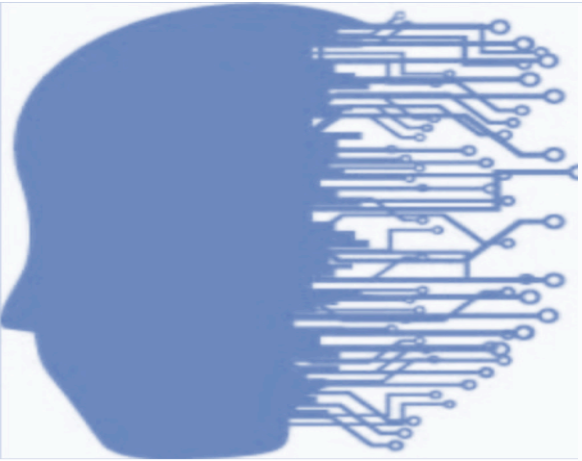
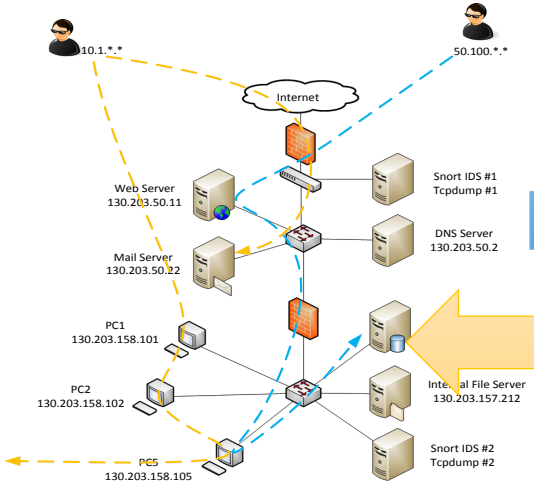


An Integrated Cognitive Task Analysis Method for Tracing Human Analysts' Cyber Security Analysis Processes

Chen Zhong, John Yen, Peng Liu,
Pennsylvania State University

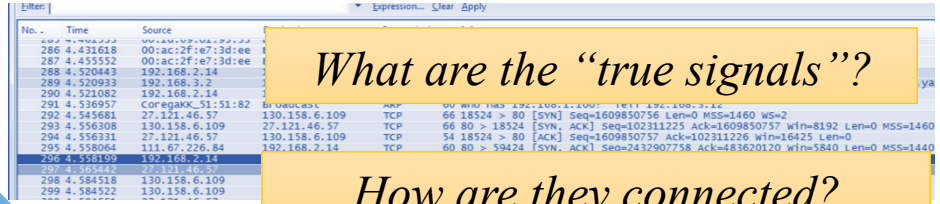
Rob Erbacher, Renee Etoty, Christopher Garneau
Army Research Lab

Cyber Security Analysis: Defense Technologies + Human Analysts



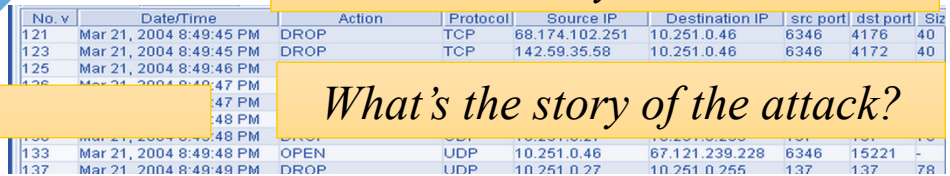
Reports

Human Analysts

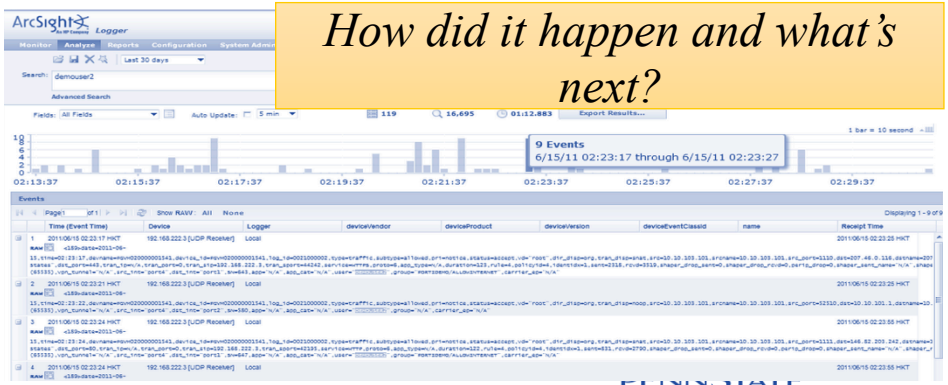


What are the "true signals"?

How are they connected?



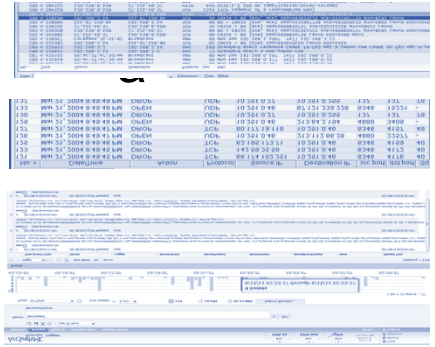
What's the story of the attack?



How did it happen and what's next?

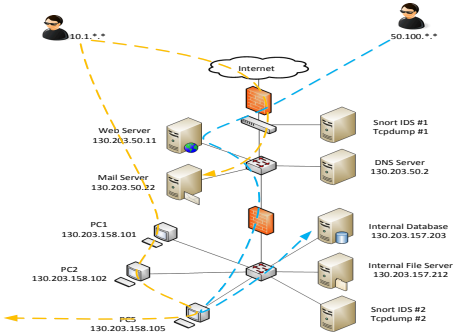
Defense Technologies

Cyber Security Analysis: A Complex Cognitive Process



Network Monitoring Data

Analytical Reasoning Process



Cyber Attacks

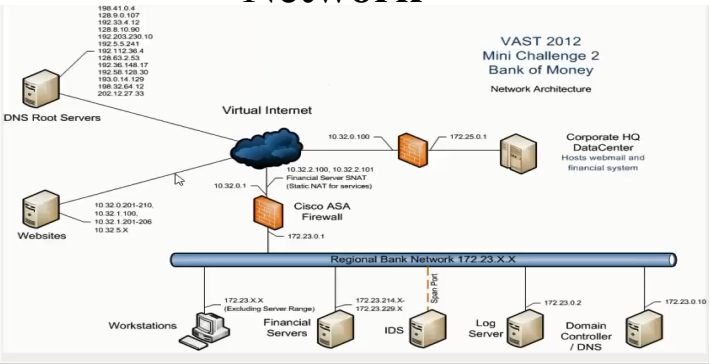
How did you make it?

I took the data and conducted reasoning based on my experience and domain knowledge.

