NetSTAT

A Network-based Intrusion Detection Approach

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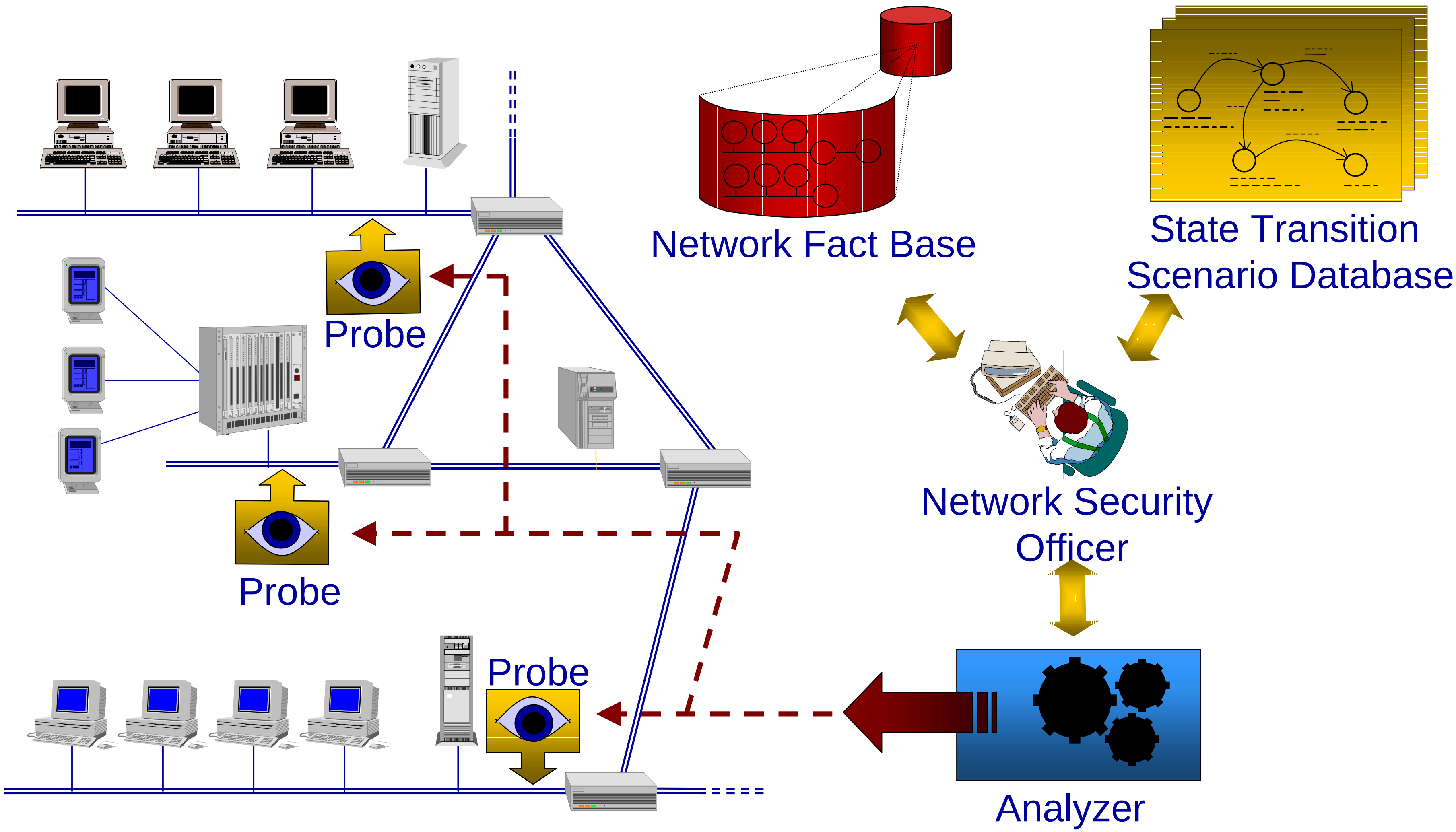
NetSTAT

