Towards efficient automation of digital crime investigation using Reinforcement Learning (RL)

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My Background

- Engineering Degree, MSc (Dist.) in Digital Forensics and PhD in Cyber Security form City, University of London

- Fellow of Higher Education Academy (FHEA)

- Deputy-Director of the Cyber Security Research Centre (applied-research in the domain of digital forensics, cyber-security, computing and AI).

- Principal Lecturerin Digital Forensics and Cyber-security (BSc course leader)

- DFIR expert (few Certifications such as CISSP, CEH, GCFE, EnCE, ACE, XRY and CPCI) with 10+ years of corporate and law-enforcement experience in digital-crime investigation and offensive cyber-security

- Founding head of Londonmet Digital Forensics Laboratory (RKE to provide Digital forensic investigations services in civil and criminal cases for law firms, businesses and private clients in UK, and Internship form our students)

What is digital forensic?

Digital Forensics is the use of scientifically derived and proven methods toward:

- ✓ the **preservation, collection, validation, identification, analysis, interpretation, documentation, and presentation** of digital evidence derived from digital devices

- ✓ for the purpose of **facilitation or furthering the reconstruction of events found to be criminal, or helping to anticipate unauthorized actions** shown to be disruptive to planned operations.

Branches of Digital Forensics

- The technical aspect of an investigation is divided into several sub-branches, relating to the type of digital devices involved:
  - ✓ ***Computer forensics***, ***Firewall Forensics***, ***Database Forensics***, ***Network forensics***, ***Forensic data analysis*** and ***Mobile device forensics***.

- The typical forensic process encompasses **the seizure**, **forensic imaging** and **analysis of digital media** and the **production of a report** into collected evidence.

Example of digital devices and contained evidences

- ✓ e-mails,
- ✓ digital photographs,
- ✓ ATM transaction logs,
- ✓ word processing documents,
- ✓ Instant message histories,
- ✓ files saved from accounting program,
- ✓ spreadsheets,
- ✓ internet browser histories,
- ✓ databases,
- ✓ the contents of computer memory,
- ✓ computer backups, computer printouts,
- ✓ Global Positioning System tracks,
- ✓ logs from a hotel's electronic door locks, and
- ✓ digital video or audio files

Digital Evidence

Evidence

A piece of information that supports a conclusion

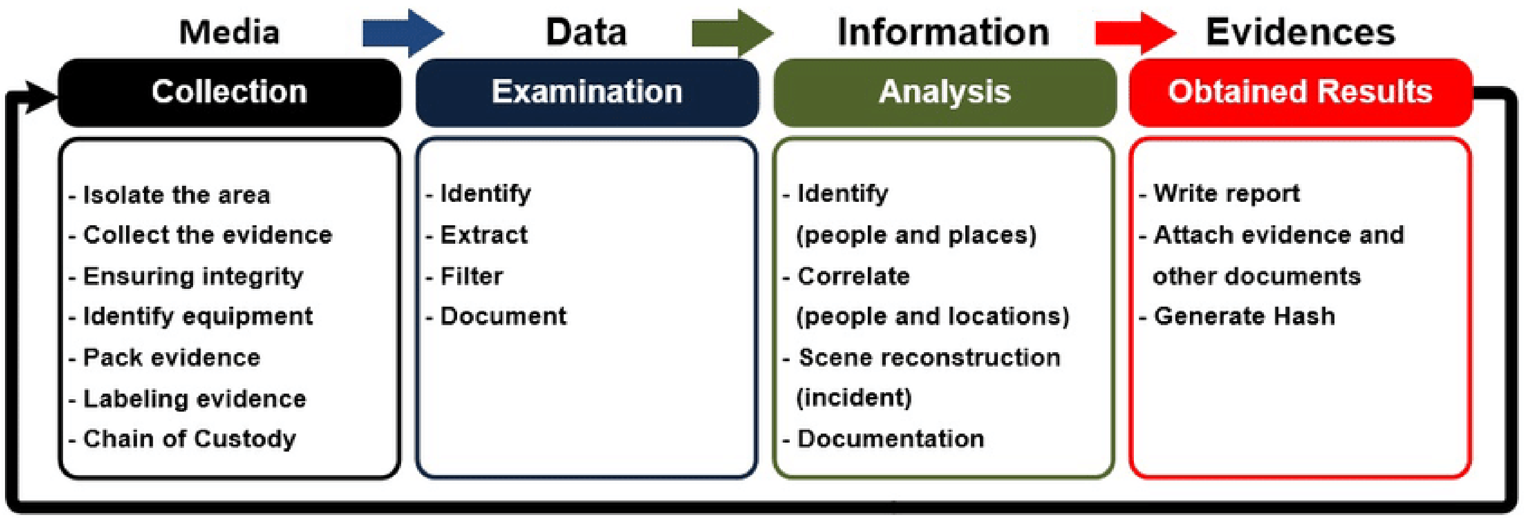
Digital evidence

Any data that is **recorded** or **preserved** on any medium in or by a **computer system** or other **similar digital device**, that can be **read or understood** by a person or a computer system or other similar device.

It includes a **display**, **printout** or **other output** of that data.

Digital Forensic Process

- ✓ Identification
- ✓ Preservation
- ✓ Analysis
- ✓ Documentation
- ✓ Presentation



Skills required for Digital Forensics

- ✓ Application of Programming or computer-related experience
- ✓ Broad understanding of operating systems and applications
- ✓ Strong analytical skills
- ✓ Strong computer science fundamentals
- ✓ Strong system administrative skills
- ✓ Knowledge of the latest intruder tools
- ✓ Knowledge of cryptography and steganography
- ✓ Strong understanding of the rules of evidence and evidence handling
- ✓ Ability to be an expert witness in a court of law

Types of Digital Evidence

Persistant data

Meaning data that **remains intact** when the digital device is turned off. E.g. hard drives, disk drives and removable storage devices (such as USB drives or flash drives).

Volatile data

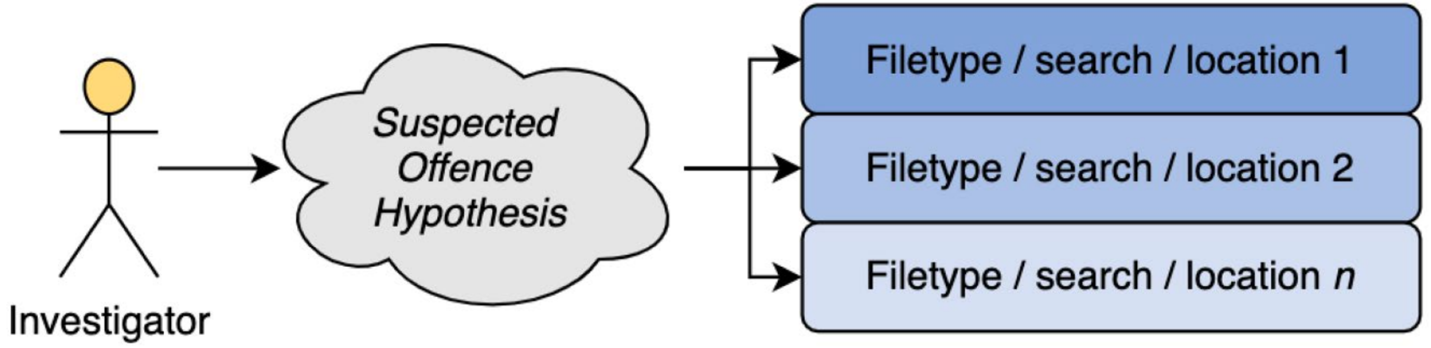
Which is data that **would be lost** if the digital device is turned off. E.g. deleted files, computer history, the computers registry, temporary files and web browsing history.