An Example of Cyber Security Analysis

Alice

Network



Intrusion Detection System (IDS) Alerts

DataTime	SourceIP	DestIP	Category	Priority	Description
4/5/2012 10:15:00 PM	172.23.0.246	172.23.0.10	Generic Protocol Command Decode	3	[1:2103003:7] GPL NETBIOS SMB-DS Session Setu
4/5/2012 10:15:00 PM	172.23.0.246	172.23.0.10	Generic Protocol Command Decode	3	[1:2102466:9] GPL NETBIOS SMB-DS IPC$ unicode
4/5/2012 10:15:00 PM	10.32.5.54	172.23.233.150	Misc activity	3	[1:2000355:5] ET POLICY IRC authorization messag
4/5/2012 10:15:00 PM	10.32.5.58	172.23.233.33	Misc activity	3	[1:2000355:5] ET POLICY IRC authorization messag
4/5/2012 10:15:00 PM	10.32.5.56	172.23.233.9	Misc activity	3	[1:2000355:5] ET POLICY IRC authorization messag
4/5/2012 10:15:00 PM	172.23.0.227	172.23.0.10	Generic Protocol Command Decode	3	[1:2103003:7] GPL NETBIOS SMB-DS Session Setu
4/5/2012 10:15:00 PM	172.23.0.227	172.23.0.10	Generic Protocol Command Decode	3	[1:2102466:9] GPL NETBIOS SMB-DS IPC$ unicode
4/5/2012 10:15:00 PM	172.23.0.236	172.23.0.10	Generic Protocol Command Decode	3	[1:2103003:7] GPL NETBIOS SMB-DS Session Setu
4/5/2012 10:15:00 PM	172.23.0.236	172.23.0.10	Generic Protocol Command Decode	3	[1:2102466:9] GPL NETBIOS SMB-DS IPC$ unicode
4/5/2012 10:15:00 PM	172.23.0.215	172.23.0.10	Generic Protocol Command Decode	3	[1:2103003:7] GPL NETBIOS SMB-DS Session Setu
4/5/2012 10:15:00 PM	172.23.0.215	172.23.0.10	Generic Protocol Command Decode	3	[1:2102466:9] GPL NETBIOS SMB-DS IPC$ unicode
4/5/2012 10:15:00 PM	172.23.0.229	172.23.0.10	Generic Protocol Command Decode	3	[1:2103003:7] GPL NETBIOS SMB-DS Session Setu
4/5/2012 10:15:00 PM	172.23.0.229	172.23.0.10	Generic Protocol Command Decode	3	[1:2102466:9] GPL NETBIOS SMB-DS IPC$ unicode
4/5/2012 10:15:00 PM	172.23.0.216	172.23.0.10	Generic Protocol Command Decode	3	[1:2103003:7] GPL NETBIOS SMB-DS Session Setu
4/5/2012 10:15:00 PM	172.23.0.216	172.23.0.10	Generic Protocol Command Decode	3	[1:2102466:9] GPL NETBIOS SMB-DS IPC$ unicode
4/5/2012 10:15:00 PM	172.23.0.219	172.23.0.10	Generic Protocol Command Decode	3	[1:2103003:7] GPL NETBIOS SMB-DS Session Setu
4/5/2012 10:15:00 PM	172.23.0.249	172.23.0.10	Generic Protocol Command Decode	3	[1:2103003:7] GPL NETBIOS SMB-DS Session Setu
4/5/2012 10:15:00 PM	172.23.0.249	172.23.0.10	Generic Protocol Command Decode	3	[1:2102466:9] GPL NETBIOS SMB-DS IPC$ unicode
4/5/2012 10:15:00 PM	172.23.0.245	172.23.0.10	Generic Protocol Command Decode	3	[1:2103003:7] GPL NETBIOS SMB-DS Session Setu
4/5/2012 10:15:00 PM	172.23.0.245	172.23.0.10	Generic Protocol Command Decode	3	[1:2102466:9] GPL NETBIOS SMB-DS IPC$ unicode
4/5/2012 10:15:00 PM	172.23.0.239	172.23.0.10	Generic Protocol Command Decode	3	[1:2103003:7] GPL NETBIOS SMB-DS Session Setu
4/5/2012 10:15:00 PM	172.23.0.239	172.23.0.10	Generic Protocol Command Decode	3	[1:2102466:9] GPL NETBIOS SMB-DS IPC$ unicode
4/5/2012 10:15:00 PM	172.23.0.233	172.23.0.10	Generic Protocol Command Decode	3	[1:2103003:7] GPL NETBIOS SMB-DS Session Setu
4/5/2012 10:15:00 PM	172.23.0.233	172.23.0.10	Generic Protocol Command Decode	3	[1:2102466:9] GPL NETBIOS SMB-DS IPC$ unicode

Firewall logs

DataTime	Priority	Operation	Protocol	SrcIP	DesIP	SrcPort	DesPort	DestService	Direction
4/5/2012 10:15:00 PM	Info	Teardown	TCP	172.23.240.152	10.32.5.56	5203	6667	6667_tcp	outbound
4/5/2012 10:15:00 PM	Info	Teardown	TCP	172.23.235.50	10.32.5.52	2316	6667	6667_tcp	outbound
4/5/2012 10:15:00 PM	Info	Teardown	TCP	172.23.238.127	10.32.5.54	3330	6667	6667_tcp	(empty)
4/5/2012 10:15:00 PM	Info	Teardown	TCP	172.23.238.124	10.32.5.54	3329	6667	6667_tcp	(empty)
4/5/2012 10:15:00 PM	Info	Teardown	TCP	172.23.238.121	10.32.5.59	3306	6667	6667_tcp	(empty)
4/5/2012 10:15:00 PM	Info	Teardown	TCP	172.23.238.78	10.32.5.52	3336	6667	6667_tcp	(empty)
4/5/2012 10:15:00 PM	Info	Built	TCP	172.23.233.51	10.32.5.51	6637	6667	6667_tcp	outbound
4/5/2012 10:15:00 PM	Info	Built	TCP	172.23.233.50	10.32.5.57	6638	6667	6667_tcp	outbound
4/5/2012 10:15:00 PM	Info	Built	TCP	172.23.233.56	10.32.5.58	6639	6667	6667_tcp	outbound
4/5/2012 10:15:00 PM	Info	Teardown	TCP	172.23.233.50	10.32.5.57	6638	6667	6667_tcp	outbound
4/5/2012 10:15:00 PM	Info	Teardown	TCP	172.23.233.56	10.32.5.58	6639	6667	6667_tcp	outbound
4/5/2012 10:15:00 PM	Info	Built	TCP	172.23.233.58	10.32.5.51	6640	6667	6667_tcp	outbound
4/5/2012 10:15:00 PM	Info	Built	TCP	172.23.233.52	10.32.5.59	6641	6667	6667_tcp	outbound
4/5/2012 10:15:00 PM	Info	Teardown	TCP	172.23.233.58	10.32.5.51	6640	6667	6667_tcp	outbound
4/5/2012 10:15:00 PM	Info	Teardown	TCP	172.23.233.52	10.32.5.59	6641	6667	6667_tcp	outbound
4/5/2012 10:15:00 PM	Info	Built	TCP	172.23.233.57	10.32.5.58	6642	6667	6667_tcp	outbound
4/5/2012 10:15:00 PM	Info	Teardown	TCP	172.23.233.57	10.32.5.58	6642	6667	6667_tcp	outbound
4/5/2012 10:15:00 PM	Info	Built	TCP	172.23.233.54	10.32.5.57	6643	6667	6667_tcp	outbound
4/5/2012 10:15:00 PM	Info	Built	TCP	172.23.233.53	10.32.5.52	6644	6667	6667_tcp	outbound
4/5/2012 10:15:00 PM	Info	Teardown	TCP	172.23.233.53	10.32.5.52	6644	6667	6667_tcp	outbound
4/5/2012 10:15:00 PM	Info	Teardown	TCP	172.23.233.54	10.32.5.57	6643	6667	6667_tcp	outbound
4/5/2012 10:15:00 PM	Info	Deny	TCP	172.23.233.54	10.32.5.57	6643	6667	6667_tcp	(empty)

Alice started with browsing the IDS alerts.