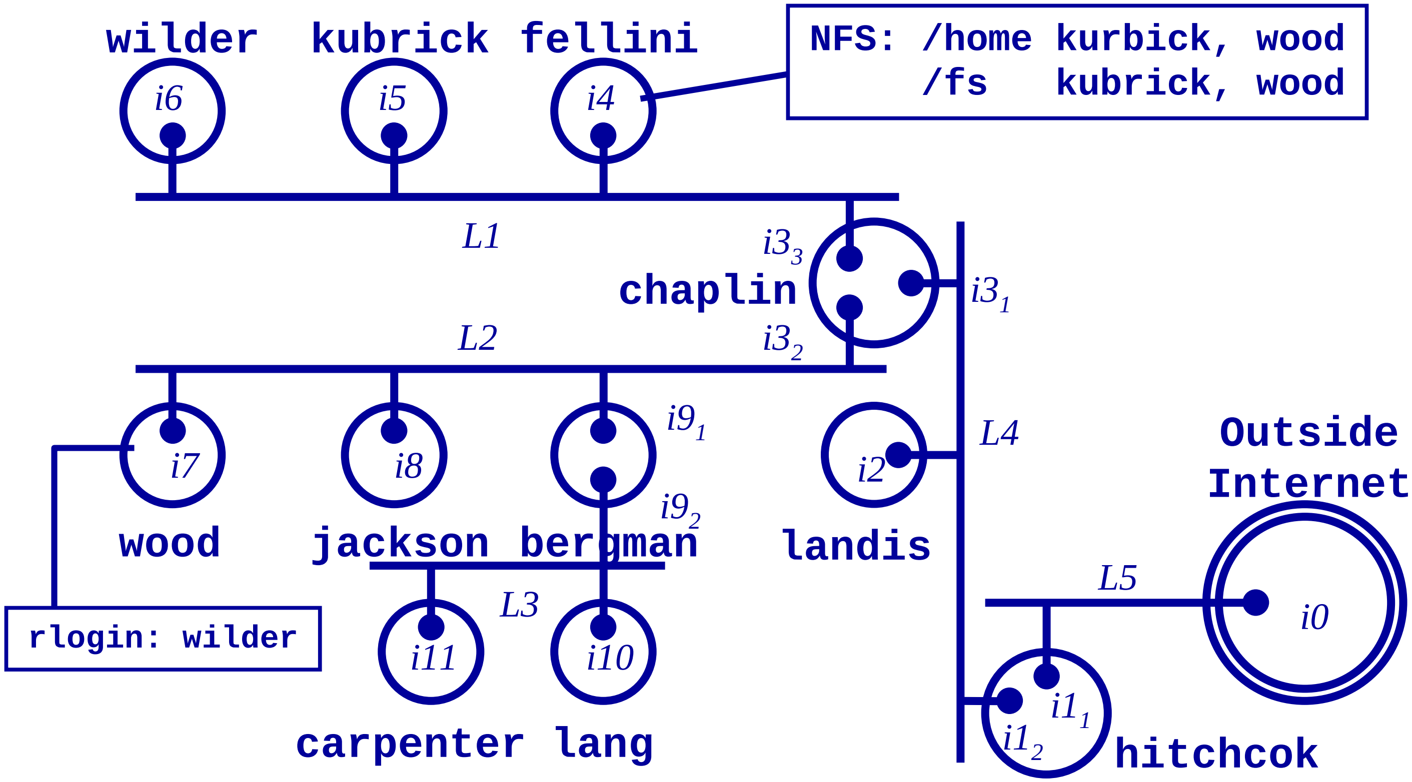
- Network-based real-time intrusion detection system
- Extends the *State Transition Analysis Technique* to represent attacks in a networked environment
- Uses *Network Hypergraphs* to represent the network topology and services
- Customizes generic attack scenarios to a target network (*what* to look for and *where* to look for it)
- Features distributed architecture with decentralized processing of events

Overview


Network Fact Base
State Transition
Scenario Database
Probe
Probe
Network Security
Officer
Probe
Analyzer

