Towards Creating a New Cybersecurity Game Theory: Gaps and Potential Bridges

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Why Game Theory For Cybersecurity?

Problem: Cybersecurity is often done *ad hoc* (i.e., Art) and needs more disciplined solutions (i.e., Science)!

Game Theory is a field of mathematics studying rigorous models of interacting decision makers.

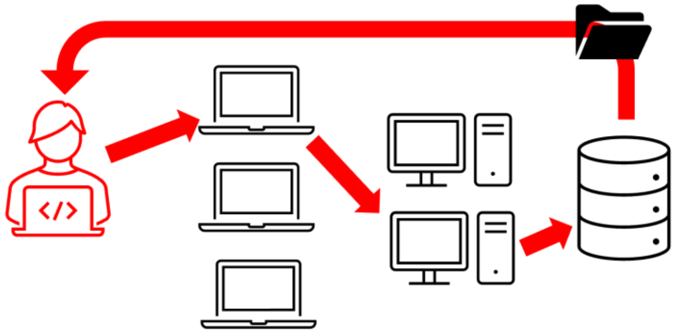
Consider an example:

Attack Successful
Attack Defended
Monitor Nothing
Nothing Happens

😈

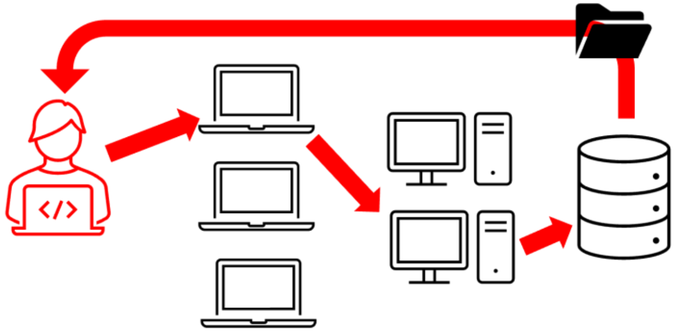
🧠	Attack	Wait
Monitor	**-1,-1**	**-1,0**
Wait	-5,5	0,0

Applications



Advanced Persistent Threats

Applications



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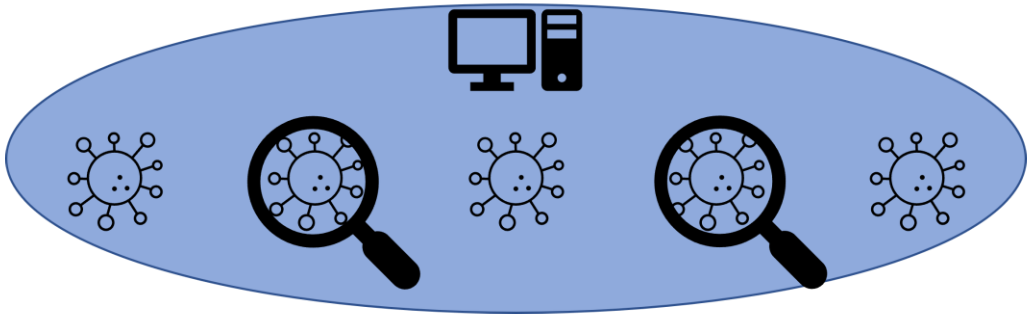
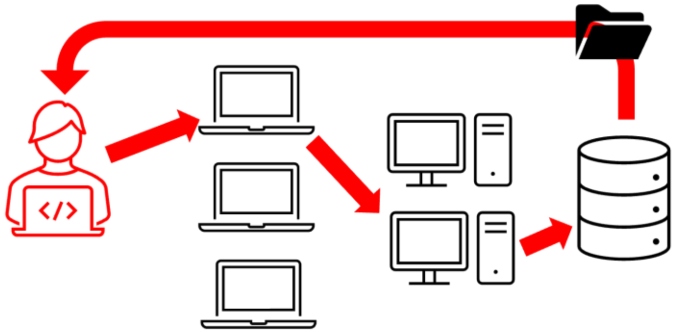


Moving Target Defense

Applications



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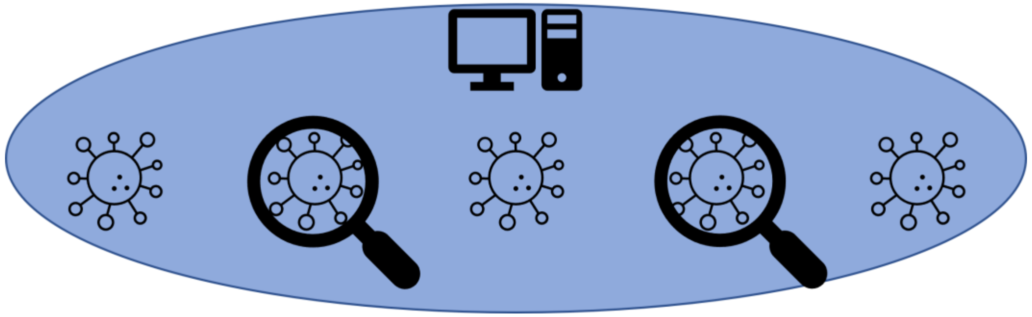

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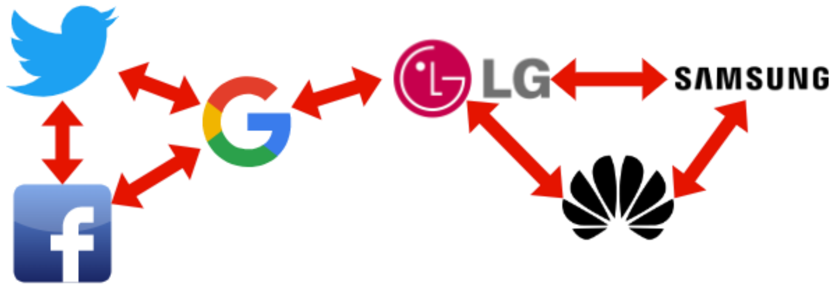
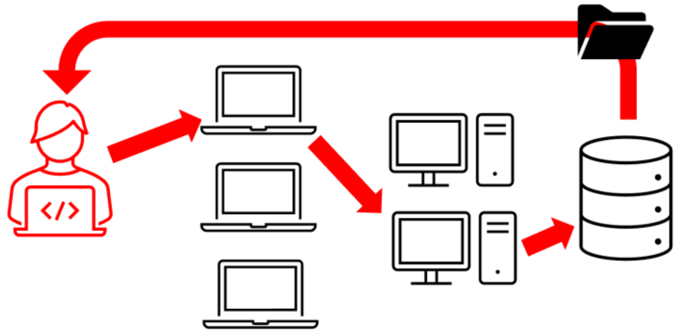


Cyber Threat Intelligence Sharing

Applications



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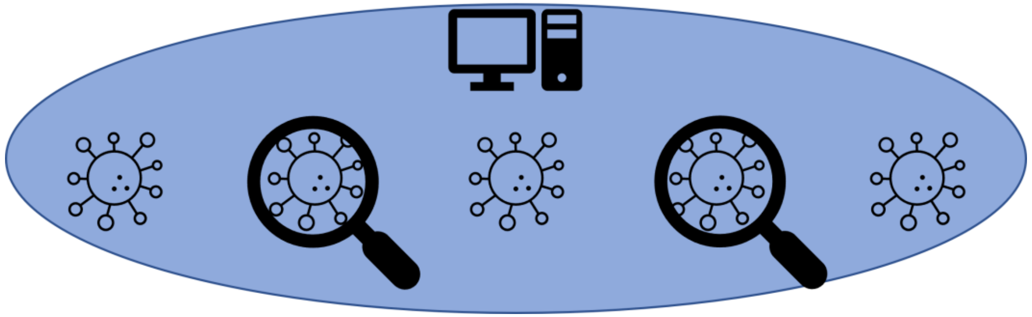