DataTime	SourceIP	DestIP	Category	Priority	Description
4/5/2012 10:15:00 PM	172.23.0.246	172.23.0.10	Generic Protocol Command Decode	3	[1:2103003:7] GPL NETBIOS SMB-DS Session Setu
4/5/2012 10:15:00 PM	172.23.0.246	172.23.0.10	Generic Protocol Command Decode	3	[1:2102466:9] GPL NETBIOS SMB-DS IPC$ unicode
4/5/2012 10:15:00 PM	10.32.5.54	172.23.233.150	Misc activity	3	[1:2000355:5] ET POLICY IRC authorization messac
4/5/2012 10:15:00 PM	10.32.5.58	172.23.233.33	Misc activity	3	[1:2000355:5] ET POLICY IRC authorization messac
4/5/2012 10:15:00 PM	10.32.5.56	172.23.233.9	Misc activity	3	[1:2000355:5] ET POLICY IRC authorization messac
4/5/2012 10:15:00 PM	172.23.0.227	172.23.0.10	Generic Protocol Command Decode	3	[1:2103003:7] GPL NETBIOS SMB-DS Session Setu
4/5/2012 10:15:00 PM	172.23.0.227	172.23.0.10	Generic Protocol Command Decode	3	[1:2102466:9] GPL NETBIOS SMB-DS IPC$ unicode
4/5/2012 10:15:00 PM	172.23.0.236	172.23.0.10	Generic Protocol Command Decode	3	[1:2103003:7] GPL NETBIOS SMB-DS Session Setu
4/5/2012 10:15:00 PM	172.23.0.236	172.23.0.10	Generic Protocol Command Decode	3	[1:2102466:9] GPL NETBIOS SMB-DS IPC$ unicode
4/5/2012 10:15:00 PM	172.23.0.215	172.23.0.10	Generic Protocol Command Decode	3	[1:2103003:7] GPL NETBIOS SMB-DS Session Setu
4/5/2012 10:15:00 PM	172.23.0.215	172.23.0.10	Generic Protocol Command Decode	3	[1:2102466:9] GPL NETBIOS SMB-DS IPC$ unicode
4/5/2012 10:15:00 PM	172.23.0.229	172.23.0.10	Generic Protocol Command Decode	3	[1:2103003:7] GPL NETBIOS SMB-DS Session Setu
4/5/2012 10:15:00 PM	172.23.0.229	172.23.0.10	Generic Protocol Command Decode	3	[1:2102466:9] GPL NETBIOS SMB-DS IPC$ unicode
4/5/2012 10:15:00 PM	172.23.0.216	172.23.0.10	Generic Protocol Command Decode	3	[1:2103003:7] GPL NETBIOS SMB-DS Session Setu
4/5/2012 10:15:00 PM	172.23.0.216	172.23.0.10	Generic Protocol Command Decode	3	[1:2102466:9] GPL NETBIOS SMB-DS IPC$ unicode
4/5/2012 10:15:00 PM	172.23.0.219	172.23.0.10	Generic Protocol Command Decode	3	[1:2103003:7] GPL NETBIOS SMB-DS Session Setu
4/5/2012 10:15:00 PM	172.23.0.249	172.23.0.10	Generic Protocol Command Decode	3	[1:2103003:7] GPL NETBIOS SMB-DS Session Setu
4/5/2012 10:15:00 PM	172.23.0.249	172.23.0.10	Generic Protocol Command Decode	3	[1:2102466:9] GPL NETBIOS SMB-DS IPC$ unicode
4/5/2012 10:15:00 PM	172.23.0.245	172.23.0.10	Generic Protocol Command Decode	3	[1:2103003:7] GPL NETBIOS SMB-DS Session Setu
4/5/2012 10:15:00 PM	172.23.0.245	172.23.0.10	Generic Protocol Command Decode	3	[1:2102466:9] GPL NETBIOS SMB-DS IPC$ unicode
4/5/2012 10:15:00 PM	172.23.0.239	172.23.0.10	Generic Protocol Command Decode	3	[1:2103003:7] GPL NETBIOS SMB-DS Session Setu
4/5/2012 10:15:00 PM	172.23.0.239	172.23.0.10	Generic Protocol Command Decode	3	[1:2102466:9] GPL NETBIOS SMB-DS IPC$ unicode
4/5/2012 10:15:00 PM	172.23.0.233	172.23.0.10	Generic Protocol Command Decode	3	[1:2103003:7] GPL NETBIOS SMB-DS Session Setu
4/5/2012 10:15:00 PM	172.23.0.233	172.23.0.10	Generic Protocol Command Decode	3	[1:2102466:9] GPL NETBIOS SMB-DS IPC$ unicode

She noticed a sequence of alerts which reports connections via port 6667.

	Priority	Description	SourcePort	DestPor
col Command Decode	3	[1:2103003:7] GPL NETBIOS SMB-DS Session Setup NTMLSSP unicode asn1 overflow atten	[illegible]	445
col Command Decode	3	[1:2102466:9] GPL NETBIOS SMB-DS IPC$ unicode share access	1912	445
	3	[1:2000355:5] ET POLICY IRC authorization message	6667	6650
	3	[1:2000355:5] ET POLICY IRC authorization message	6667	6651
	3	[1:2000355:5] ET POLICY IRC authorization message	6667	6657
col Command Decode	3	[1:2103003:7] GPL NETBIOS SMB-DS Session Setup NTMLSSP unicode asn1 overflow atten	3420	445
col Command Decode	3	[1:2102466:9] GPL NETBIOS SMB-DS IPC$ unicode share access	3420	445
col Command Decode	3	[1:2103003:7] GPL NETBIOS SMB-DS Session Setup NTMLSSP unicode asn1 overflow attempt	3504	445
col Command Decode	3	[1:2102466:9] GPL NETBIOS SMB-DS IPC$ unicode share access	3504	445
col Command Decode	3	[1:2103003:7] GPL NETBIOS SMB-DS Session Setup NTMLSSP unicode asn1 overflow attempt	3444	445
col Command Decode	3	[1:2102466:9] GPL NETBIOS SMB-DS IPC$ unicode share access	3444	445
col Command Decode	3	[1:2103003:7] GPL NETBIOS SMB-DS Session Setup NTMLSSP unicode asn1 overflow attempt	3484	445
col Command Decode	3	[1:2102466:9] GPL NETBIOS SMB-DS IPC$ unicode share access	3484	445
col Command Decode	3	[1:2103003:7] GPL NETBIOS SMB-DS Session Setup NTMLSSP unicode asn1 overflow attempt	3471	445
col Command Decode	3	[1:2102466:9] GPL NETBIOS SMB-DS IPC$ unicode share access	3471	445

She knew that this port is used for IRC (Internet Relay Chat) connections and IRC connections could be used for malicious purpose.

So she generated a hypothesis about an attack event: malicious communications are going through this port (true alert).

To investigate the hypothesis, she decided to check the detailed information about these connections in firewall logs.

DataTime	Priority	Operation	Protocol	SrcIP	DesIP	SrcPort	DesPort	DestService	Direction
4/5/2012 10:15:00 PM	Info	Teardown	TCP	172.23.240.152	10.32.5.56	5203	6667	6667_tcp	outbound
4/5/2012 10:15:00 PM	Info	Teardown	TCP	172.23.235.50	10.32.5.52	2316	6667	6667_tcp	outbound
4/5/2012 10:15:00 PM	Info	Teardown	TCP	172.23.238.127	10.32.5.54	3330	6667	6667_tcp	(empty)
4/5/2012 10:15:00 PM	Info	Teardown	TCP	172.23.238.124	10.32.5.54	3329	6667	6667_tcp	(empty)
4/5/2012 10:15:00 PM	Info	Teardown	TCP	172.23.238.121	10.32.5.59	3306	6667	6667_tcp	(empty)
4/5/2012 10:15:00 PM	Info	Teardown	TCP	172.23.238.78	10.32.5.52	3336	6667	6667_tcp	(empty)
4/5/2012 10:15:00 PM	Info	Built	TCP	172.23.233.51	10.32.5.51	6637	6667	6667_tcp	outbound
4/5/2012 10:15:00 PM	Info	Built	TCP	172.23.233.50	10.32.5.57	6638	6667	6667_tcp	outbound
4/5/2012 10:15:00 PM	Info	Built	TCP	172.23.233.56	10.32.5.58	6639	6667	6667_tcp	outbound
4/5/2012 10:15:00 PM	Info	Teardown	TCP	172.23.233.50	10.32.5.57	6638	6667	6667_tcp	outbound
4/5/2012 10:15:00 PM	Info	Teardown	TCP	172.23.233.56	10.32.5.58	6639	6667	6667_tcp	outbound
4/5/2012 10:15:00 PM	Info	Built	TCP	172.23.233.58	10.32.5.51	6640	6667	6667_tcp	outbound
4/5/2012 10:15:00 PM	Info	Built	TCP	172.23.233.52	10.32.5.59	6641	6667	6667_tcp	outbound
4/5/2012 10:15:00 PM	Info	Teardown	TCP	172.23.233.58	10.32.5.51	6640	6667	6667_tcp	outbound

It indicates that such connections are between internal workstations and external web servers.

Policy Violated!

Strengthen previous hypothesis (i.e. malicious IRC connections).

Motivation: The Potential Benefits of Understanding the Analysis Process

Decision Maker:

Assess how valid and reliable the conclusion is.