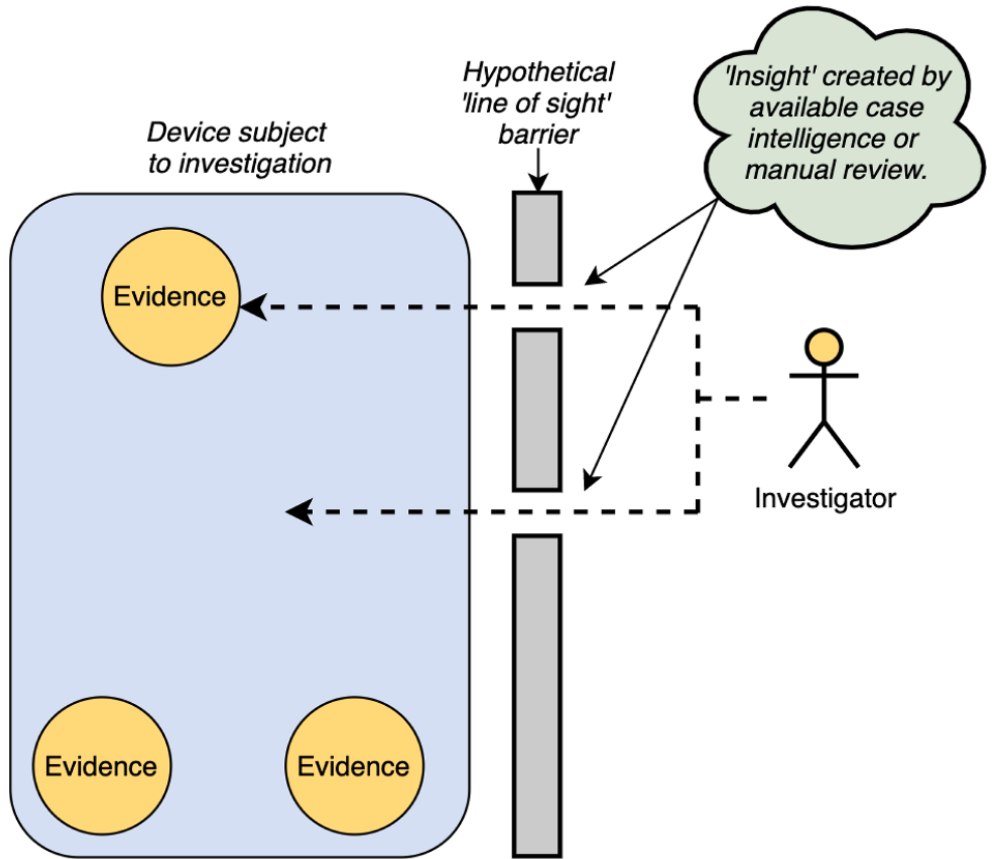
Challenges in DFIR

- **Explosion of complexity:** evidence is **no longer confined** within a single host but, rather, is **scattered** among different physical or virtual locations.
- **Development of standards:** **No standard** formats, schema, and **ontologies**
- **Privacy-preserving investigations:** **people** bring into cyberspace many aspects of their lives, primarily through online social networks or social media sites. **other hurdles** when cloud computing is involved.
- **Legitimacy:** modern infrastructures are becoming complex and virtualized, often **shifting** their complexity at the border or **delegating** some duties to third parties
- **Rise of Anti-forensics techniques:** defensive measures encompass **encryption**, **obfuscation**, and **cloaking** techniques, including information hiding.

Limits of Current Human-led DFIR practice

Volume of Evidence
High level of complexity
Usage of security and anti-forensics





Expertise of Investigator
Time constraint
Investigative Lead

The four Vs challenges in DFIR

The four main challenges that big data bought into Digital Forensics are:

Volume is often used to reference the amount of data collected from an individual or multiple seized devices.

Variety to reference the different types of files or data present within the medium (for example this could be allocated data from known file systems and unallocated data from volume and file slack spaces).

Velocity is concerned with the amount of time needed to process and analyse the acquired data and indeed the time often needed to acquire the data initially.

Value of the data. this is not the resale value, but the value of the actual intelligence collected when the data is processed correctly.

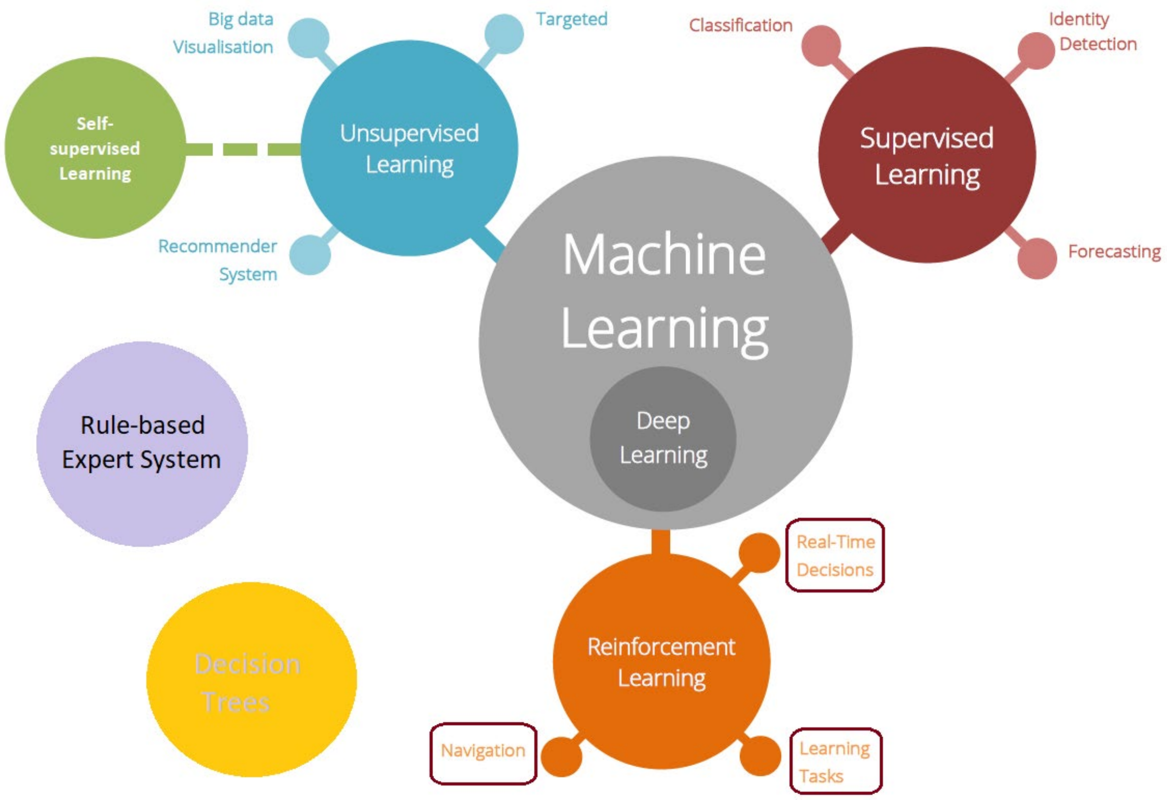
Artificial Intelligence in DFIR

AI-led digital forensics would allow:

- **Tracing** the evidence in a more enhanced and streamlined fashion to conduct an in-depth investigation
- **Identify** critical forensic evidence and renders it to further analysis objectively and reproducible.
- **Cover** more ground (search and identification) of important trends from large volumes of data followed by visualization of the results
- **Report** investigations results to reveal trends and patterns that were previously unknown

Artificial Intelligence

AI is "the theory and development of computer systems able to perform tasks normally requiring human intelligence, such as visual perception, speech recognition, decision-making, and translation between languages".

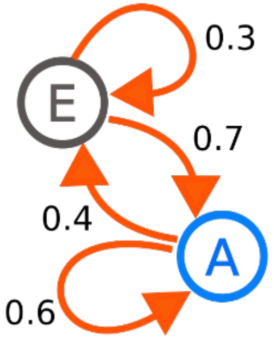


AI would be invaluable in identifying crime as it has been observed that an algorithms based would be more effective in determining the existence of criminal or illegal activity.

Why RL for DFIR – Sequential Decision Process

- RL Agent Mimic Human Expert; **assigned what to do** but **not how to do it.**
- RL Agent Determine **ideal/best behaviour;** decisions-making sequences to achieve target. “Markov Chain: What happens next depends only on the state of affairs *now*.“
- **Repetitive** tasks with same/different input and parameters
- **No Human expert intervention** during learning process **(Reward/punishment feedback)**.
- RL reflect Action-Effect-Reward characteristic which fully represent DFIR.
- Less time for learning and efficient in sequential decision-making problems if **well represented.**
- RL allow a the **Explainability**

DFIR as Markov Chain



Markov Models		Do we have control over the state transitions? NO	YES
Are the states completely observable?	YES	**Markov Chain**	**MDP** Markov Decision Process
	NO	**HMM** Hidden Markov Model	**POMDP** Partially Observable Markov Decision Process

Reinforcement Learning contribution to DFIR

1. DFIR is rapidly **evolving** and very **complex** environment, therefore representing all these information as MDP is challenging
2. Working with a **Reward Function** to act as feedback provider for the system is a tricky sub-problem (relying on human reward is not practical and **unsafe**)
3. The **Uncertainty** in some of the tasks' outcome (POMDP is not an option)
4. **Capturing** the Expertise is relative, and the Learning time required for the system to reach **maturity** is uncertain
5. **Scaling-up** and reduce size of MDP environment to allow Solving algorithms performing better.

RL-led DFIR

Explainability: relates to the idea of connecting a machine's decision-making process with human explanations that are both accurate and understandable

Interpretability: is the ability to communicate an explanation or meaning in a way that is comprehensible.

Understandability: or intelligibility, refers to the features of a model that allow it to be self-explanatory in terms of its operational functionality without the need to describe its internal structure or the underlying algorithms used to process data

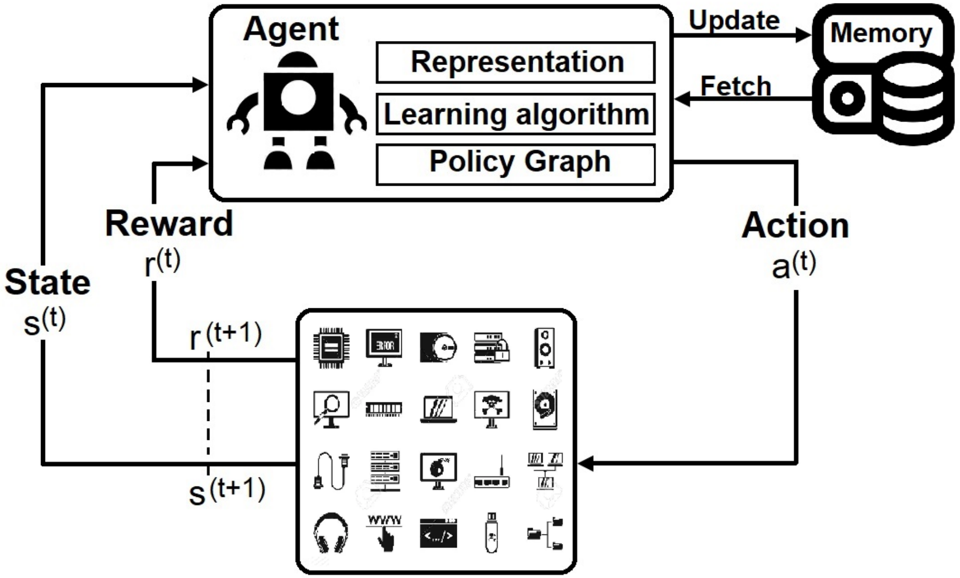
Transparency: Algorithmic transparency, simulatability, decomposability, and transparency are all characteristics that a transparent model should posses

Comprehensibility: is often quantified in terms of the model's complexity, which includes the model's ability to describe its learning process in a comprehensible manner

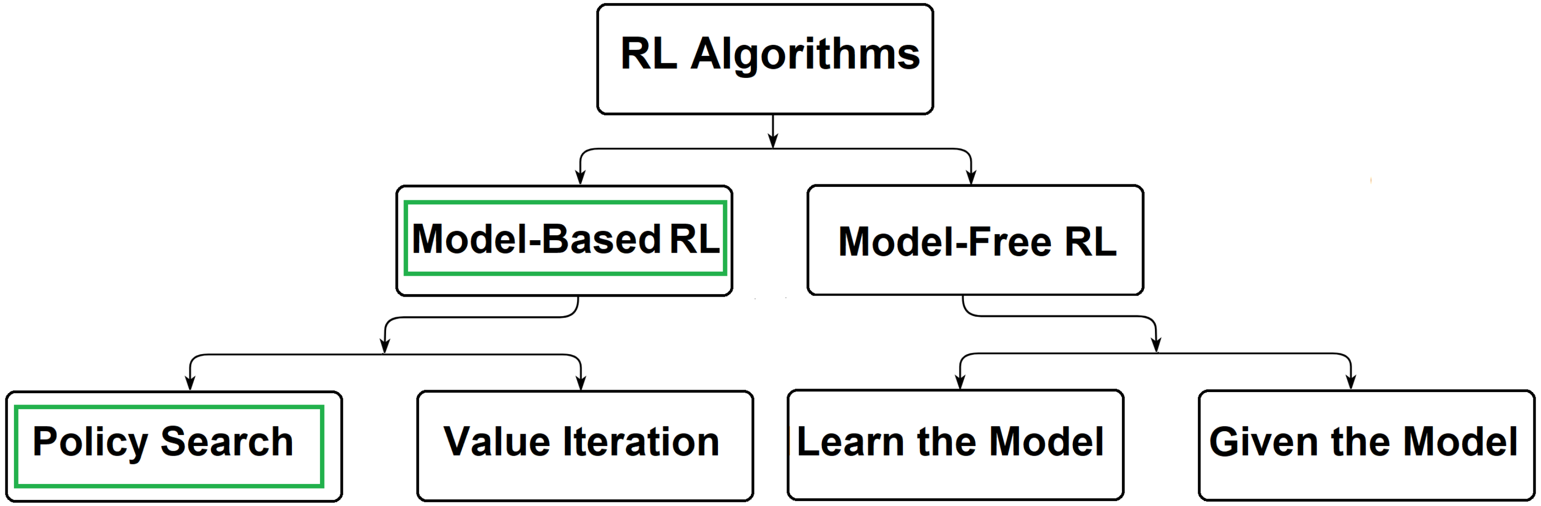
Markov Decision Process (MDP)