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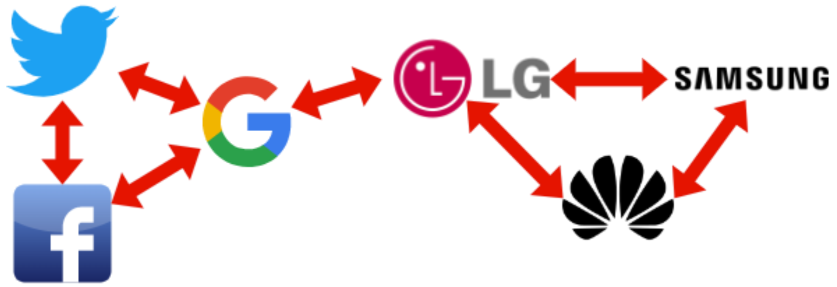

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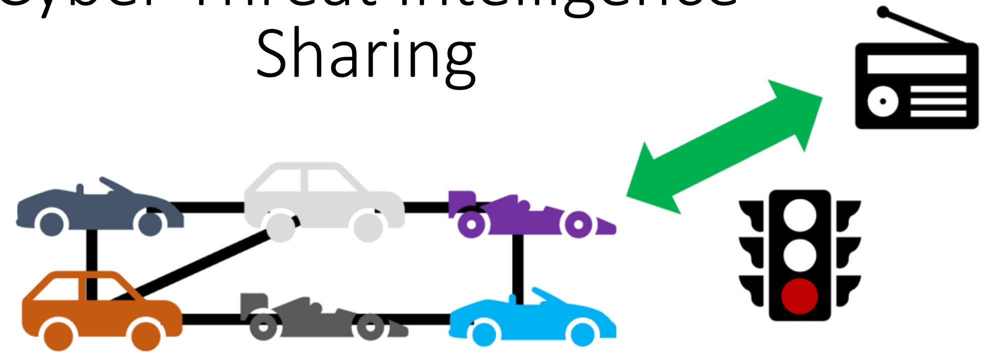
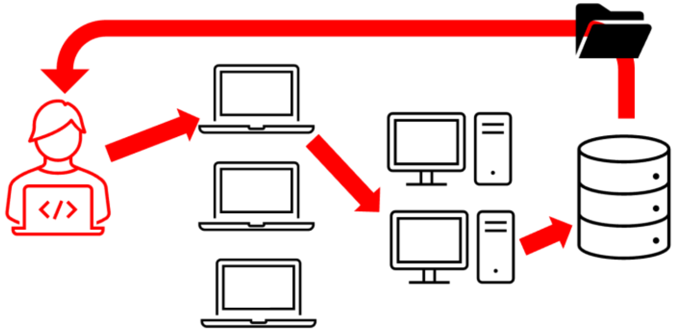


Ad Hoc Networks

Applications



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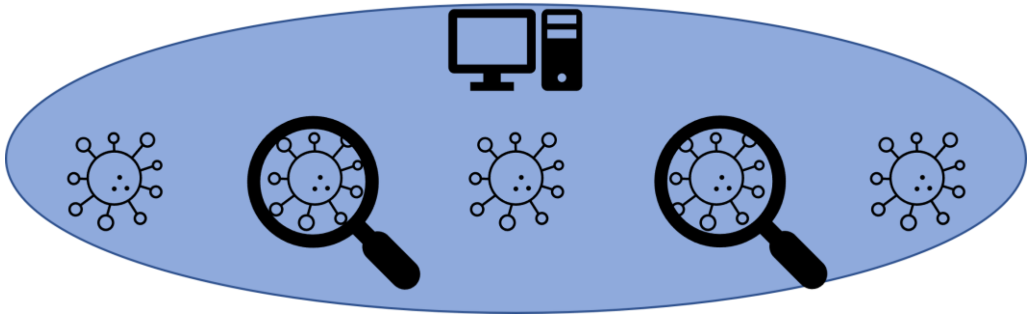

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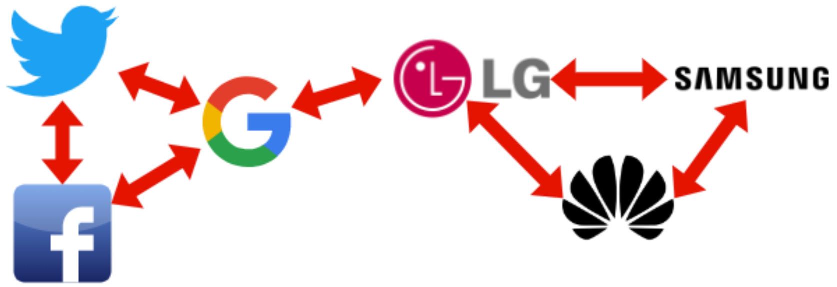

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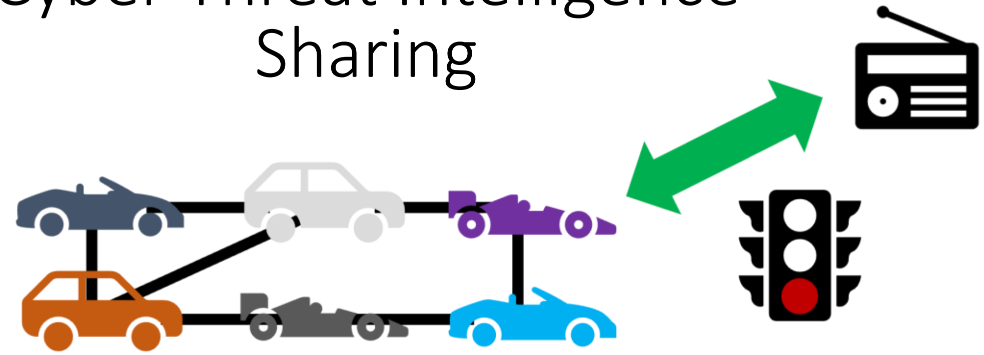

