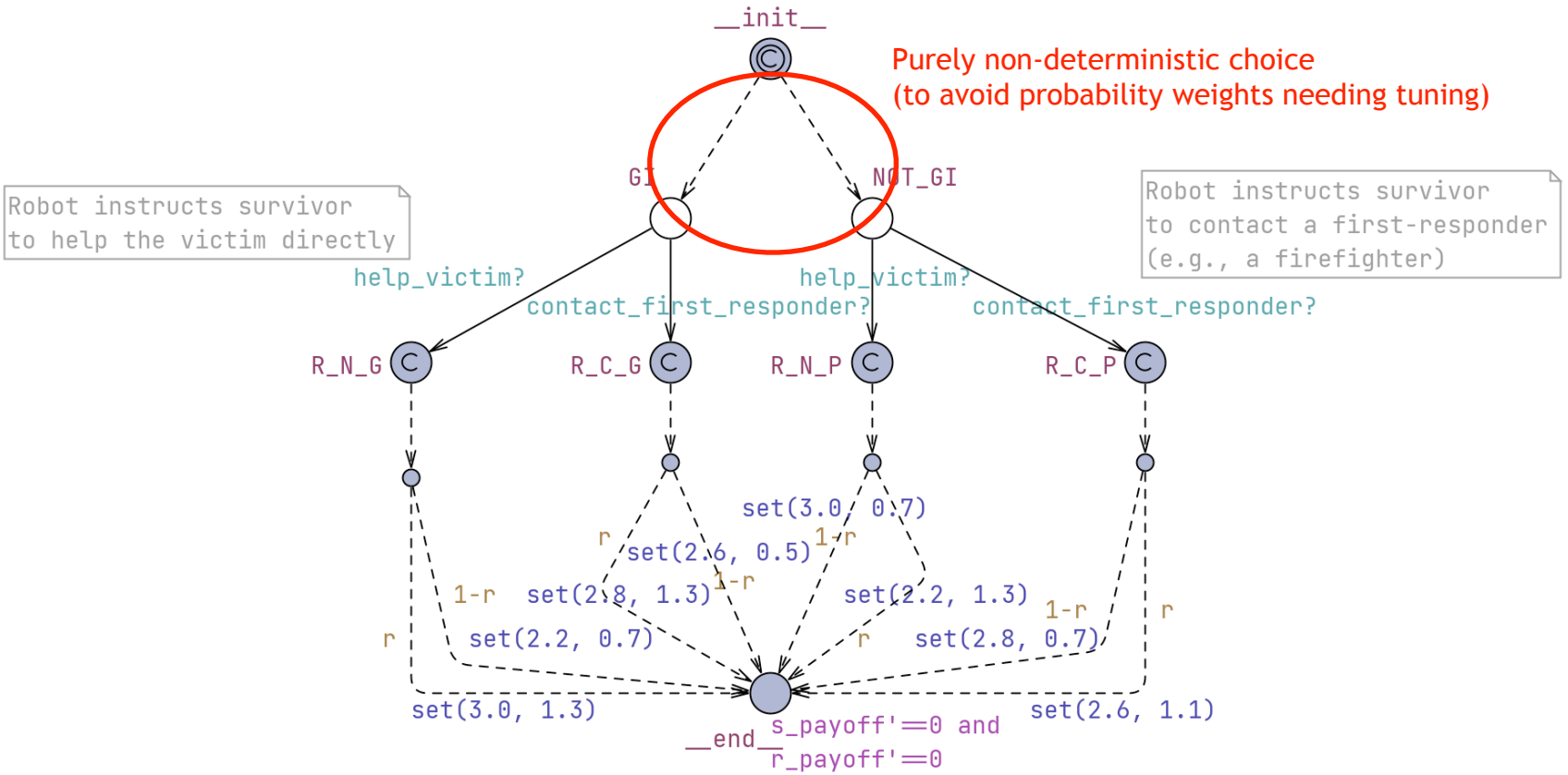

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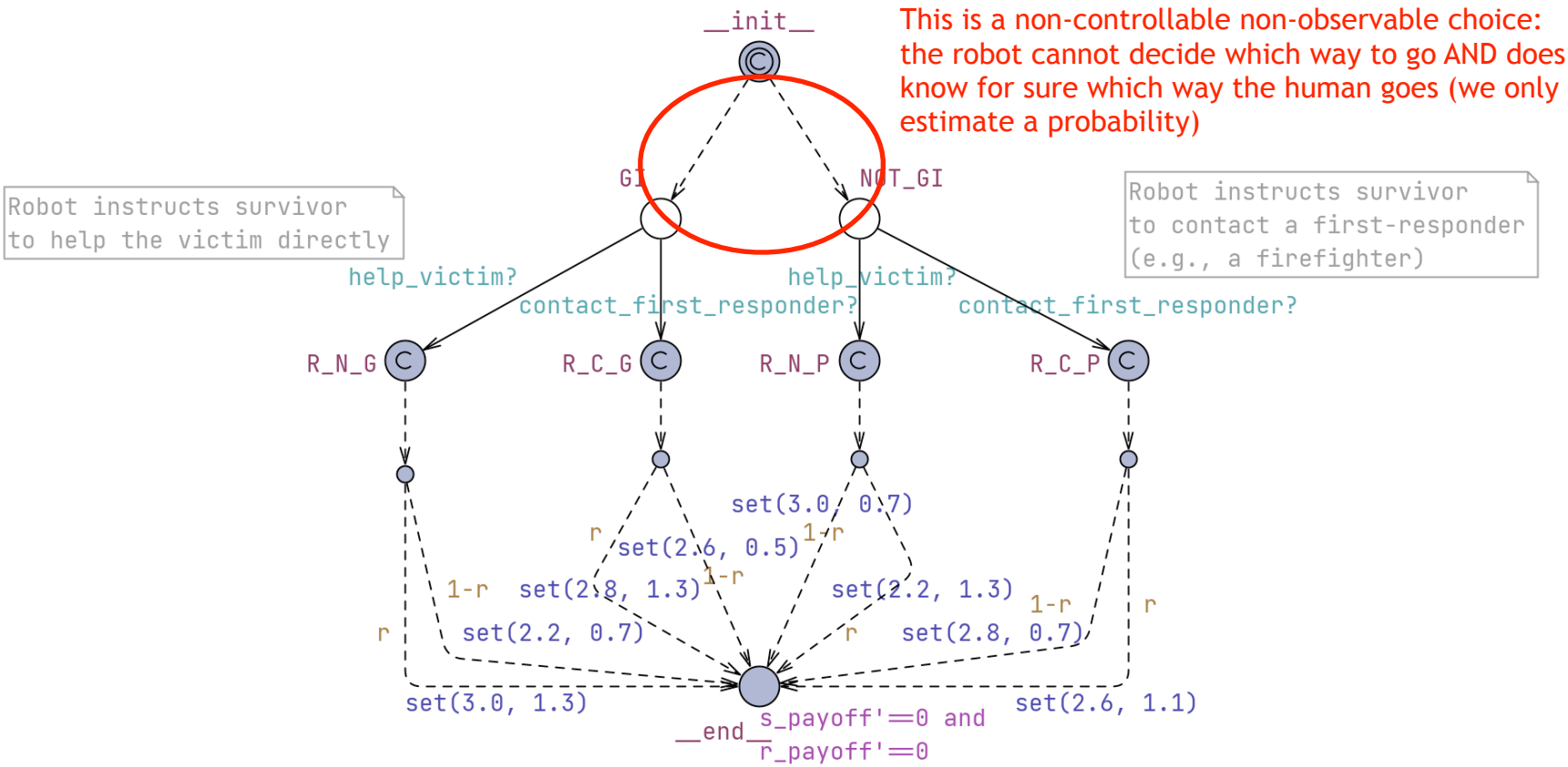

This is a non-controllable non-observable choice: the robot cannot decide which way to go AND does not know for sure which way the human goes (we only estimate a probability)

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DEIB, DeepSE Group
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Synthesized controller: Payoffs?

The robot has two possible choices: $A_s = \{\text{contact-staff}, \text{do-help}\}$

Uppaal Stratego synthesizes a controller for the robot indicating the expected payoff value when choice act $\in A_s$ is selected in GI or NOT_GI, indicated as $U(\text{GI}, \text{act})$ and $U(\text{NOT\_GI}, \text{act})$, respectively.