Analyst:

Reflect and improve.

Analyst/ Instructor:

Extract knowledge and experience.

Instructor/ Program Manager:

Training

Technology Provider:

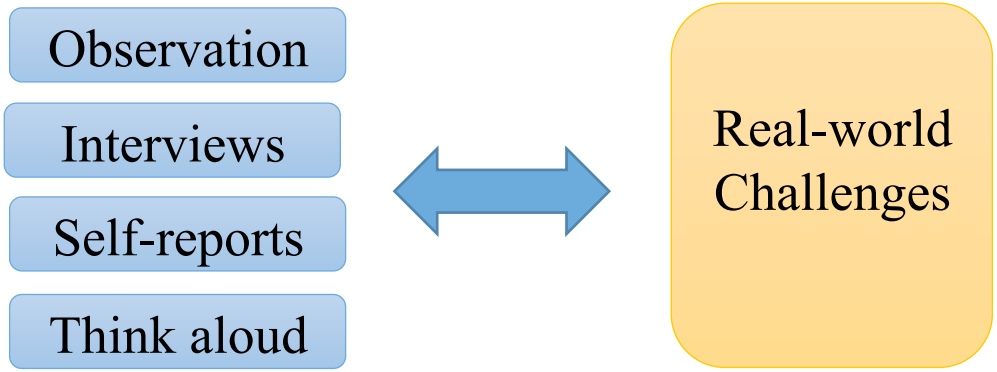
Identify analysts' need and improve tools.

PENNSTATE 1855 ARL

Cognitive Task Analysis (CTA)

Cognitive Task Analysis (CTA) is a family of methods that help researchers understand the human's cognitive activities in performing tasks.

Related Work: Existing CTAs in this Domain



Sensitive information of the network and employees.

Tight schedule

Sensitive to interruption

- Resource-intensive, hard for researcher/administrator to replicate.
- Growing need for studying the analysts' analysis process

Our Method for Capturing Analysts' Cognitive Processes

An Integrated Computer-Aided Cognitive Task Analysis Data Collection Method

A Conceptual Model:
Representing the analytical reasoning processes

An Interactive Tool:
Capturing the analytical reasoning processes

An Experiment:
Traces are collected when subjects are performing a cyber analysis task.

Part 1: What to Capture

An Integrated Computer-Aided Cognitive Task Analysis Data Collection Method

A Conceptual Model:
Representing the analytical reasoning processes

An Interactive Tool:
Capturing the analytical reasoning processes

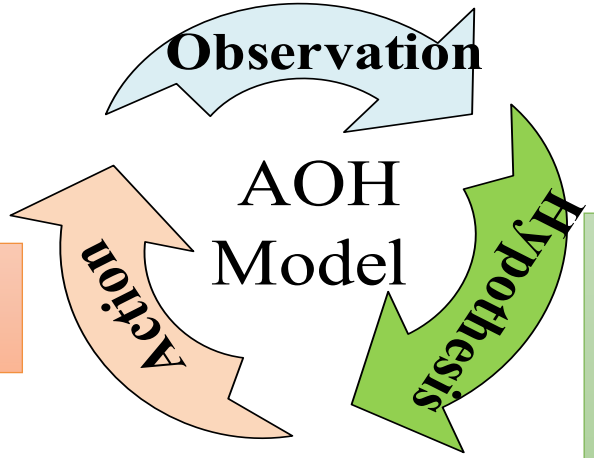
An Experiment:
Traces are collected when subjects are performing a cyber analysis task.

- Critical Elements in Analysts' Analysis Processes
  - **A: Actions** in data exploration
  - **O: Observations** of evidence
  - **H: Hypothesis** about the attack events

PENNSTATE 1855 ARL

The AOH Conceptual Model: Main Elements

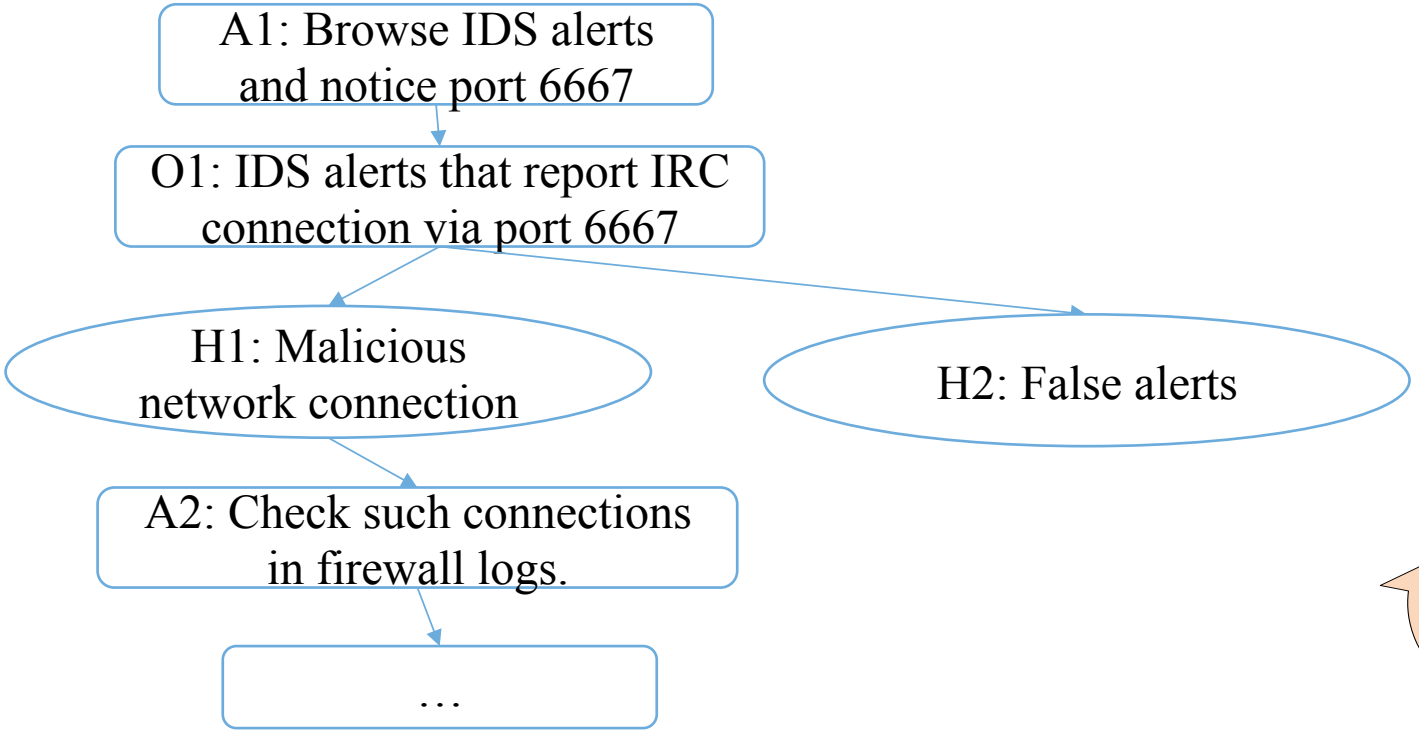
e.g. A sequence of IDS alerts about the IRC connection.

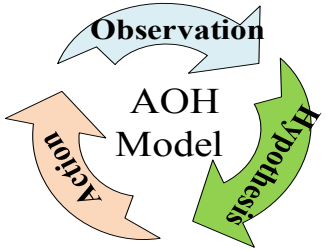


e.g. Browsing the IDS alerts.

A vague insight or a in-depth understanding of an attack event
e.g. The IDS alerts indicate that IRC connections could be used for malicious purpose.