A Markov Decision Process is composed of the following building blocks:

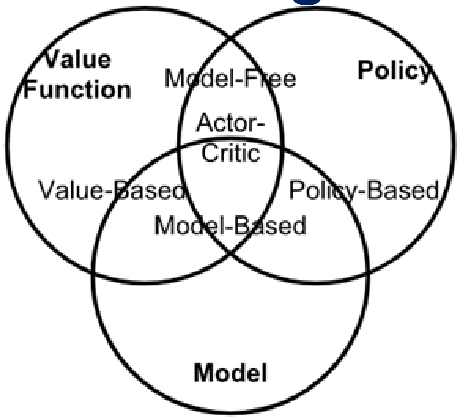
- **State space S —** The state contains all possible states whether physical, information or belief attributes, and which the RL agent(s) could face.
- **Action space A —** The set containing all (feasible) actions. For state-dependent decisions a(s), it may be necessary to subject the action space to a set of constraints, e.g., using mathematical programming.
- **Reward function R —** Denoting the direct reward when taking action a in state s.
- **Transition function T —** The function governing the dynamics of the system over time, guiding the agent from state s to s'. The transition typically involves both a deterministic component (the action a) and a stochastic one (exogenous information ω).
- **Discount factor γ —** Defines the degree to which future rewards impact current decisions. When the problem is infinite-horizon and relies on a cumulative reward objective function, a discount rate γ<1 is necessary to ensure convergence.



Research Choices



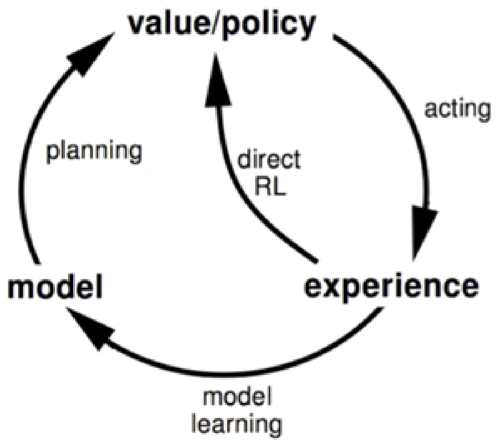
Modelling DFIR



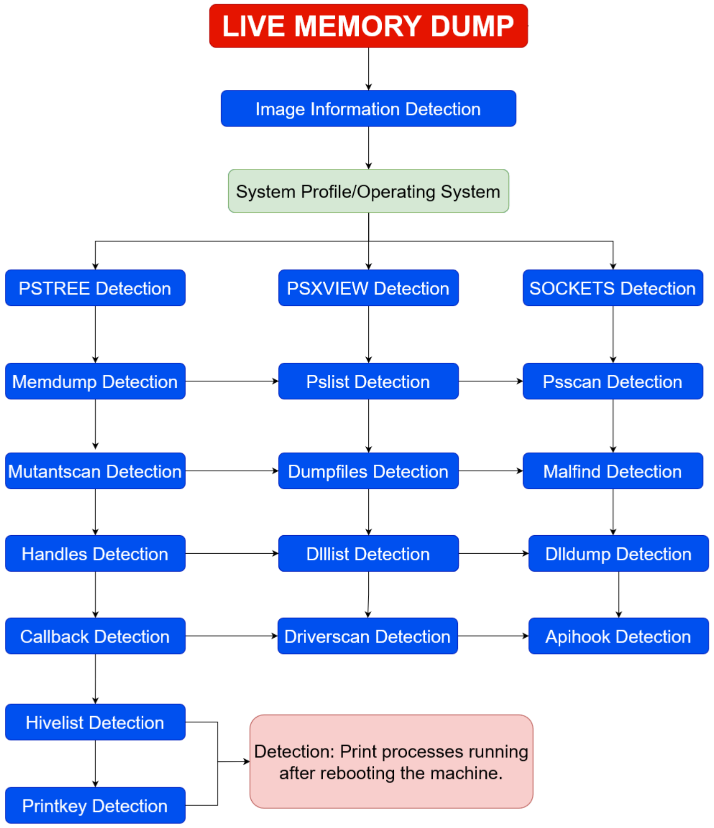
Evaluation Metrics:

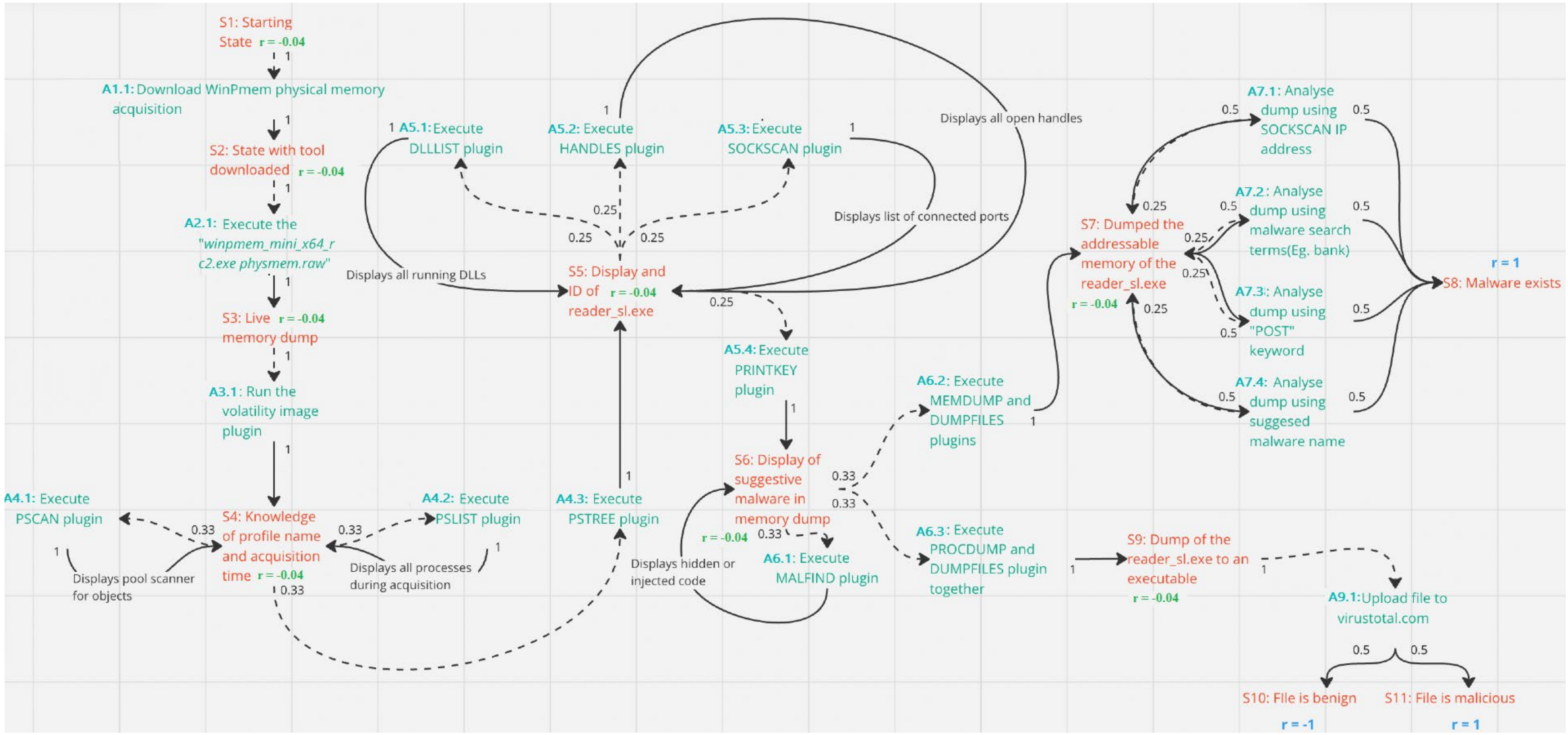
- **Consumed time (Criteria 1) - Cost (efficiency)**
- **Covered Artefacts (Criteria 2)- result reliability (effectiveness)**
- **Success rate – Subjective**

Solving the MDP



RL representation of Incident Response – Malware

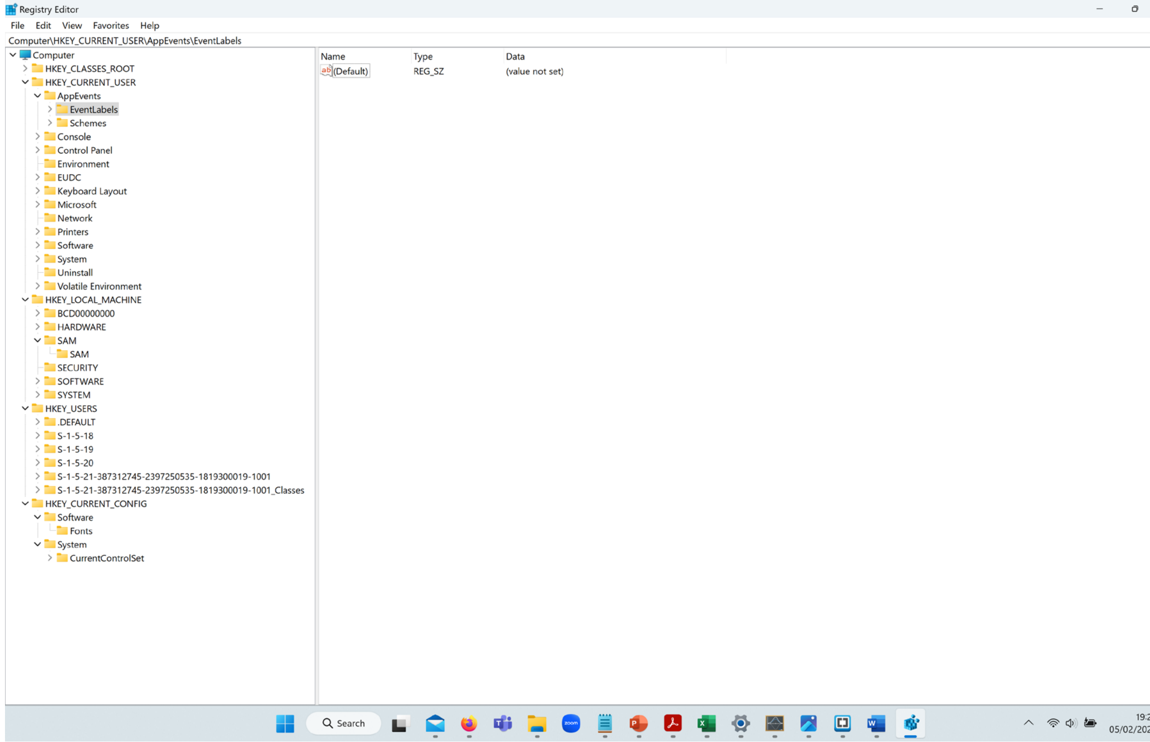




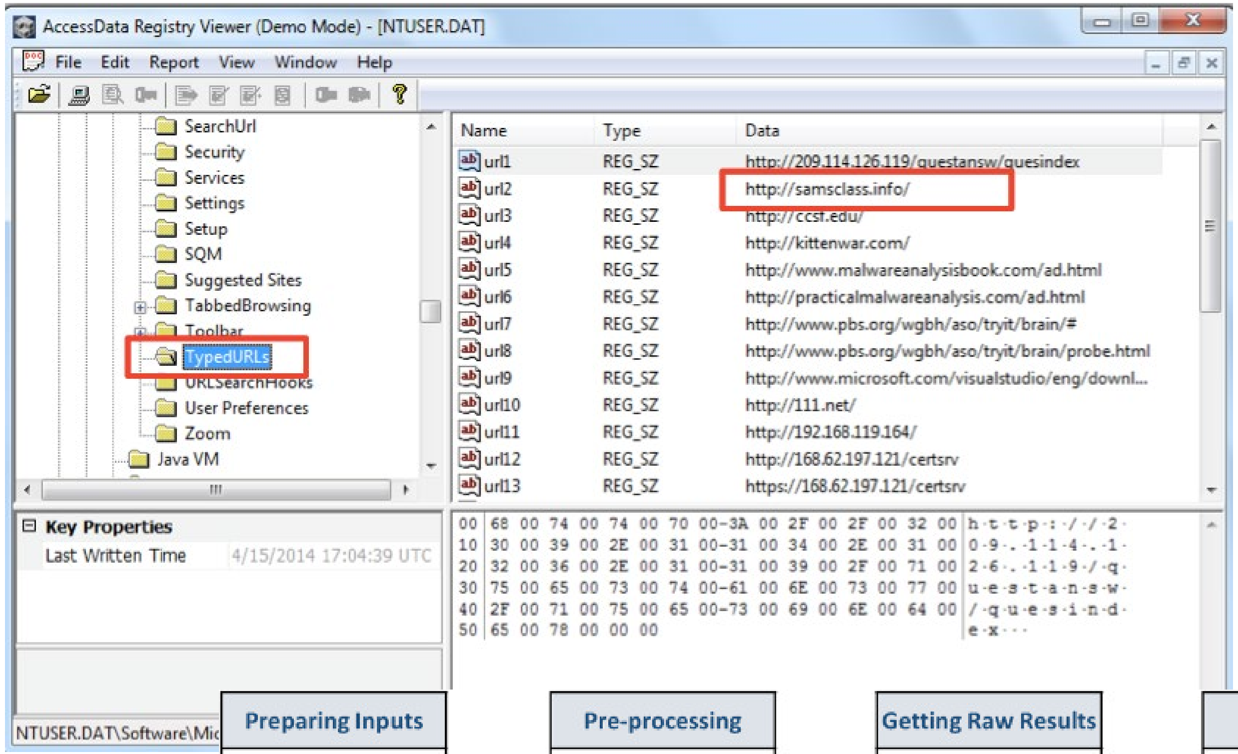
Windows Registry (our case study)