Network Fact Base

- Contains information about the network topology and the services deployed



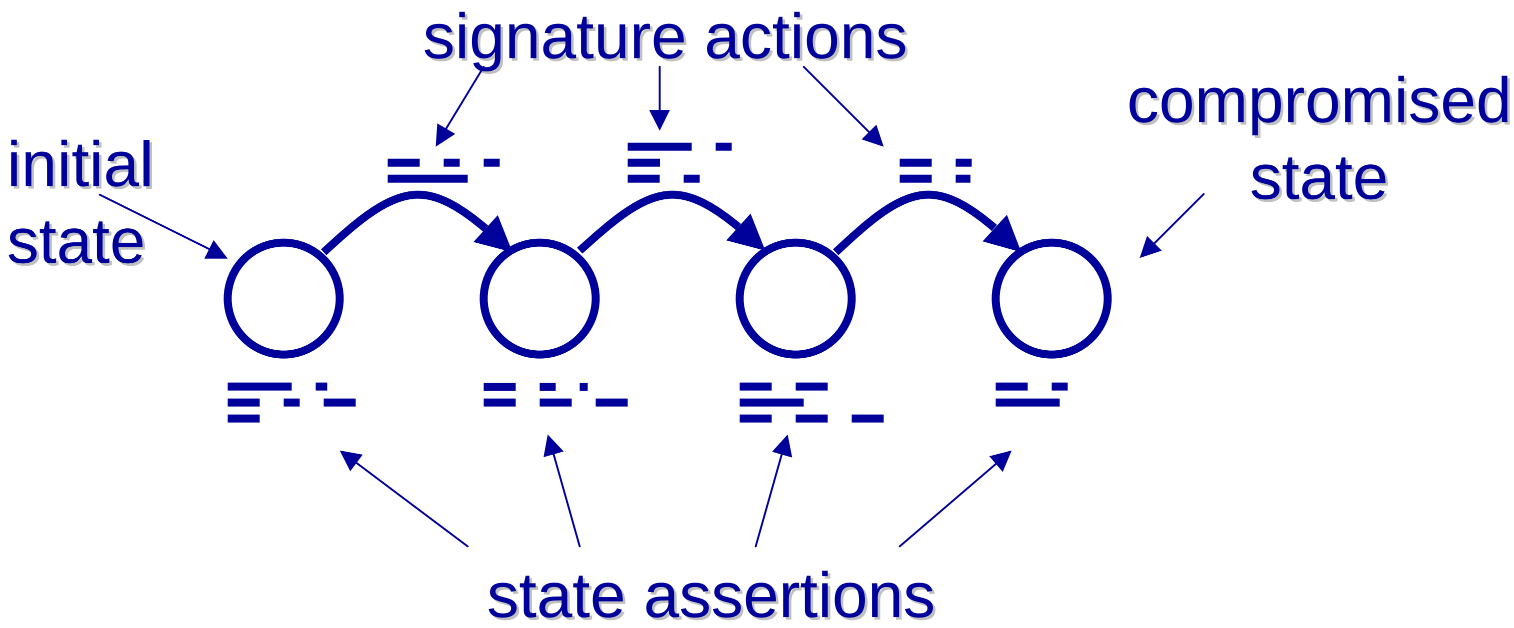
Advantages

- Provides well-defined semantics
- Supports reasoning and automation
- Models hosts and links in a uniform way (sets of interfaces)
- Allows natural modeling of shared-bus links

State Transition Scenario Database

- Manages the state/transition representations of the intrusion scenarios to be detected
- Representations based on the State Transition Analysis Technique (STAT)
- STAT born to represent intrusions in host-based IDSs (USTAT) and extended to distributed IDSs (NSTAT)
- Extended to represent intrusions in a networked environment
- State Transition Diagram: from a safe state to a compromised state through a series of signature actions

State Transition Diagrams



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States and Assertions

- State of the network
  - Active connections (connection-oriented services)
  - State of interactions (connectionless services)
  - Tables
- Assertions
  - Static assertions
  - Dynamic assertions

Static and Dynamic Assertions

- *Static assertions*
  - Verified by examining the Network Fact Base
  - Used to customize state transition representation for particular scenarios

```
Service s in server.services |
        s.name == “www” and
        s.application.name == “CERN httpd”;
```

- *Dynamic assertions*
  - Verified by examining the state of the network
  - Used to determine what relevant network state events should be monitored

```
ConnectionEstablished(addr1, port1, addr2, port2)
```

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Signature Actions

- Signature actions represent critical changes in the security state of the system
- For NetSTAT signature actions leverage off of an *event model*
- Basic event: *link-level message*

```
Message m {i_x,i_y} |
      m.length > 512;
```

- Composite events:
  - IP datagrams (sequence of link-level message used for delivery)
  - UDP datagrams and TCP segments (encapsulated in IP datagrams)
  - Application-level events (encapsulated in UDP datagrams or TCP streams)

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Examples

```
[IPDatagram d [UDPDatagram u [RPC r]]] {i_x, i_y} |
    d.dst == a_y and
    u.dst == 2049 and
    r.type == CALL and
    r.proc == MKDIR;

TCPSegment t in [VirtualCircuit c] {i_x, i_y} |
    c.dstIP == a_y and
    c.dstPort == 80 and
    t.syn == true;
```