The AOH Conceptual Model: Relationships Between the Objects of A, O and H





Cyber Security Analysis: Creating and Linking Actions, Observations and Hypotheses

Operation	Description
BROWSE	BROWSE$(D_i), D_i \subseteq \bigcup DS_i$*: Browse the data sources.
FILTER	FILTER$(DS_i, Cond.)$: Filter the source data DS_i based on condition $Cond.$
SEARCH	SEARCH$(D_i, K), D_i \subseteq \bigcup DS_i$: Search K in data D_i.
INQUIRE	INQUIRE(T_m): Inquire about a term T_m
SELECT	SELECT$(D_i), D_i \subseteq \bigcup DS_i$:Select the data of interest in D_i .
SELECTED *	*(*Come in pairs with SELECT*) SELECTED$(D_i), D_i \subseteq \bigcup DS_i$: The selected data of interest
LINK	LINK$(D_i,\ L), D_i \subseteq \bigcup DS_i$: The links L among the selected data D_i (e.g. common features in D_i)
NEW_HYPO	NEW(h, O): Generate a *hypothesis* h in the context of *observation* O.
MODIFY	MODIFY$(h,\ v_1, v_2)$: Modify the content of an hypothesis h from v_1 to v_2
SWITCH CONTEXT	SWITCH_CONTEXT(h_1, h_2): Change current focus of attention from *hypothesis* h_1 to *hypothesis* h_2.
CONFIRM/ DENY	CONFIRM_DENY$(h_1, Y/N)$: Confirm or deny an *hypothesis* h_1.

Trace: Representation of the Analysis Process

Definition 1: A cognitive trace $\mathcal{T}\mathbf{r}$ is a sequence of items $\mathbf{p}_1,\ldots,\mathbf{p}_n$, $\forall \mathbf{p}_i\ 1 \leq i \leq n$, $\mathbf{p}_i$ is a tuple $(t_i, op_i(I, C_i))$, where $\mathbf{t}_i$ is the timestamp, $op_i(I, C_i)$ is an operation on a cognitive activity I under the context C_i. I is an action, observation or hypothesis, C_i is a set of connections between I with the existing actions, observations and hypotheses.

Timestamp	Operation
t1	**FILTER** (Firewall logs, Port = 6667)
t2	**SELECT**(Log entries with Port 6667)
t3	**NEW_HYPO**(IRC communication)
t4	…

Part 2: A Tool (ARSCA) for CTA Data Collection

An Integrated Computer-Aided Cognitive Task Analysis Data Collection Method

A Conceptual Model:
Representing the analytical reasoning processes

An Interactive Tool:
Capturing the analytical reasoning processes

An Experiment:
Traces are collected when subjects are performing a cyber analysis task.

- Reduce interruption and alleviate the privacy concern
- Capturing in an efficient way

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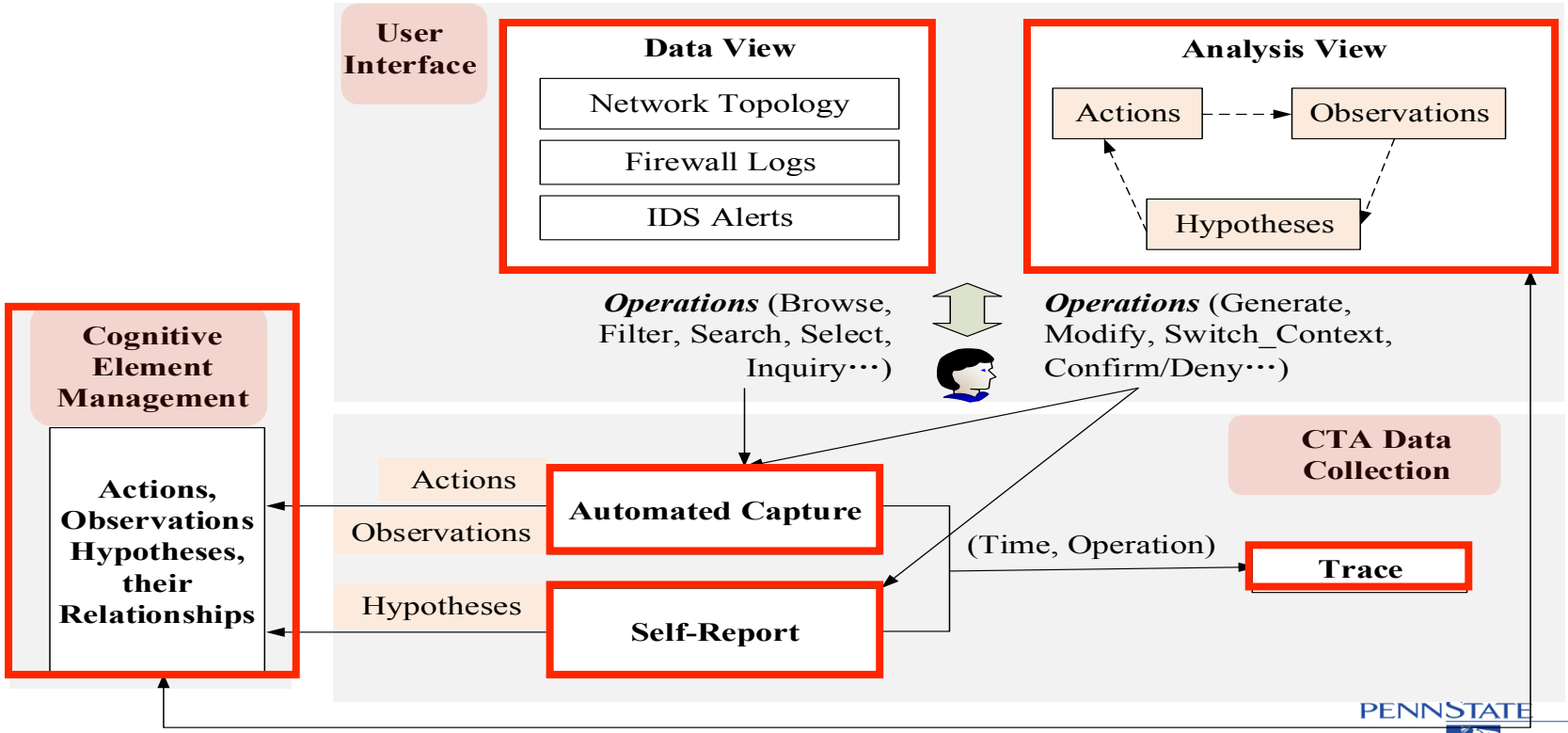
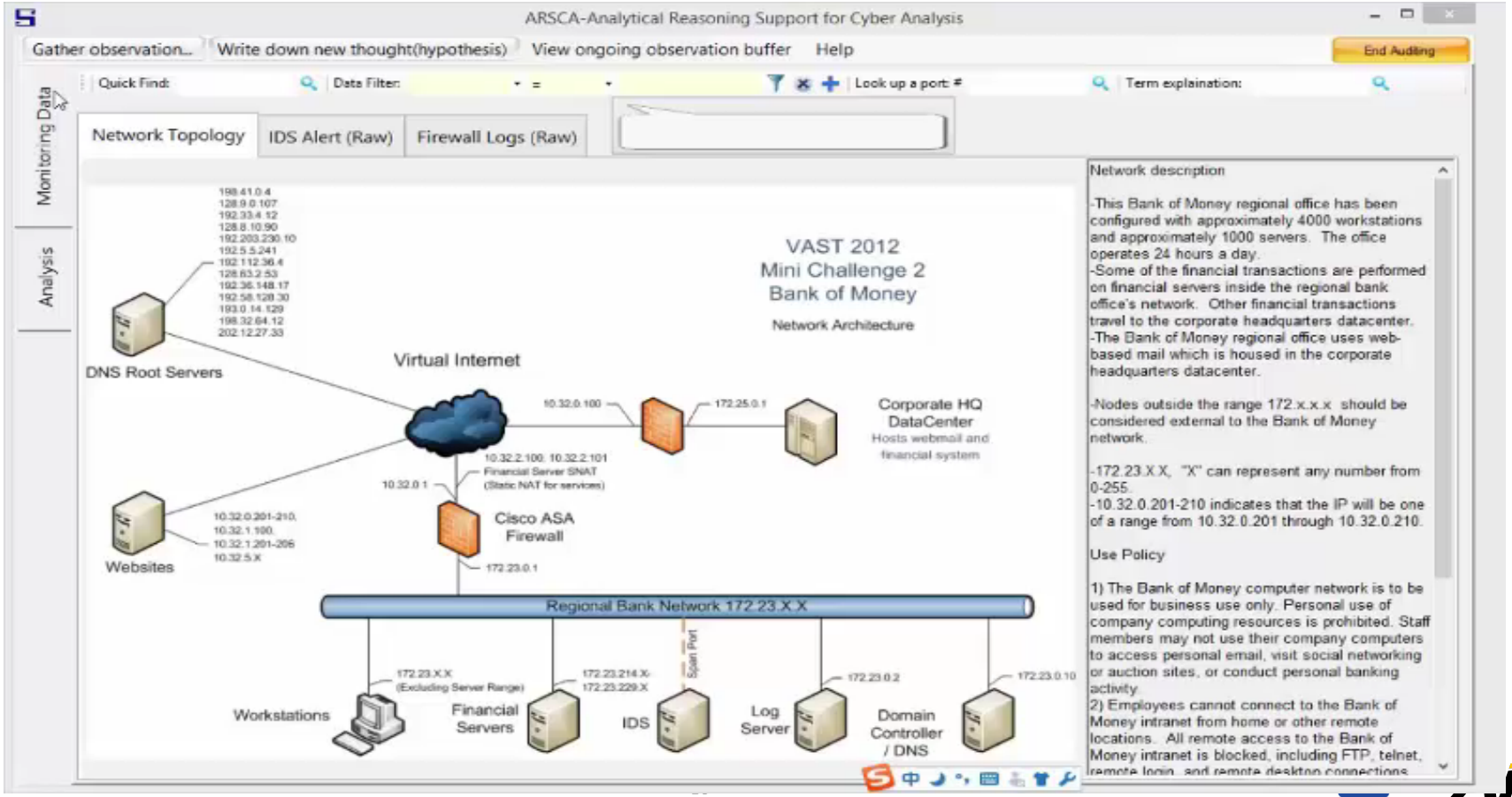
ARSCA Architecture