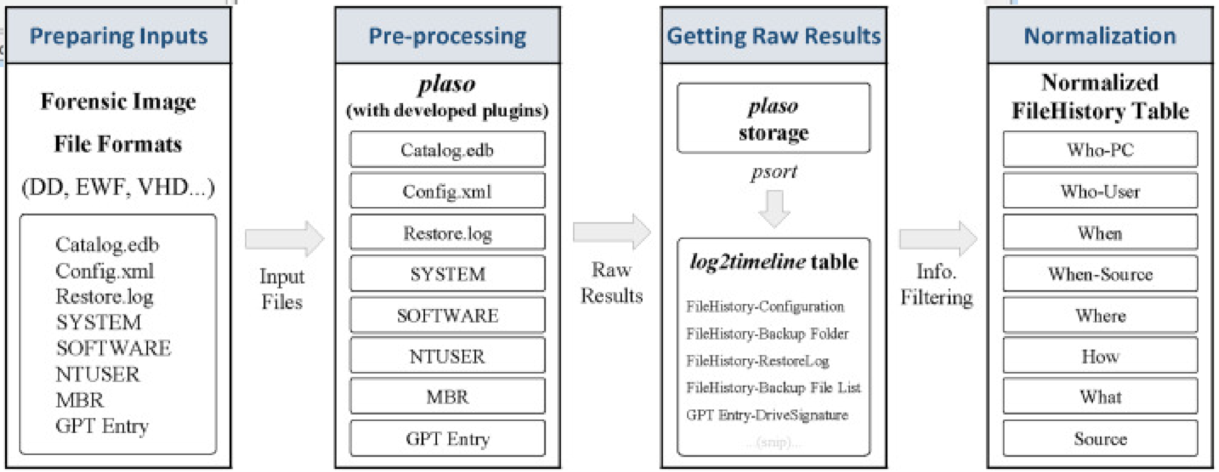
registry is a “central hierarchal database” intended to store information that is necessary to configure the system for one or more users, applications, and hardware devices.

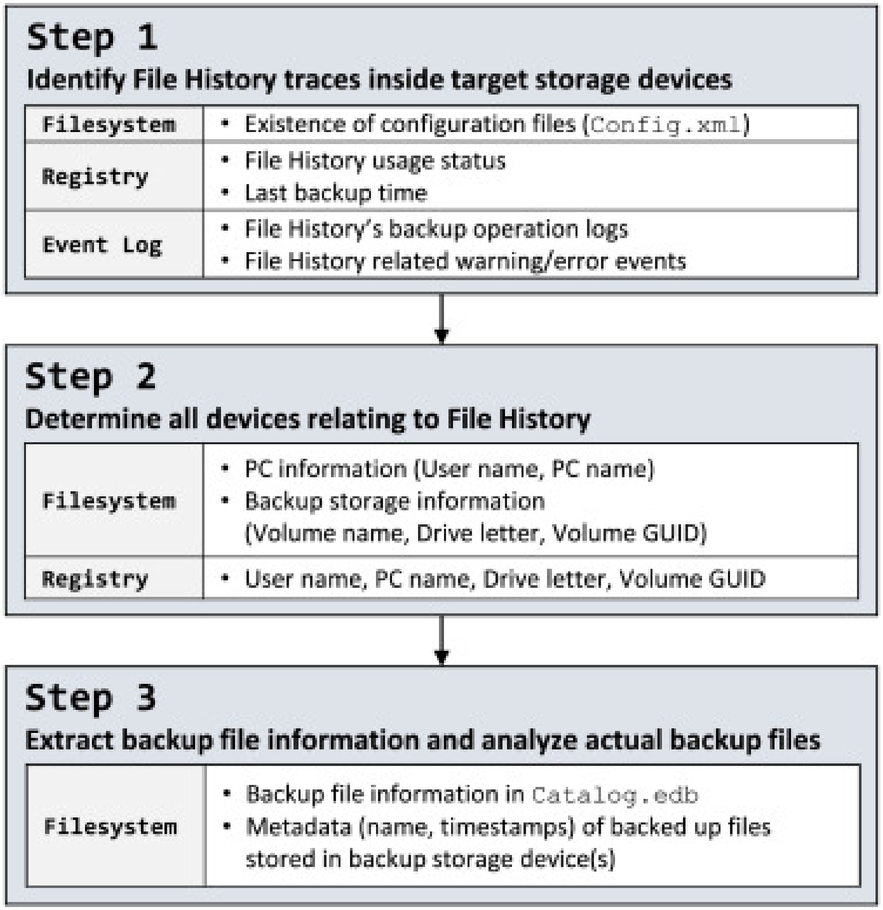
- Goldmine for digital forensics.
- Registry Breakdown
- Hives (binary database files)
- Keys & Subkeys (analogous to a folders)
- Values (analogous to a file)
- Type (strings, binary or DWORD)
- Data