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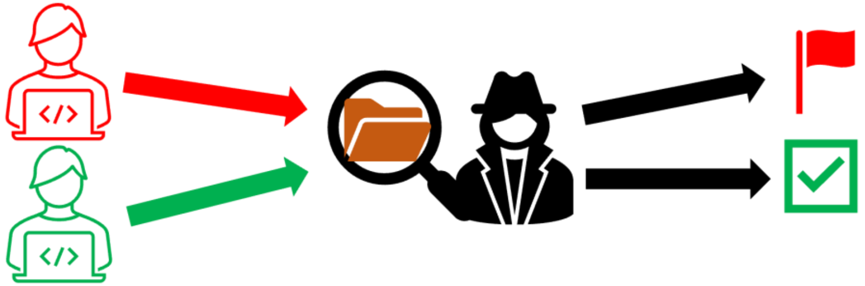
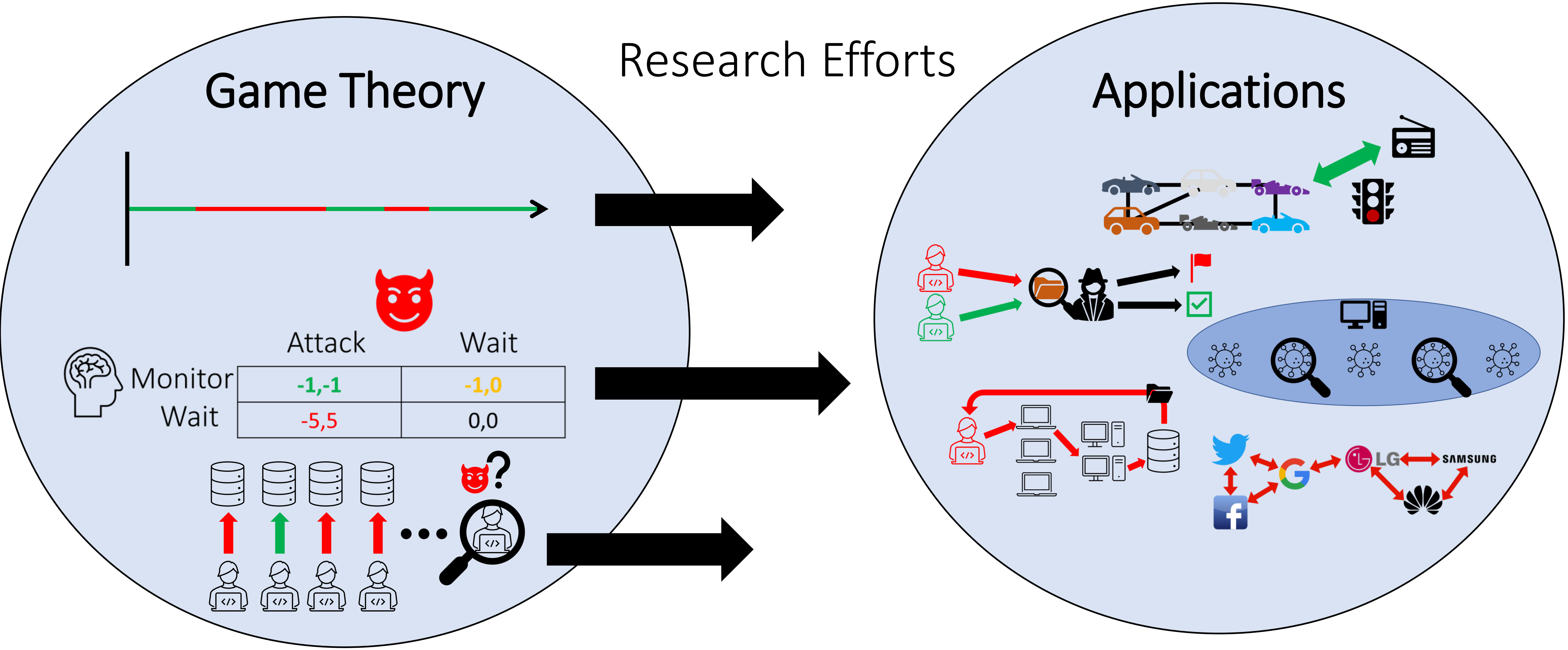


Intrusion Detection System Optimization

Our Research



Game Theory

Research Efforts

Applications

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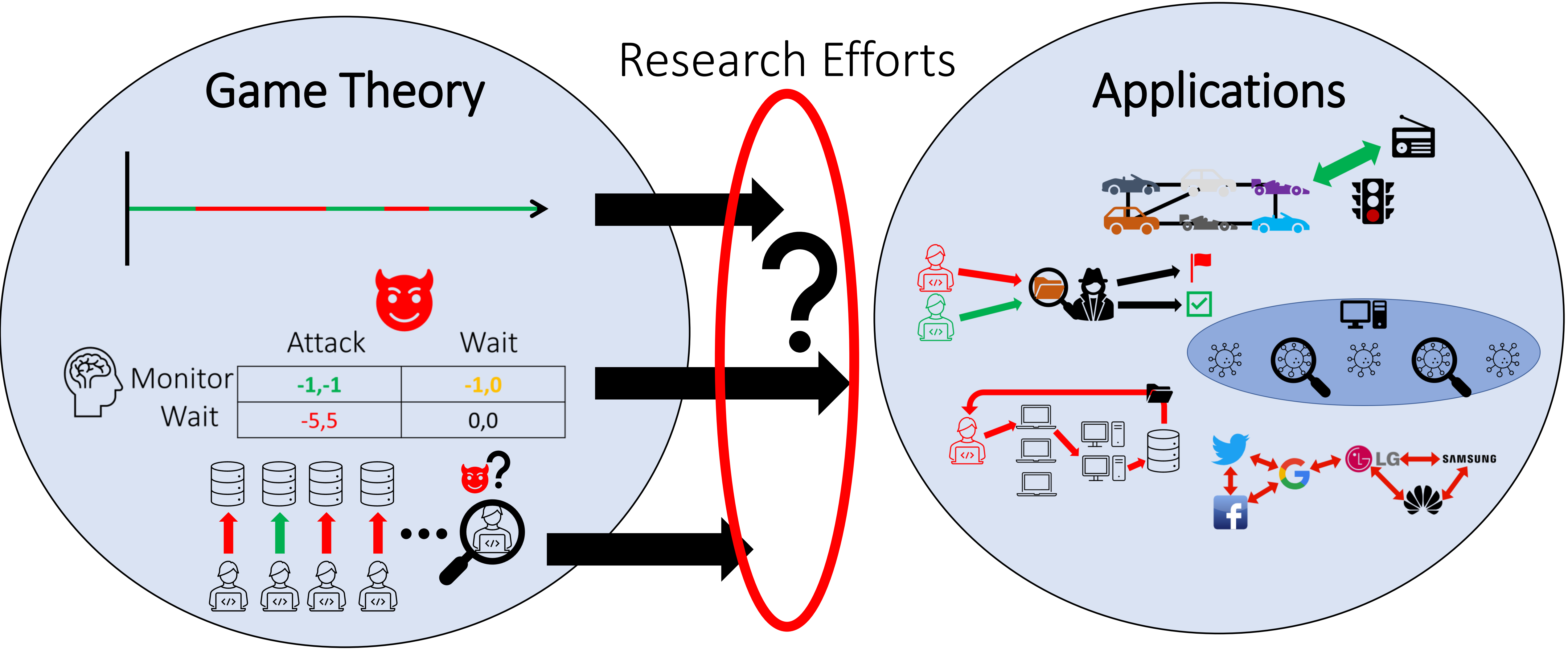
Our Research



Research Efforts

Game Theory

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Q:What is the current state of research?

Models: The Nash Equilibrium

	Attack	Wait
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Wait	-5,5	0,0

Assumption: Both agents react to each other over time

A **Nash Equilibrium** is a joint selection of actions such that no agent can unilaterally improve their utility

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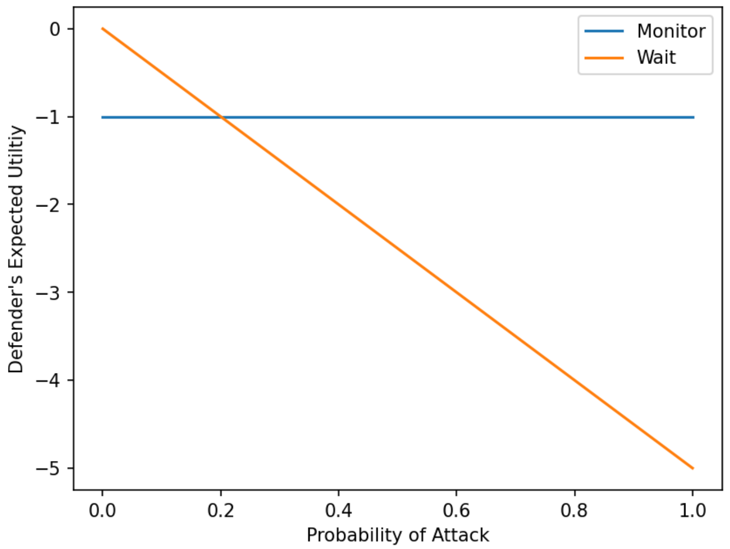