How an Analyst Works with ARSCA? (Video)



ARSCA Output: Trace

```
23  <Item Timestamp="07/31 13:01:41">
24  FILTER(
25   SELECT * FROM Task2IDS WHERE SourcePort = '6667',
26  Task2IDS
27  )
28  </Item>
29
30  <Item Timestamp="07/31 13:01:46">,
31  SELECT (
32  A[1:2000355:5]-[10.32.5.54]-[172.23.232.252],
33  A[1:2000355:5]-[10.32.5.56]-[172.23.233.59],
34  A[1:2000355:5]-[10.32.5.54]-[172.23.238.124],
35  ...)
36  </Item>
37
38  <Item Timestamp="07/31 13:02:01">
39  LINK (
40  Same Sourt Port and IDS alert
41  )
42  </Item>
43
44  <Item Timestamp="07/31 13:04:06">
45  NEW (
46  H46131157 The network is not secure,
47  H67531068 IDS IRC Alerts are true: The IDS alerts are showing IRC authorization alerts over tcp/6667.
    This is the default IRC communication port, and this communication is between the workstation IPs and
    external resources.
48
49  In this situation this could indicate that there has been a policy violating because IRC communication
    on this network isn't allowed.  Or this could also be an indicator of compromise because malware can
    leverage IRC for Command to Control (C2) communication.
50  )
51  </Item>
```

FILTER: Filter the IDS alerts

SELECT: Select a set of entries as an observation

LINK: The selected entries have common source port and alerts

NEW_HYPO: create a hypothesis based on the above observation.

Integration of Automated Tracing and Self-Reports

Tracking Actions (A)
Automated Capture

Tracking Observations (O)
Automated Capture

Automated tracing

+ Efficient
+ Not interruptive
- No comments from subjects, hard to analyze the captured data

Management of As, Os and Hs

- Automatically maintain the relationships between A, O, H
- Facilitate reflection

Tracking Hypotheses (H)
Self-reports

Self-reports

+ Information confirmed by the subjects.
- Depends on the subjects' willingness.
- Distraction

Part 3: Experiment for CTA Data Collection

An Integrated Computer-Aided Cognitive Task Analysis Data Collection Method

A Conceptual Model:
Representing the analytical reasoning processes

An Interactive Tool:
Capturing the analytical reasoning processes

Lab Experiment:
Traces are collected when subjects are performing a cyber analysis task.

- Evaluate the method
- Traces can be used for studying the analysis processes

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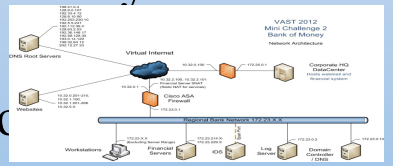
Overview of the Lab Experiment

30 Participants

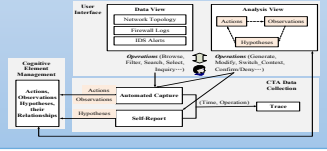
- 13 professional analysts
- 17 doctoral students

Simulated Cyber Security Analysis Task

- 2 Network Data Sources
- Multi-step Attack Scenario



Process Tracing Tool (ARSCA)



ARSCA collected the **Traces** of the participants' cognitive processes.

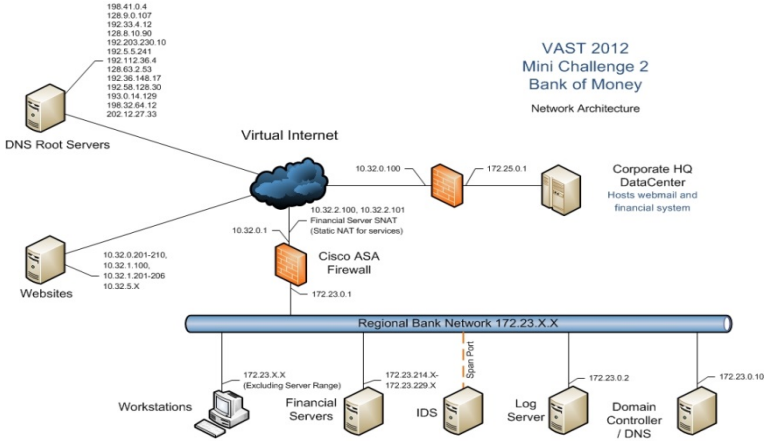
Post-task questionnaires collected Feedbacks.

Experiment Design: Task Design

- Requirements:
  - Reasonable complexity for the analysts
  - Close to the real-world data
    - Volume and Complexity of the monitoring data sets
  - Moderate workload so that analysts can finish the task in the experiment.

Tailored from VAST 2012 Challenge

- A 10-minute time window (in the original 40-hour attack scenario)
- Contain 3 main attack events
  - IRC communications,
  - Denied FTP connections for data stealing
  - Successful SSH connections for data stealing
- 239 IDS alerts and 115,524 firewall logs.



Experiment Design: Procedure

- **Pre-task Questionnaire (5 min)**
  - Demographic factors
  - Domain knowledge and expertise of cyber security analysis
  - Familiarity with VAST Challenge 2012
  - Current mental and physical status
- **Tutorial (20 min)**
  - Introduce the tool features.
  - Analysts need to pass a quiz before going to the next step
- **Conducting the task (At most 60 min)**
  - At the beginning, we just introduce the task and background information.
  - We didn't provide any instruction to intentionally ask analysts to self report.
- **Post-task Questionnaire (15 min)**
  - Open-ended questions
  - Close-ended rating questions using a 5-point Likert scale

The effect of analysts' proficiency with the tool on their task performance

To ensure self-motived behavior.

Evaluate the Method from Four Aspects

- Q1: Whether the method can help us successfully conduct CTA data collection in the cyber security domain?
- Q2: Whether the collected data (traces) contain the key elements in analysts' analysis processes?
- Q3: Whether the analysts' analysis process can be recovered from the captured data (traces)?
- Q4: Whether the analysts' analysis processes recovered from the traces are close to the original ones?