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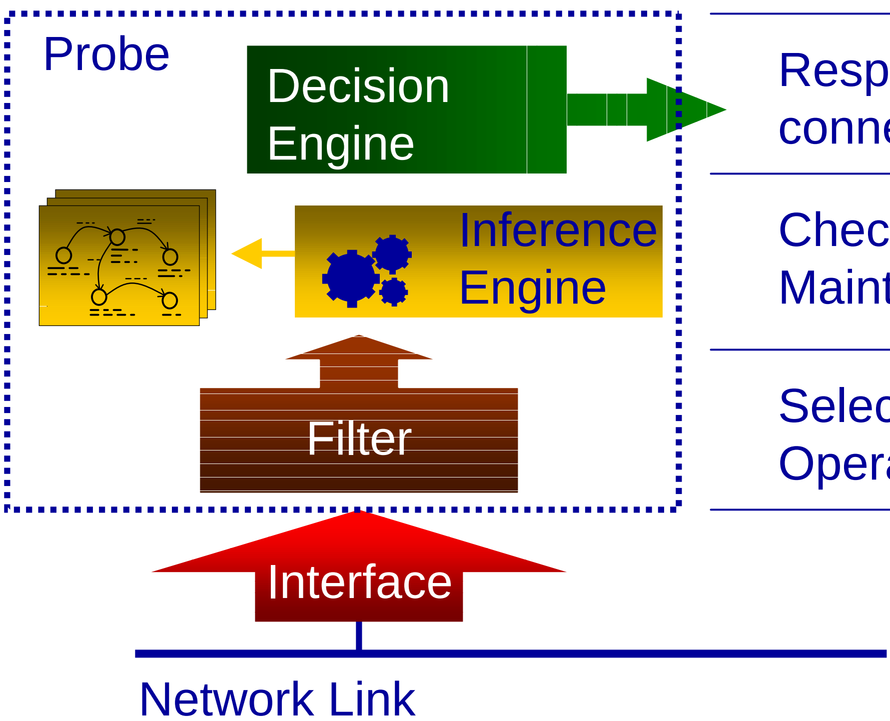
Probes

- Responsible for analyzing the stream of network events
- Configured and positioned by the Analyzer



Responds to attacks (log, warn, reset connections, etc.)

Checks for signature actions
Maintains track of STD evolution

Selects messages of interest
Operates reassembling

Analyzer

- Takes as input the Network Fact Base and the State Transition Scenario Database
- Determines:
  - Which events have to be monitored
  - Where the events have to be monitored
  - What information about the topology of the network is required to perform detection
  - What information about the state of the network must be maintained to be able to verify state assertions
- Produces a set of *probe configurations* and a *deployment plan*