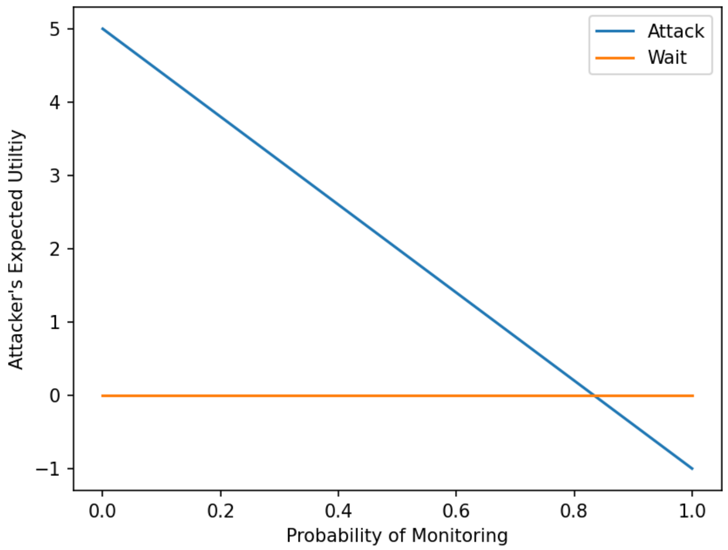

Applications

- Advanced Persistent Threats
- Moving Target Defense
- Intrusion detection systems
- Cyberthreat Intelligence Sharing

Attacker strikes with probability 0.2! Defender monitors with probability 0.83!

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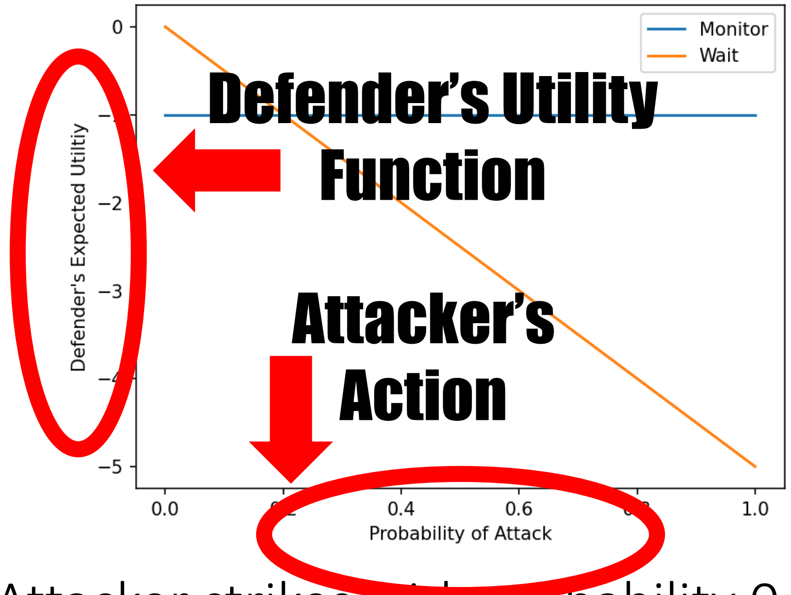
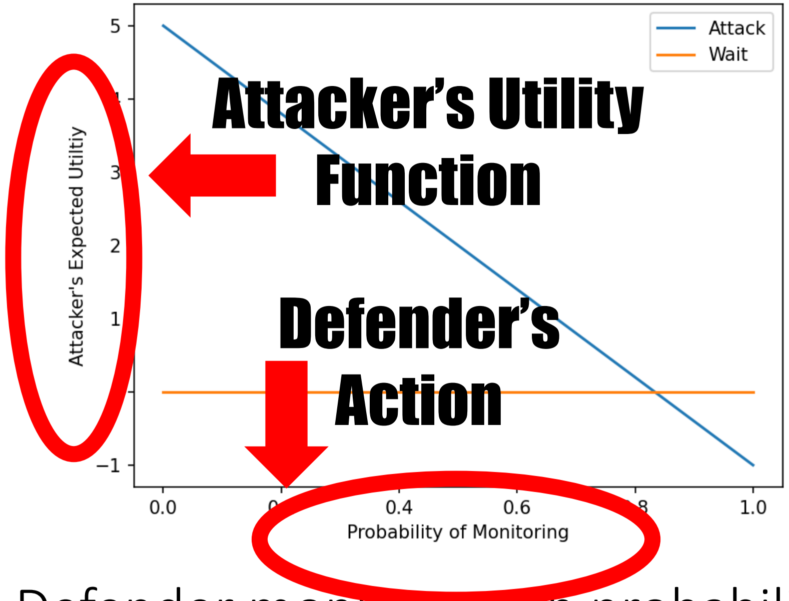


Defender's Utility Function

Attacker's Action



Attacker's Utility Function

Defender's Action

Agents use other agent's perspective to calculate their own action!

Attacker strikes with probability 0.2! Defender monitors with probability 0.83!

Models: The Stackelberg Equilibrium

	Attack	Wait
Monitor	-1,-1	-1,0
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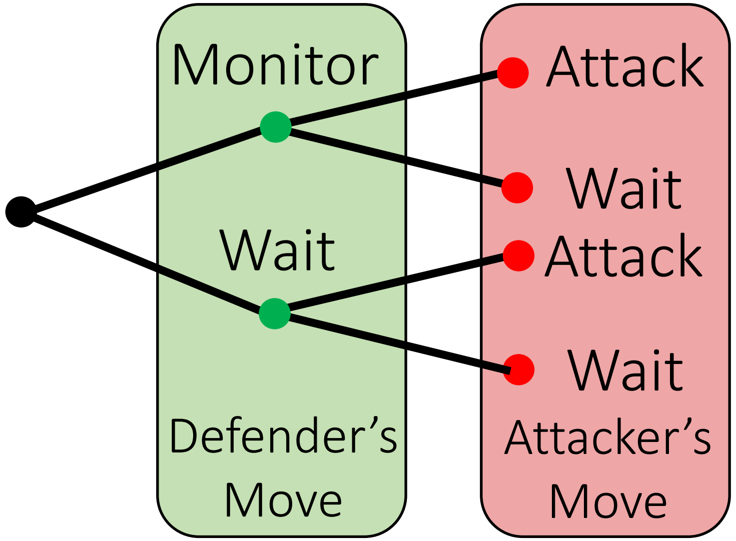
Assumption: Defender acts first

A **Stackelberg Equilibrium** is a joint selection of actions by a leader and a follower such that no agent can unilaterally improve their utility



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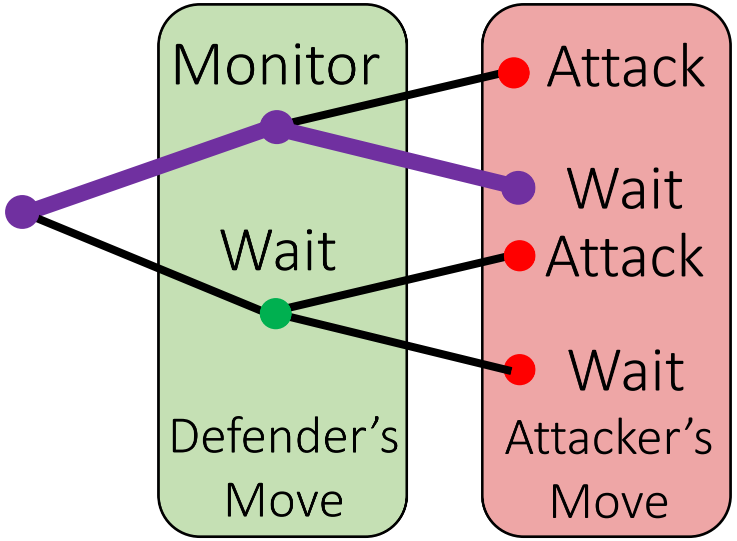
Modeling choices impact outcomes!