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Participants' Feedbacks

(1) **TASK_CMP:** *"The task is of reasonable complexity regarding the analysis activities it involves (e.g. data exploration, thinking reasoning, making decisions)."*

(2) **SET_CFT:** *"I felt comfortable with the provided software, and my performance is not hindered by it."*

(3) **EXP_RFL:** *"My capability/expertise of cyber analysis is fully leveraged and is reflected in accomplishing the task."*

(4) **CONC:** *"I'm fully concentrated in accomplishing the task."*

Likert Scale Response*		Post-task Questions				Total
		TASK_CMP	SET_CFT	EXP_RFL	CONC	
Disagree	**1**	0 (0,0)	1 (1,0)	0 (0,0)	0 (0,0)	1
	2	1 (1,0)	3 (1,2)	4 (3,1)	2 (0,2)	10
Neutral	**3**	9 (5,4)	7 (2,5)	11 (6,5)	4 (2,2)	31
Agree	**4**	**14** (9,5)	**14** (9,5)	**13** (4,9)	**21** (12,9)	**62**
	5	6 (2,4)	5 (0,5)	2 (0,2)	3 (3,0)	16

* Numbers in brackets refer to *professional analysts* and *doctoral students* respectively.

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Q2: Whether the collected data (traces) contain the key elements in analysts' analysis processes?

Open-ended Questions in Post-task Questionnaire:

(1) **IMP_OBS**: *"Reflecting back, what are the 3 most important evidences that you observed in the data that contributed to your conclusion?"*

(2) **FD_OBS**: *"Please explain how you find the above evidences."*

(3) **IMP_HPY**: *"Reflecting back, what are the 3 most important thoughts in your mind that contributed to your conclusion?"*

(4) **EVTS**: *"Based on your analysis, please create one or more narratives that describe the events on the network (i.e. tell the storyline of the potential events)".*

To check whether the information in the answers had been captured in the traces.

Q2: Whether the method captures the key elements in analysts' analytical reasoning processes?

Cleaning

To weed out the irrelevant answers ("the tool is helpful") and vacuous answers ("I don't have any comment").

Compare with Traces

Content Analysis

I conclude that there was likely IRC communication on the network. This could have
#[H]: IRC communication #

been a policy violation or malware C2 communication. In addition, I saw attempts for
#[H]: Policy violation or Malware C2 Communication #

FTP (tcp/21), SSH (tcp/22), and HTTP (tcp/80) from internal address space to the
[H]: FTP attempt # #[H]: SSH attempt # # [H]: HTTP attempt#

internet, which are policy violations. Lastly, there were a large number of IDS alerts
#[O]: inside->outside # #[O]: inside->outside # #[O]: inside->outside #

that were generated about SMB null sessions and overflow attempts which point to
#[O]: IDS alerts about SMB null session # #[O]: IDS alerts about SMB overflow attempts #

potentially malicious activity over SMB.
#[H] Malicious activity over SMB) #

Q2: Whether the method captures the key elements in analysts' analysis processes?

- Data Cleaning:
  - "IMP_OBS": 30 answers
  - "FD_OBS": 27 answers
  - "IMP_HPY": 29 answers
  - "EVTS": 29 answers
- Content Analysis
  - Generated 318 themes in these answers.

- "IMP_OBS", "IMP_HPY" and "EVTS"
  - All the themes are captured in traces.
- "FD_OBS"
  - 5 themes in its answers are not captured by the trace.
  - Domain knowledge (e.g. "some ports are always used for malicious connections")
  - Implicit assumption made by the participants (e.g. "outbound connections are not allowed by the network policy")

Not explicitly captured but can be inferred.

Evaluate the Method from Four Aspects

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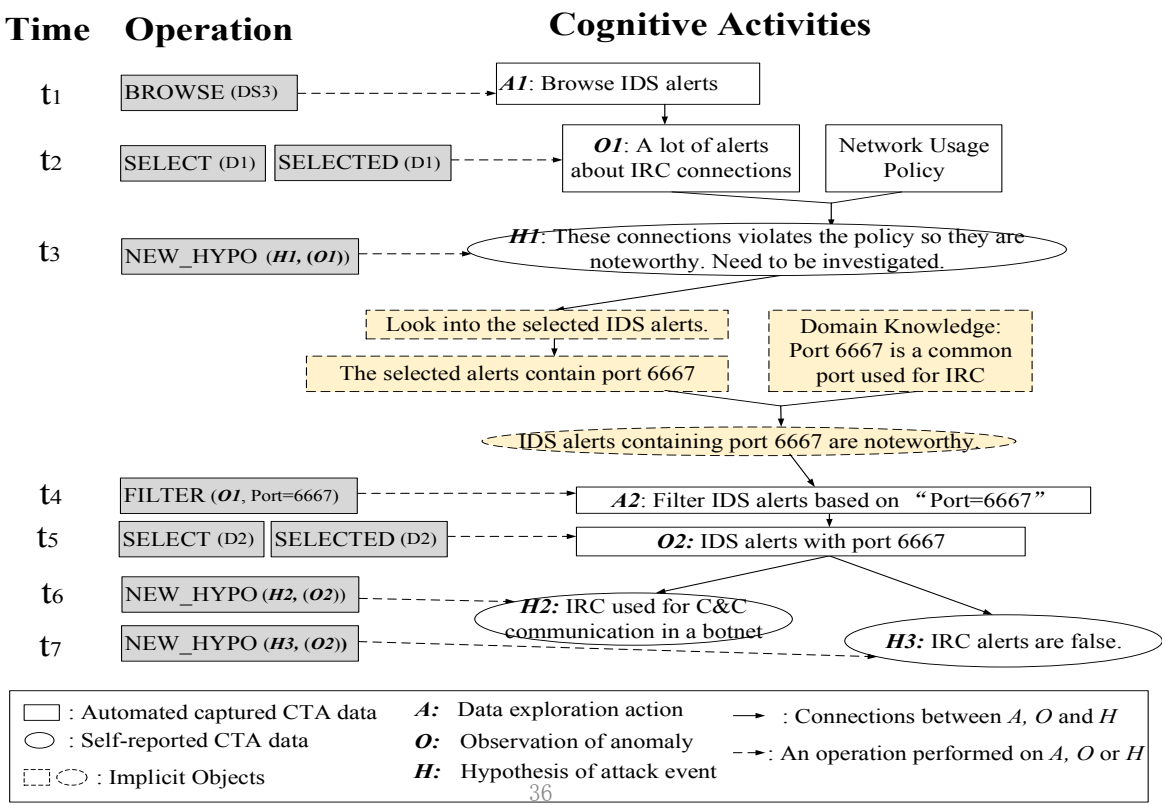
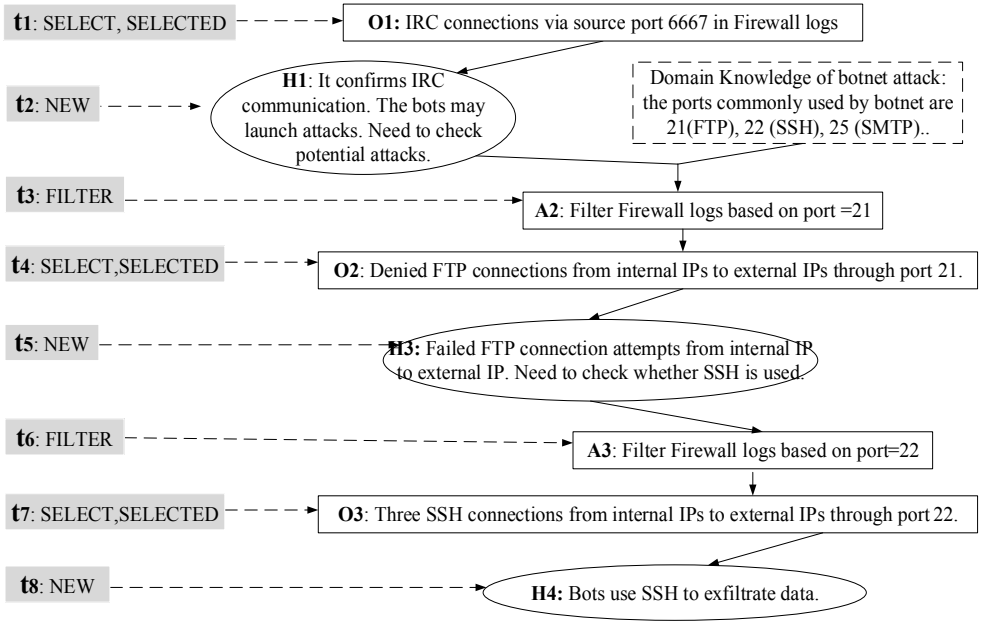
Q3: Whether the analysts' analysis process can be recovered from the captured data (traces)?