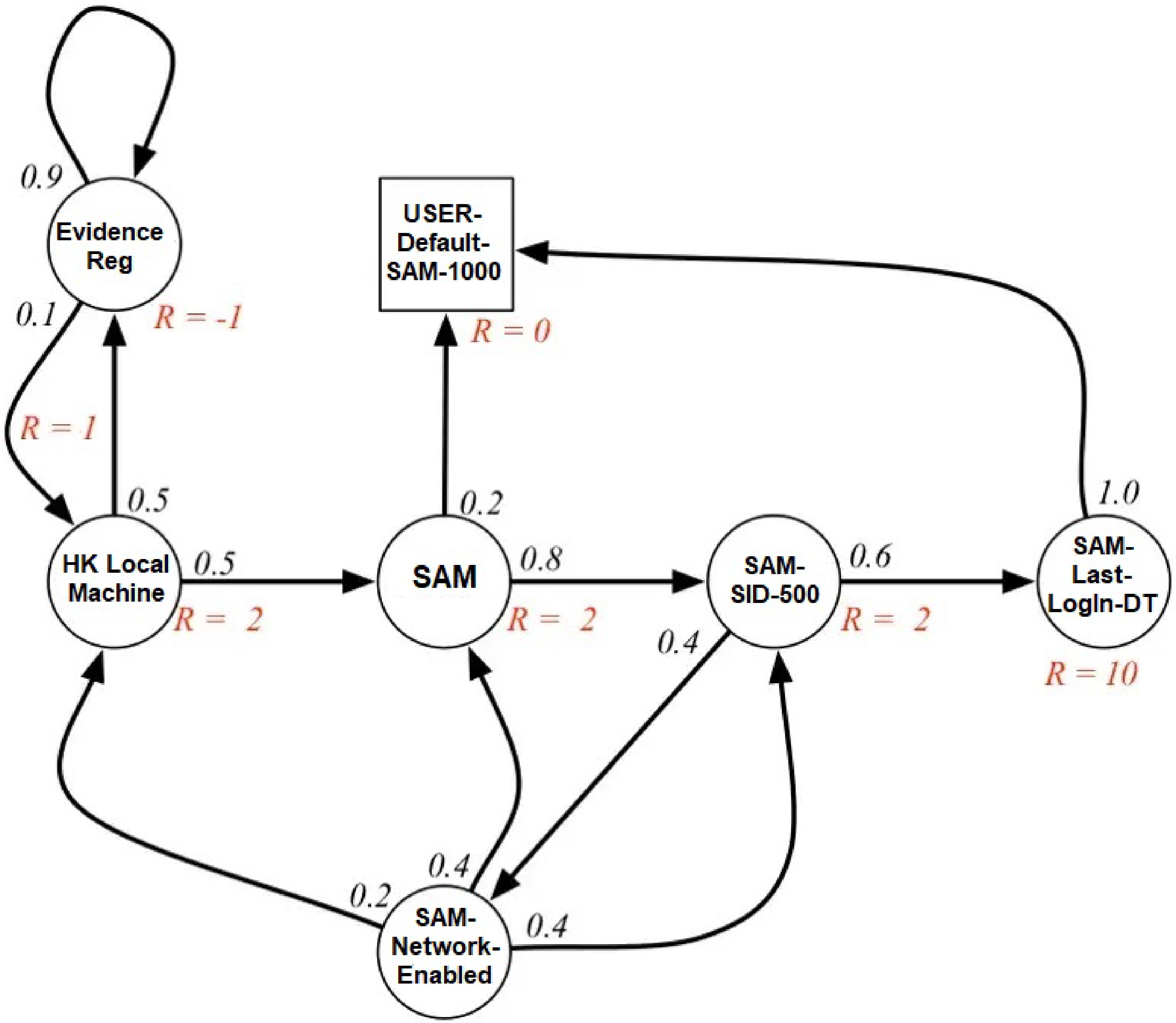
Windows Registry Forensics workflow







Markov Decision Process for Registry Forensics



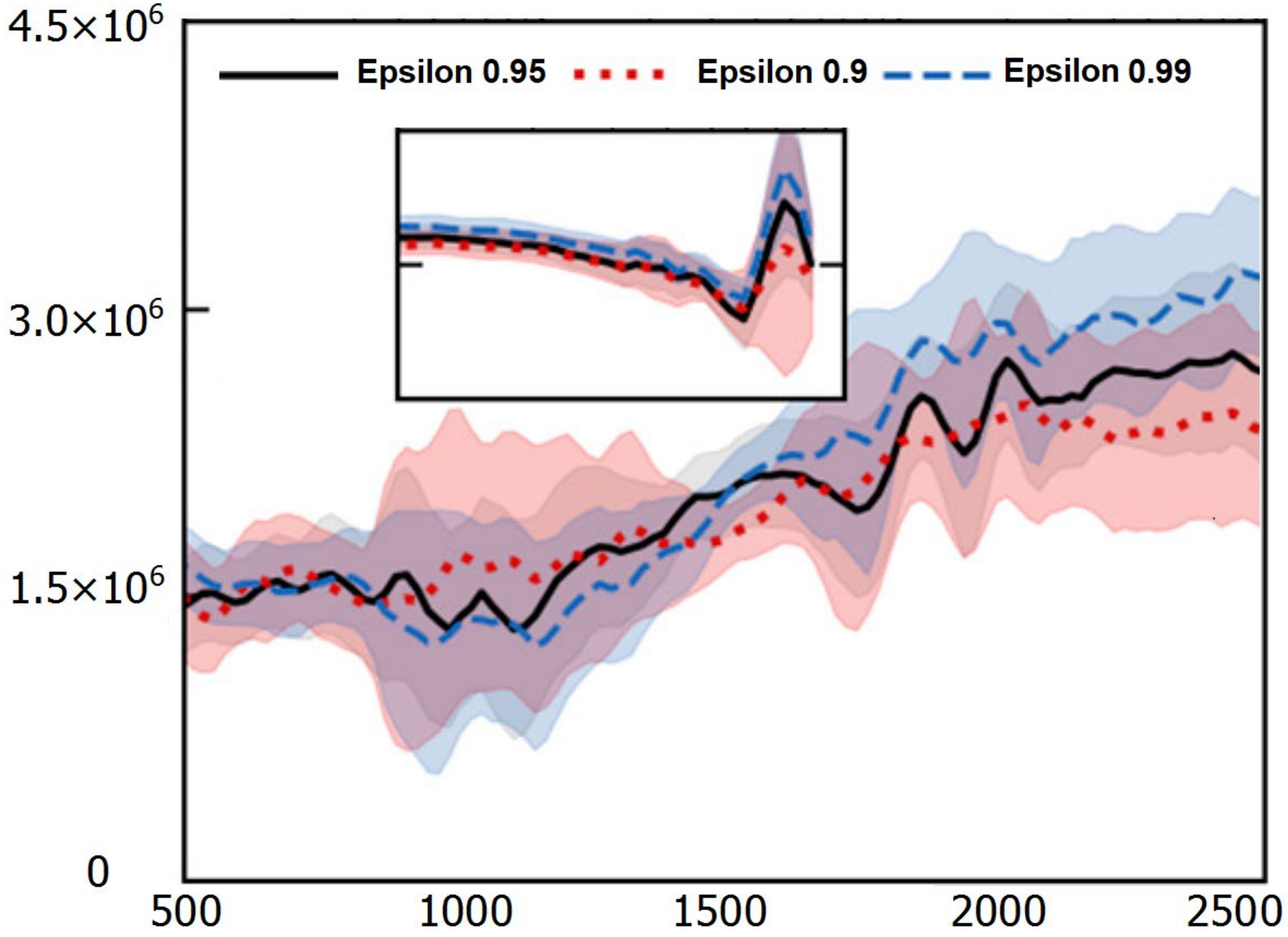
RL representation of Windows Registry Forensics

```
############################  REG_FOR_V5####################################################

values: reward

discount : 0.95



# NUMBER  States 1034   Actions  43
###################  THE STATES SPACE   ############################################

states:

Evidence-reg

HKEY_CLASSES_ROOT
HKEY_CURRENT_USER
HKEY_LOCAL_MACHINE
HKEY_USERS
HKEY-CURRENT-CONFIG

LOCAL-MACHINE-SAM
lOCAL-MACHINE-SECURITY
LOCAL-MACHINE-SYSTEM
LOCAL-MACHINE-SOFTWARE
LOCAL-MACHINE-NTUSER-dat

USER-DEFAULT-SAM
USER-DEFAULT-SECURITY
USER-DEFAULT-SYSTEM
USER-DEFAULT-SOFTWARE
USER-DEFAULT-NTUSER-dat
USER-2-SAM
USER-2-SECURITY
USER-2-SYSTEM
USER-2-SOFTWARE
USER-2-NTUSER-dat
USER-3-SAM
USER-3-SECURITY
USER-3-SYSTEM
USER-3-SOFTWARE
USER-3-NTUSER-dat
```