Applications

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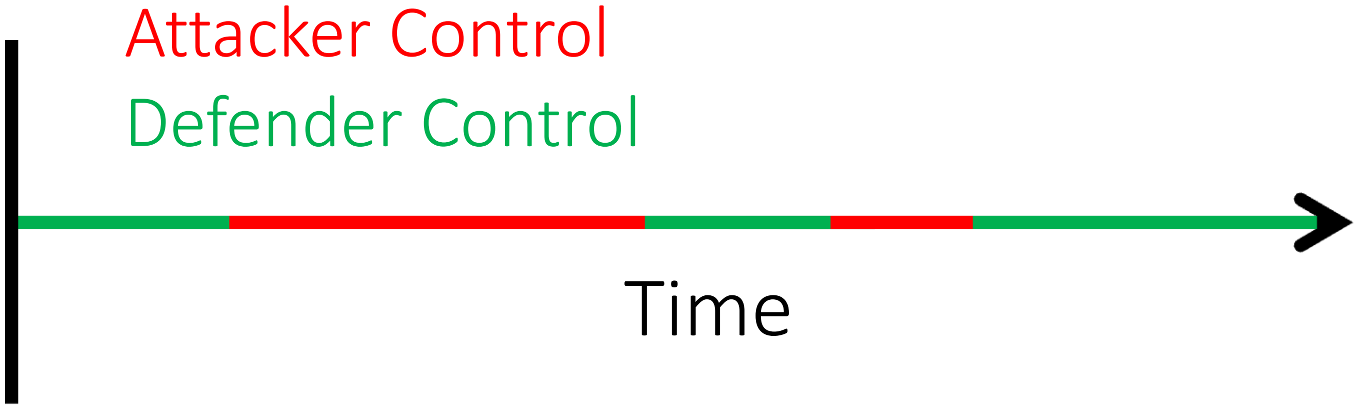
Defender will always monitor, attacker will never attack!

Models: FlipIt

- Attacker and defender fight for control of a system
- At any time either party may seize control
- Neither know who is currently in control



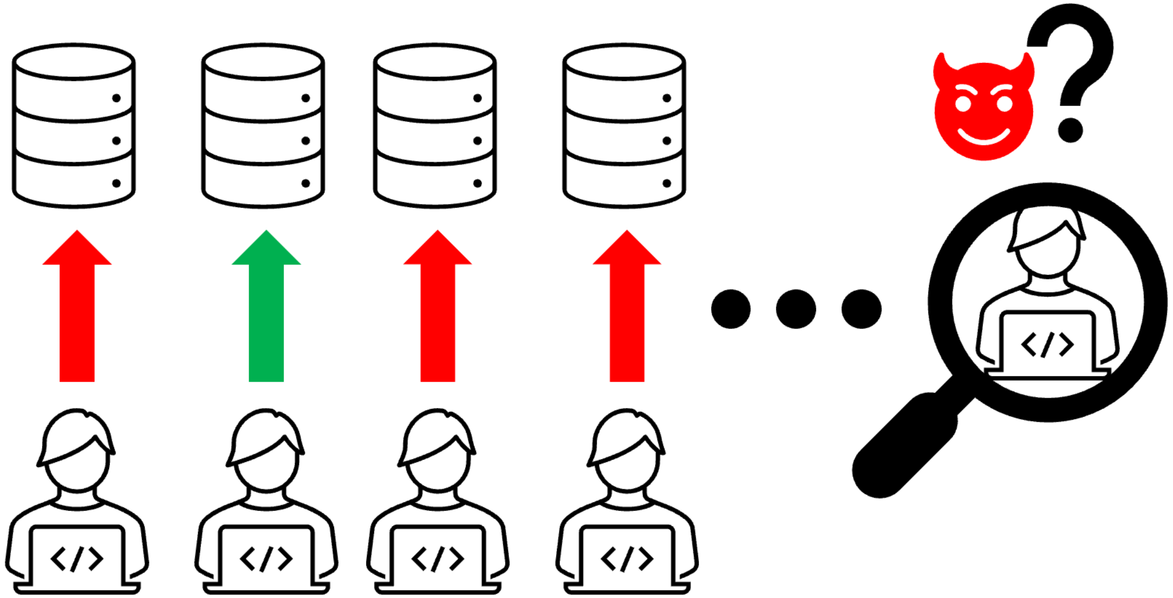
Applications

- Advanced Persistent Threats
- Zero Day Exploits

Q: When should both parties act?

Models: The Bayesian Game

- Agents are unsure of each others' identity
- Each agent maintains a probabilistic belief about other's identities



Applications

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Q: What is the best course of action given dynamic belief updates?

Our Framework

- Models assumptions often implicit
- What information agents have to base decisions on is critical

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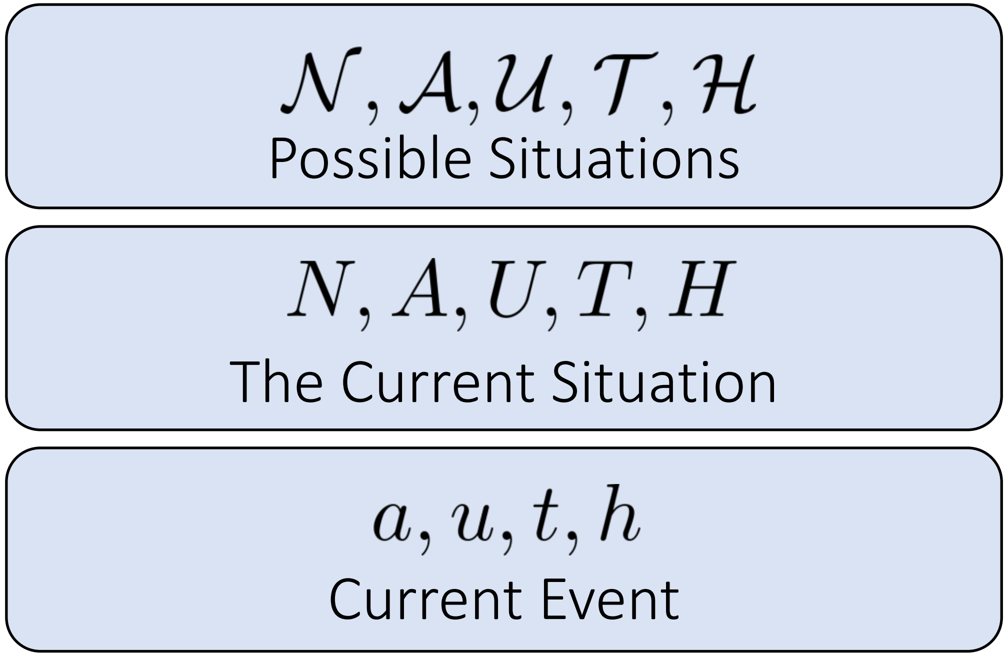
Our three-level framework