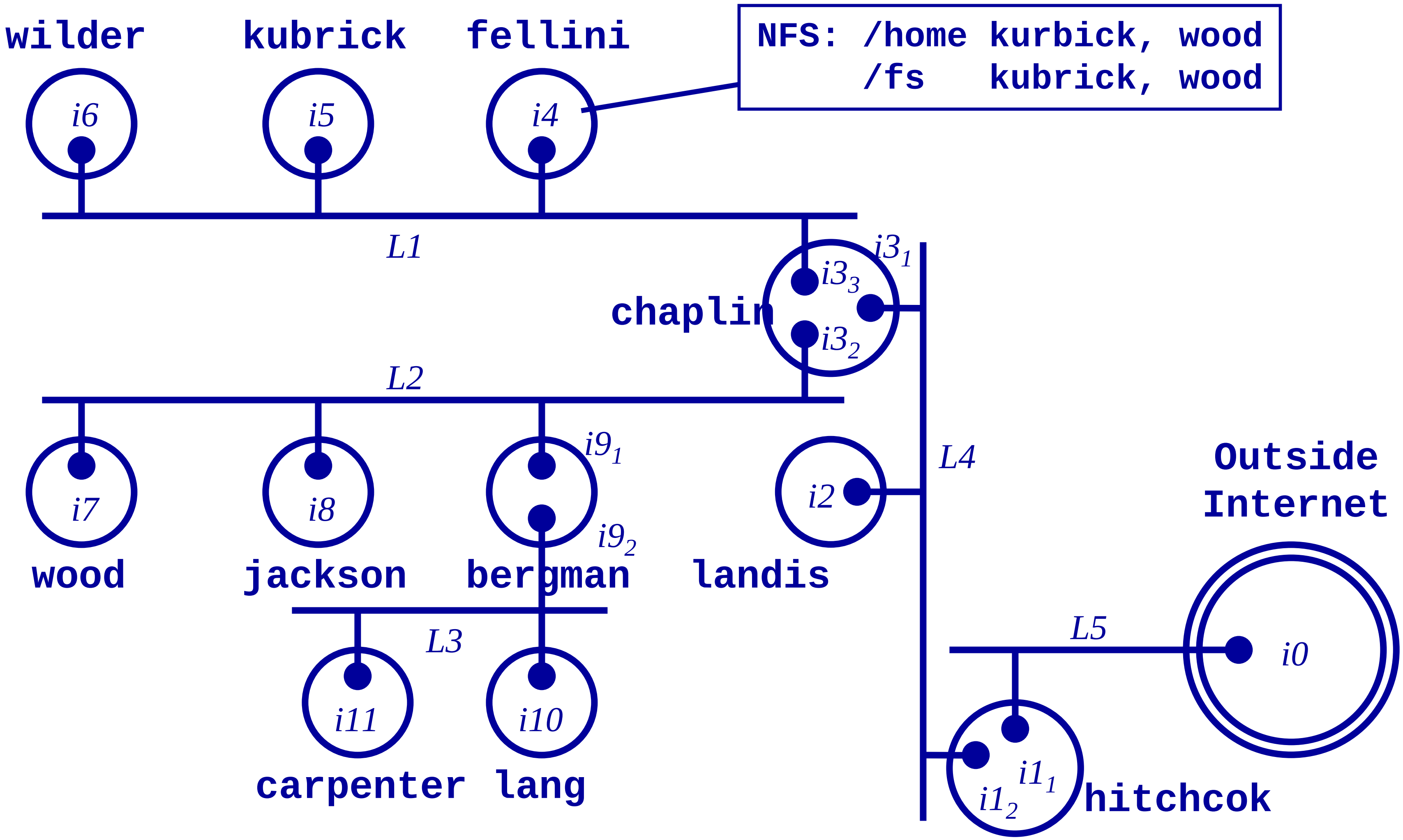
Configuration and Deployment

- NSO builds a database of attack scenarios using the State Transition Scenario Database
- NSO builds a network description using the Network Fact Base
- NSO selects a set of scenarios to be detected on the network
- The Analyzer performs the analysis and customization process
  - Mostly automated
  - May require help from the NSO in specific situations
- Configuration files are sent to probes

Example: UDP spoofing

- Service authentication based on source IP address
- An attacker tries to access a UDP-based service by pretending to be one of its trusted clients
- Attacker sends a forged UDP-over-IP datagram
- Attack detectable in particular topologies only

Sample Network



Attack Representation

```
Message m in [IPDatagram d [UDPDatagram u]] {i, a_v.interface}|
        d.src == a_t and
        d.dst == a_v and
        u.dst == s.port and
        not (Network.detachFromLink(m.src)).
                existsPath(m.src, d.src.interface);
```


```
Host victim in ProtectedNetwork.hosts;
Service s in victim.services |
        s.protocol == "UDP" and
        s.authentication == "IPaddress";
IPAddress a_v in s.addresses;
IPAddress a_t in s.trustedAddr;
Host attacker in Network.hosts |
        attacker != victim and
        not attacker.Ipaddresses.contains(a_t);
Interface i in attacker.interfaces;
```

Customization to Target Network

victim	s	a_v	a_t	attacker	i
fellini	**NFS**	*a4*	*a5*	**Outside**	*i0*
fellini	**NFS**	*a4*	*a7*	**Outside**	*i0*
fellini	**NFS**	*a4*	*a5*	**hitchcock**	$i1_1$
fellini	**NFS**	*a4*	*a7*	**hitchcock**	$i1_1$
…	…	…	…	…	…
fellini	**NFS**	*a4*	*a5*	**lang**	*i10*
fellini	**NFS**	*a4*	*a7*	**lang**	*i10*
fellini	**NFS**	*a4*	*a5*	**carpenter**	*i11*
fellini	**NFS**	*a4*	*a7*	**carpenter**	*i11*

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Probe placement and configuration

- For each scenario, the analyzer simulates the link-level messages that would be used to execute the attack
- The messages are then matched against the predicates contained in the attack's signature action
- The messages that satisfy the predicate can be used as a basis for attack detection
- One possible probe placement is chosen