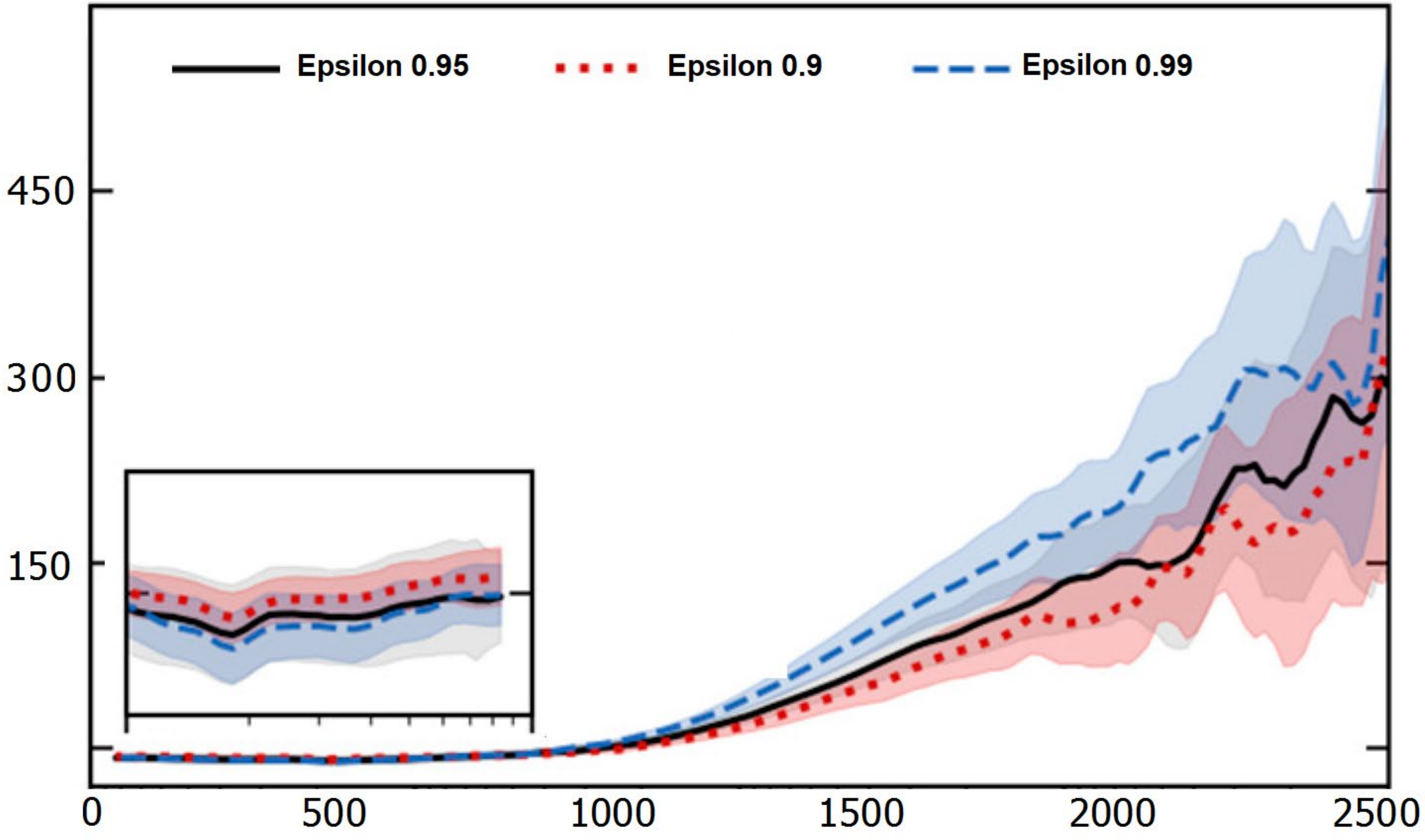
```
SAM-SID-Unknown
SAM-SID-500    # ROOT
SAM-SID-501    # Guest
SAM-SID-1000   # User 1
SAM-SID-1001   # User 3
SAM-SID-1002   # User 3
SAM-Last-LogIn-Blank
SAM-Last-LogIn-DT
SAM-Password-False  #REG_BINARY Binary Data
SAM-Password-True   #REG_BINARY Binary Data
SAM-Password-Change-Blank
SAM-Password-Change-DT
SAM-Last-FailedLogIn-Blank
SAM-Last-FailedLogIn-DT
SAM-NetworkEnabled-False   #REG_BINARY Binary Da
SAM-NetworkEnabled-True    #REG_BINARY Binary Da
```

```
REG_QWORD 64-bit Number


actions:

import_REG
extract_HIVE
parse_SAM
examine_SAM_SID
examine_SAM_Account
parse_SYSTEM
examine_SYSTEM
examine_sys_Profil_list
examine_sys_Current
examine_config_files
examine_sys_Coltrole
examine_TimeZone
examine_Timestamp
examine_NetInterface
examine_Share
parse_SOFTWARE
examine_Version
examine_NetworkHistory
examine_SSIDHistory
examine_gatwayMAC
examine_NetworkList
collate_AutoStart
examine_Run
examine_Run_Once
examine_Start_Services
parse_NTUSERDAT
examine_SearchHistory
examine_TypedURLs
examine_RecentDoc
examine_FileMRU
examine_API_openMRU
examine_API_visitMRU
examine_RunMRU
examine_UserAssist
examine_MUICache
parse_RegRipper
examine_RegRipper_Plugins
collate_USB
examine_USB_SerialNmbr
examine_USB_PartMgr
examine_USB_Mountpoint
extract_ShellBag
examine_ShellBag
```

Results: Solving Time with SD (standard deviation) for different size MDP problems



Results: Number of relevant Artefacts for different size MDP problems



RL contribution to Registry Forensics

- Provides investigators with an “intelligent assistant” that allows cutting in cost (time is money) and avoid delays.

- Makes the practice accessible to non-expert users allowing them to process sensitive forensic information with only minimal technical knowledge

- Allows learning and expertise capturing and re-use (future similar cases)

- Minimises risks and mistakes (miscarriage of justice) due to human Digital examiners fatigue or misjudgement.

Conclusion and Future works

1. **RL works** (everyone knows that), it **works well** in DFIR context despite some challenges.
2. The **Proposed Model of Registry Forensics** as MDP is fits to purpose (can be extended to further applications)
3. Performance **enhancement** is clear **But** we might need to introduction a Hierarchical MDP model
4. Exploration capabilities of the MDP model **were beyond expectation and exceed Human expert.**

Thank You

Any questions ?