Uppaal optimizes the system's payoff value assuming a certain degree of rationality on the human's side, i.e., parameter r.

For example:
If r = 1.0 (the human is perfectly rational), they developed a shared identity (GI), and the robot instructs them to help, they will help with probability 1 since 1.3 > 0.7.

Synthesized controller: Payoffs?

!! At runtime (when applying the controller), the robot does not know whether the human is in location GI or NOT_GI !!

A NN estimates $P(\text{GI}), P(\text{NOT\_GI}) = 1 - P(\text{GI})$ given the following inputs: helper's gender, age, and culture, and fallen person's gender, age, and culture.

Formal Model: How to deal with uncontrollable actions affected by uncertainty?

Re-calibrate the expected payoff value to account for the probability to reach the corresponding state (where act is either call-staff or do-help):

$$u_S(\text{GI}, \text{act}) = U(\text{GI}, \text{act}) \times P(\text{GI})$$

$$u_S(\text{NOT\_GI}, \text{act}) = U(\text{NOT\_GI}, \text{act}) \times (1 - P(\text{GI}))$$

Extracted from Uppaal strategy

Estimated (at runtime) by NN

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$$u_S(\mathsf{NOT\_GI}, \mathsf{act}) = U(\mathsf{NOT\_GI}, \mathsf{act}) \times (1 - P(\mathsf{GI}))$$

	contact-staff	do-help
GI	2.8	3.0
NOT_GI	2.6	2.2

Formal Model: How to deal with uncontrollable actions affected by uncertainty?

Re-calibrate the expected payoff value to account for the probability to reach the corresponding state (where act is either call-staff or do-help):

$$u_S(\mathsf{GI}, \mathsf{act}) = U(\mathsf{GI}, \mathsf{act}) \times P(\mathsf{GI})$$

$$u_S(\mathsf{NOT\_GI}, \mathsf{act}) = U(\mathsf{NOT\_GI}, \mathsf{act}) \times (1 - P(\mathsf{GI}))$$

P(GI) = 0.8	contact-staff	do-help
GI	2.8*0.8=2.24	3.0*0.8=2.4
NOT_GI	2.6*0.2=0.52	2.2*0.2=0.44

Formal Model: How to deal with uncontrollable actions affected by uncertainty?

Re-calibrate the expected payoff value to account for the probability to reach the corresponding state (where act is either call-staff or do-help):

$$u_S(\text{GI}, \text{act}) = U(\text{GI}, \text{act}) \times P(\text{GI})$$

$$u_S(\text{NOT\_GI}, \text{act}) = U(\text{NOT\_GI}, \text{act}) \times (1 - P(\text{GI}))$$

P(GI) = 0.8	contact-staff	do-help
GI	2.8*0.8=2.24	3.0*0.8=2.4
NOT_GI	2.6*0.2=0.52	2.2*0.2=0.44

2.76 < 2.84

(do-help is preferable)

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Formal Model: How to deal with uncontrollable actions affected by uncertainty?

Re-calibrate the expected payoff value to account for the probability to reach the corresponding state (where act is either call-staff or do-help):

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$$u_S(\mathsf{NOT\_GI}, \mathsf{act}) = U(\mathsf{NOT\_GI}, \mathsf{act}) \times (1 - P(\mathsf{GI}))$$

P(GI) = 0.12	contact-staff	do-help
GI	2.8*0.12=0.33	3.0*0.12=0.36
NOT_GI	2.6*0.88=2.28	2.2*0.88=1.93

Formal Model: How to deal with uncontrollable actions affected by uncertainty?

Re-calibrate the expected payoff value to account for the probability to reach the corresponding state (where act is either call-staff or do-help):

$$u_S(\text{GI}, \text{act}) = U(\text{GI}, \text{act}) \times P(\text{GI})$$

$$u_S(\text{NOT\_GI}, \text{act}) = U(\text{NOT\_GI}, \text{act}) \times (1 - P(\text{GI}))$$

P(GI) = 0.12	contact-staff	do-help
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NOT_GI	2.6*0.88=2.28	2.2*0.88=1.93

2.61 > 2.29

(contact-staff is preferable)

Experimental Results

Experimental results?