$\mathcal{N}, \mathcal{A}, \mathcal{U}, \mathcal{T}, \mathcal{H}$

Possible Situations

N, A, U, T, H

The Current Situation

a, u, t, h

Current Event

"What capabilities could they have" $\mathcal{A}$

"How many attackers could there be" $\mathcal{N}$

"What capabilities do they have" A

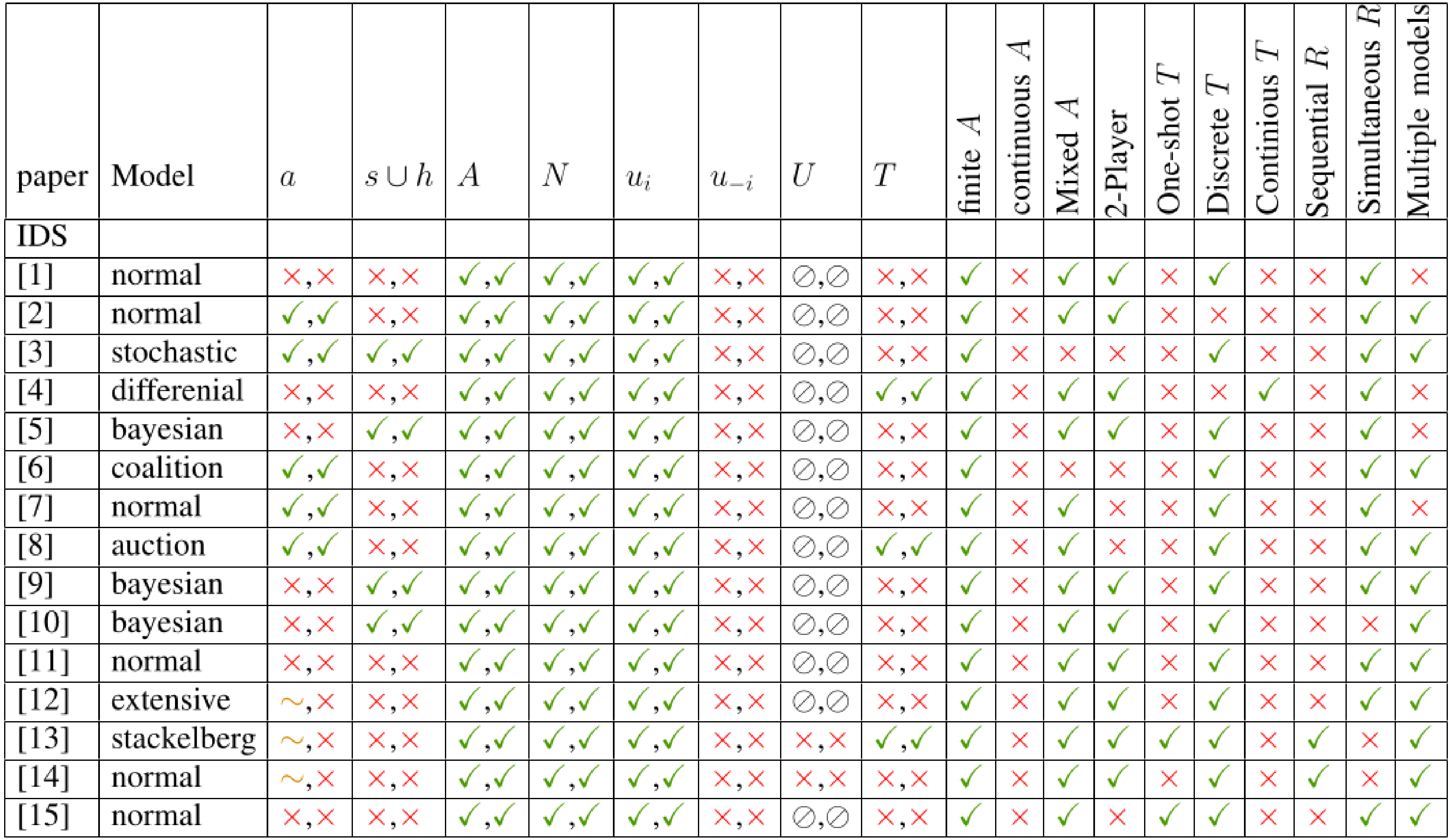
"How many attackers are there" N

"What are they doing right now" a

Key:

N	A	U	T	H
agents	actions	utility	time	history

Findings



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IDS																			
[1]	normal	×,×	×,×	✓,✓	✓,✓	✓,✓	×,×	⊘,⊘	×,×	✓	×	✓	✓	×	✓	×	×	✓	×
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[5]	bayesian	×,×	✓,✓	✓,✓	✓,✓	✓,✓	×,×	⊘,⊘	×,×	✓	×	✓	✓	×	✓	×	×	✓	×
[6]	coalition	✓,✓	×,×	✓,✓	✓,✓	✓,✓	×,×	⊘,⊘	×,×	✓	×	×	×	×	✓	×	×	✓	✓
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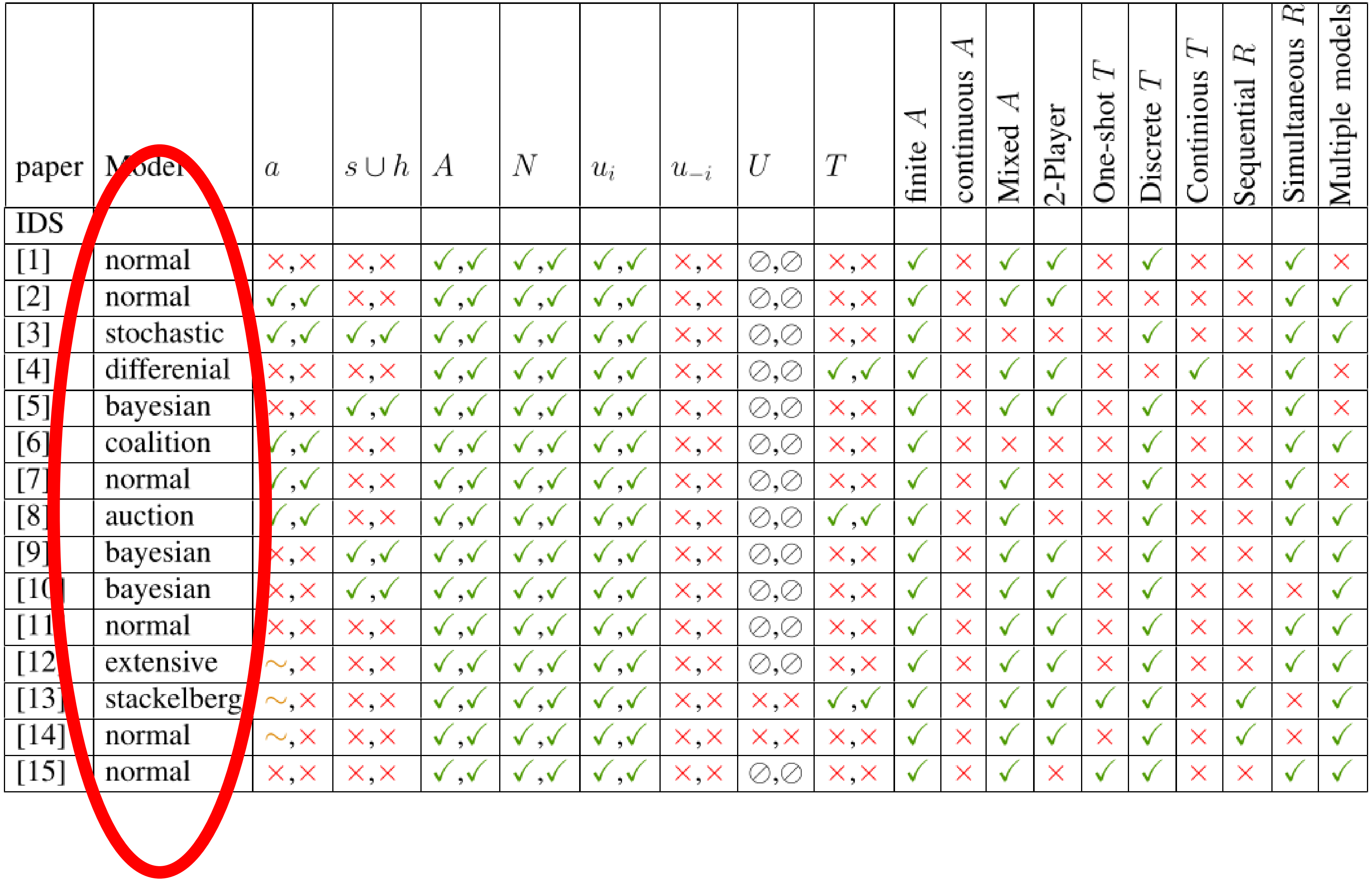
Observations