An Example: Proceeding From One Event to its Associated Events



Hypotheses:

- Malicious IRC communication to C&C
- →
- Possible Follow-up events: Data Exfiltration

Largely relies on his experience gained from long-term on-the-job training.

Evaluate the Method from Four Aspects

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Q4: Whether the analysts' analysis processes recovered from the traces are close to the original ones?

CTA Data in Traces Complement Each Other

Automated-captured CTA data

Operations on Action and Observation
e.g. FILTER, SEARCH, SELECT

Self-reported CTA data

Operations on Hypothesis
e.g. NEW_HYPO

1. Automatically captured **action** describes automatically captured **observation**

Our Interpretation

A3: Go to Firewall logs,
Filter Firewall logs based on source port 6667

O3: Connections between internal IPs and external IPs via source port 6667

Information in Trace

```
<Item Timestamp="05/24 13:24:15">
    FILTER ( SELECT * FROM Task2Firewall WHERE Port = 6667,
Task2Firewall)
</Item>
```

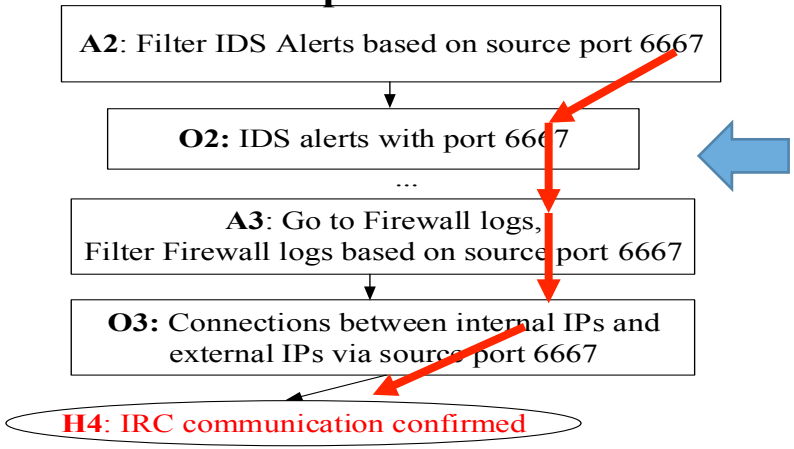
```
<Item Timestamp="05/24 13:25:29">
  SELECT (
    FIREWALL-[4/5/2012 10:15:00]-[Built]-[TCP]
      (172.23.240.254, 10.32.5.59),
    FIREWALL-[4/5/2012 10:15:00]-[Built]-[TCP]
      (172.23. 30.220, 10.32.5.57)  )
</Item>
```

CTA Data in Traces Complement Each Other

Automated-captured CTA data	Self-reported CTA data
Operations on Action and Observation e.g. FILTER, SEARCH, SELECT	Operations on Hypothesis e.g. NEW_HYPO

2. Automatically captured o**bservation** provides the context information for self-reported **hypothesis**

Our Interpretation



Information in Trace

```
...
<Item Timestamp="09/12 14:25:33">
  NEW_HYPO(
   Should be malicious IRC communication
</Item>
```

CTA Data in Traces Complement Each Other

Automated-captured CTA data	Self-reported CTA data
Operations on Action and Observation e.g. FILTER, SEARCH, SELECT	Operations on Hypothesis e.g. NEW_HYPO

3. Self-reported **hypothesis** explains the motivation of the following automatically captured **action**

Our Interpretation

O2: Denied FTP connections from internal IPs to external IPs through port 21.

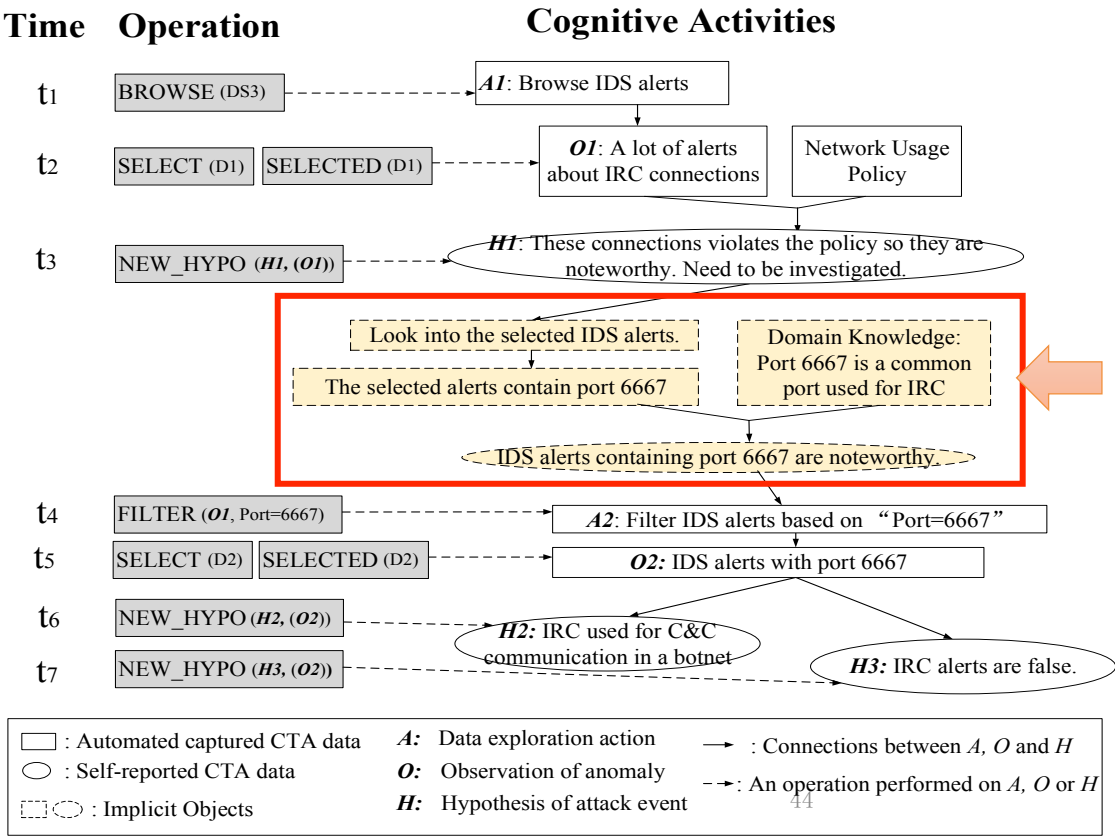
↓

H3: Failed FTP connection attempts from internal IP to external IP. Need to check whether SSH is used.

↓

A3: Filter Firewall logs based on port=22

Preliminary Trace-Stimulated Recall with a Professional Analyst



"I saw strings within the IDS alerts that meant IRC communication/traffic that was based on my <u>prior experience this is a default port for IRC</u>.

Conclusion: Integrating Automated Capture and Self-Report

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A Conceptual Model:
Representing the analytical reasoning processes

An Interactive Tool:
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An Experiment:
Traces are collected when subjects are performing a cyber analysis task.

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Benefits of Integrated Process Tracing

Tracking Actions (A)
Automated Capture

Tracking Observations (O)
Automated Capture

Overview of Analysis Process

- Automatically maintain the relationships between A, O, H
- Enable editing and Maintain Relationships

Tracking Hypotheses (H)
Self-reports

Automated capture facilitates self-reports

Self-Reports provides the subjects' comments on the automated captured information.

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Work in Progress…

An Integrated Computer-Aided Cognitive Task Analysis Data Collection Method

A Conceptual Model:
Representing the analytical reasoning processes

An Interactive Tool:
Capturing the analytical reasoning processes

An Experiment:
Traces are collected when subjects are performing a cyber analysis task.

Next Step: In-depth Trace Analysis

1. Behavior patterns, analysis strategy
2. Difference between experts and novices

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Thank You!
Q&A

Contact: czz111@psu.edu