- Every green checkmark information are assumed to know

Findings



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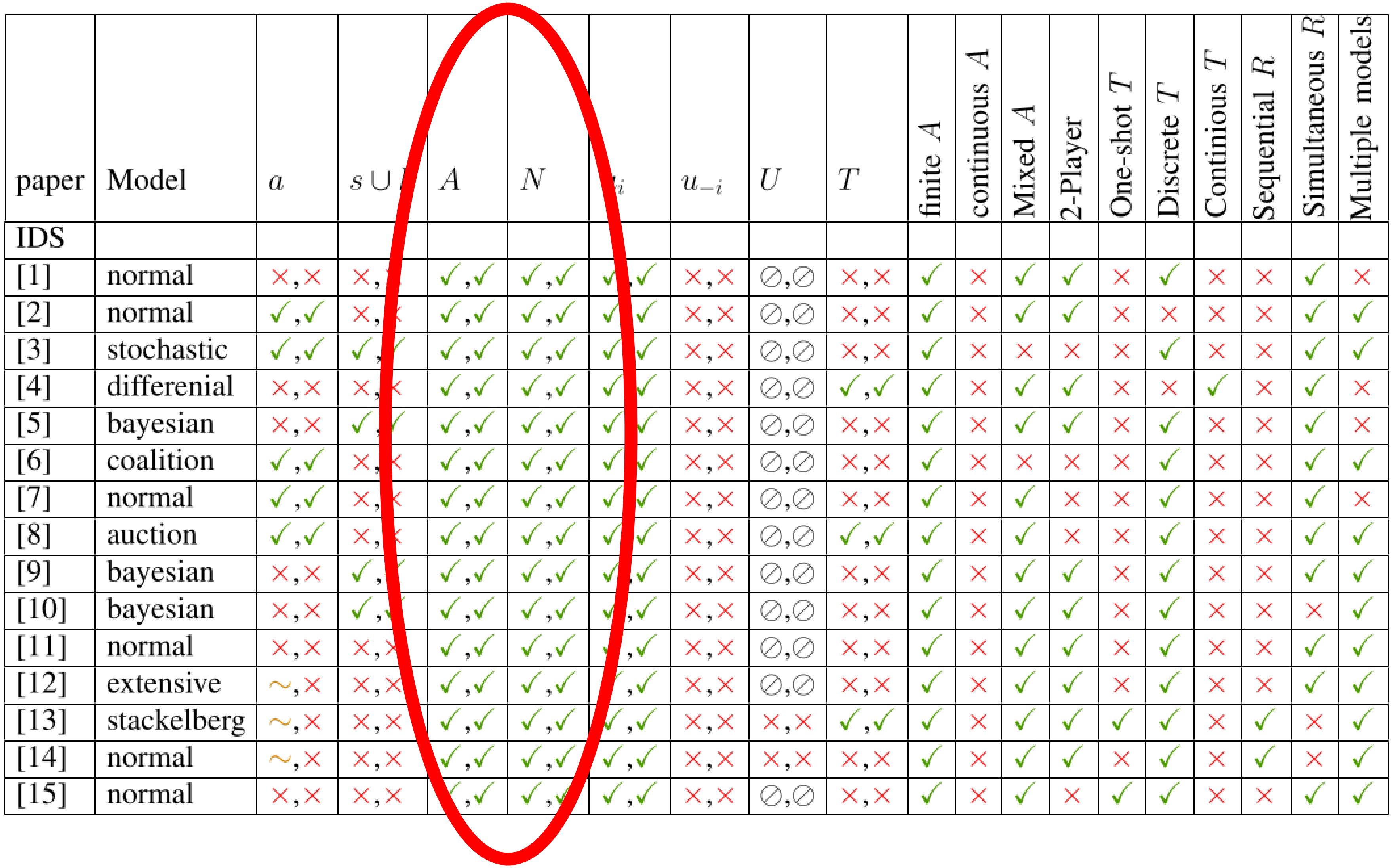
- Every green checkmark information are assumed to know
- Handful of Game Theoretic Models
- Limited efforts to push them for the needs of cyber security

Findings



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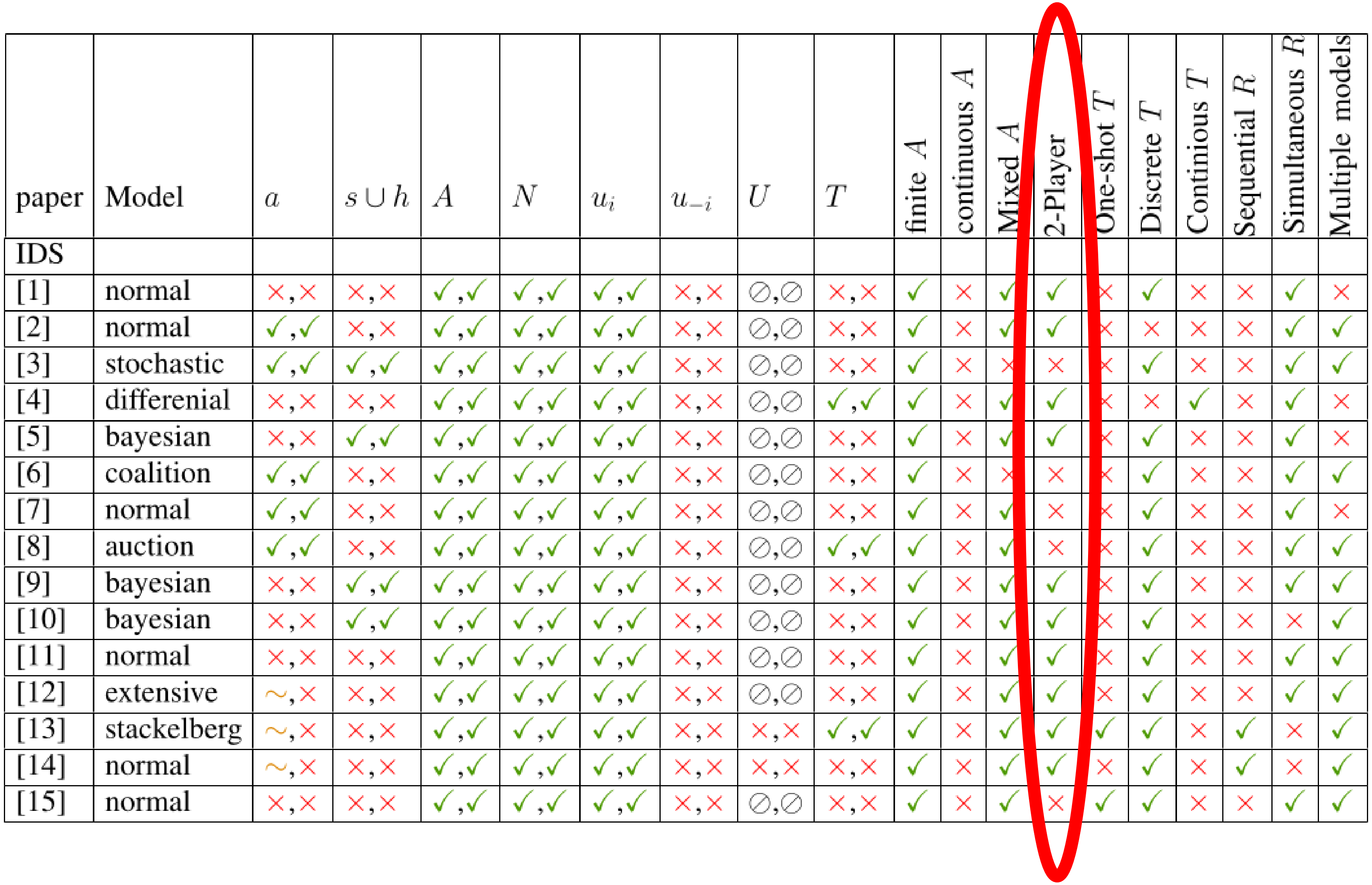
- Universally assumes agents have precise knowledge of game model

Findings



paper	Model	a	$s \cup h$	A	N	u_i	u_{-i}	U	T	finite A	continuous A	Mixed A	2-Player	One-shot T	Discrete T	Continious T	Sequential R	Simultaneous R	Multiple models
IDS																			
[1]	normal	✗,✗	✗,✗	✓,✓	✓,✓	✓,✓	✗,✗	⊘,⊘	✗,✗	✓	✗	✓	✓	✗	✓	✗	✗	✓	✗
[2]	normal	✓,✓	✗,✗	✓,✓	✓,✓	✓,✓	✗,✗	⊘,⊘	✗,✗	✓	✗	✓	✓	✗	✗	✗	✗	✓	✓
[3]	stochastic	✓,✓	✓,✓	✓,✓	✓,✓	✓,✓	✗,✗	⊘,⊘	✗,✗	✓	✗	✗	✗	✗	✓	✗	✗	✓	✓
[4]	differenial	✗,✗	✗,✗	✓,✓	✓,✓	✓,✓	✗,✗	⊘,⊘	✓,✓	✓	✗	✓	✓	✗	✗	✓	✗	✓	✗
[5]	bayesian	✗,✗	✓,✓	✓,✓	✓,✓	✓,✓	✗,✗	⊘,⊘	✗,✗	✓	✗	✓	✓	✗	✓	✗	✗	✓	✗
[6]	coalition	✓,✓	✗,✗	✓,✓	✓,✓	✓,✓	✗,✗	⊘,⊘	✗,✗	✓	✗	✗	✗	✗	✓	✗	✗	✓	✓
[7]	normal	✓,✓	✗,✗	✓,✓	✓,✓	✓,✓	✗,✗	⊘,⊘	✗,✗	✓	✗	✓	✗	✗	✓	✗	✗	✓	✗
[8]	auction	✓,✓	✗,✗	✓,✓	✓,✓	✓,✓	✗,✗	⊘,⊘	✓,✓	✓	✗	✓	✗	✗	✓	✗	✗	✓	✓
[9]	bayesian	✗,✗	✓,✓	✓,✓	✓,✓	✓,✓	✗,✗	⊘,⊘	✗,✗	✓	✗	✓	✓	✗	✓	✗	✗	✓	✓
[10]	bayesian	✗,✗	✓,✓	✓,✓	✓,✓	✓,✓	✗,✗	⊘,⊘	✗,✗	✓	✗	✓	✓	✗	✓	✗	✗	✗	✓
[11]	normal	✗,✗	✗,✗	✓,✓	✓,✓	✓,✓	✗,✗	⊘,⊘	✗,✗	✓	✗	✓	✓	✗	✓	✗	✗	✓	✓
[12]	extensive	~,✗	✗,✗	✓,✓	✓,✓	✓,✓	✗,✗	⊘,⊘	✗,✗	✓	✗	✓	✓	✗	✓	✗	✗	✓	✓
[13]	stackelberg	~,✗	✗,✗	✓,✓	✓,✓	✓,✓	✗,✗	✗,✗	✓,✓	✓	✗	✓	✓	✓	✓	✗	✓	✗	✓
[14]	normal	~,✗	✗,✗	✓,✓	✓,✓	✓,✓	✗,✗	✗,✗	✗,✗	✓	✗	✓	✓	✗	✓	✗	✓	✗	✓
[15]	normal	✗,✗	✗,✗	✓,✓	✓,✓	✓,✓	✗,✗	⊘,⊘	✗,✗	✓	✗	✓	✗	✓	✓	✗	✗	✓	✓

Observations

- Every green checkmark information are assumed to know
- Handful of Game Theoretic Models
- Limited efforts to push them for the needs of cyber security
- Universally assumes agents have precise knowledge of game model
- Many works only consider 2-agent situation

Metrics

- Agents must measure every green checkmark somehow
- Ad Hoc metrics must go!

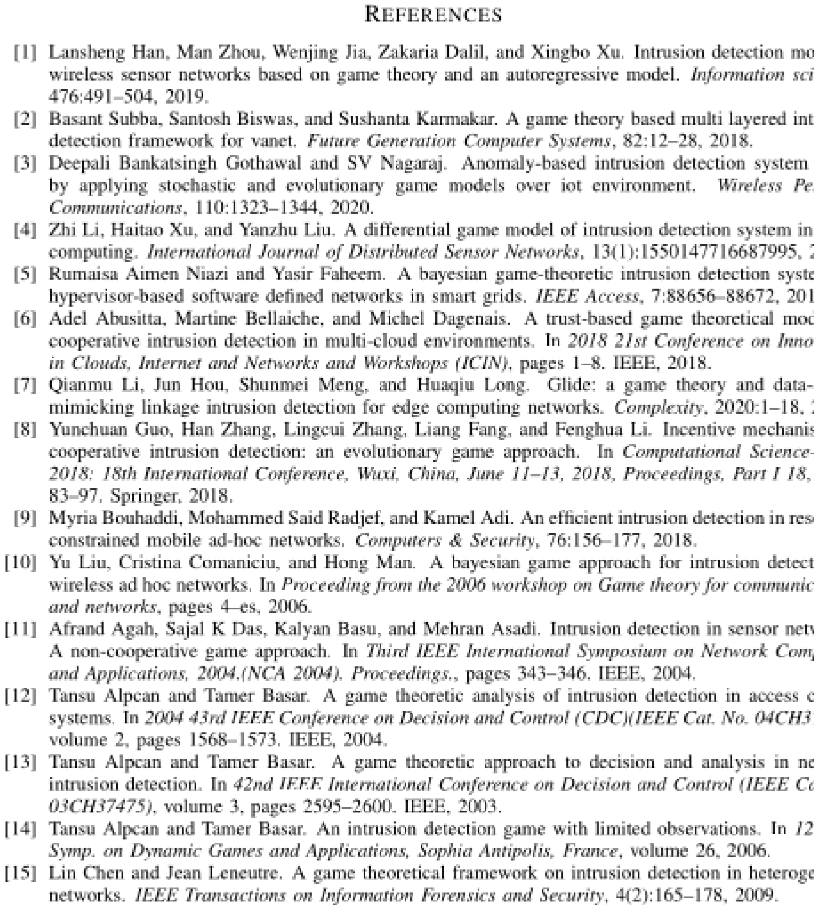
Common Vulnerability Scoring System (CVSS)

- Assigns numeric score to real world exploits describing their severity and ease of use
- Experts use guidelines to qualitatively classify exploits
- CVSS scores leveraged in game theoretics models to understand decision making in the presence of classified exploits!

Conclusion

- Models handle uncertainty in a very limited ways
- Focus on a handful of very well-established models
- Limited work to develop new or push existing models the needs of cybersecurity
- Limited use of metrics to measure needed information

Need to develop new models explicitly for cybersecurity application!



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Acknowledgement. NSF Grants #2122631, #2115134, and ECCS-#2013779, and Colorado State Bill 18-086.