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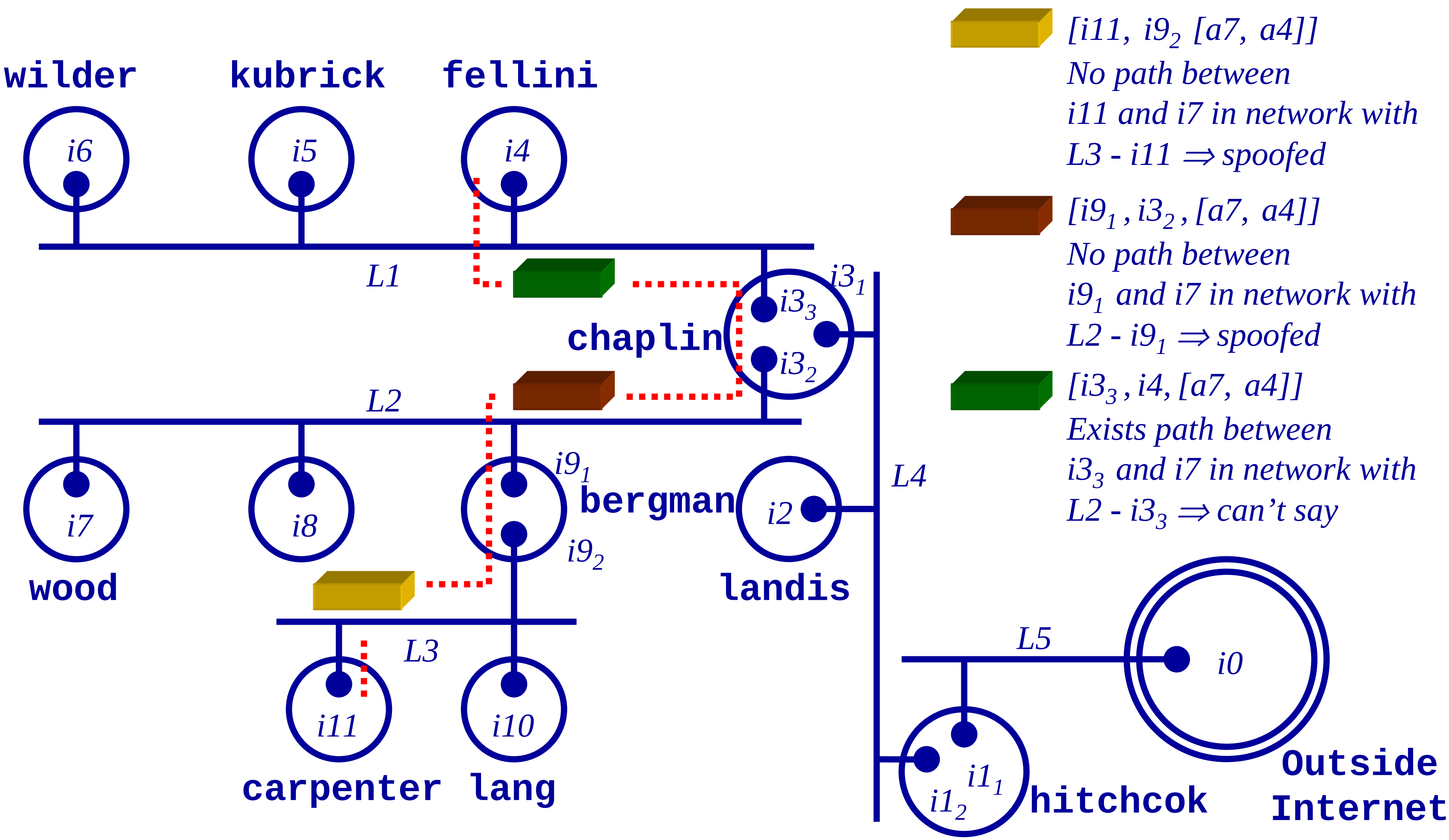
Example



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Conclusions

- Focused and efficient real-time network-based intrusion detection in complex topologies
- Attacks represented as STDs
- Networks represented as hypergraphs
- Detection mechanisms highly tailored to target networks
- Automated tool support for the Network Security Officer
- Distributed, modular architecture with local processing
- Scalable and interoperable

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Status

- Generic probe module completed
- Automatic deployment mechanisms for dynamic probe configuration developed
- More than 30 attacks analyzed and corresponding detection plug-ins developed
- Recently successfully completed participation to LL/AFRL IDSs evaluation
- People involved:
  - Richard Kemmerer, Steve Eckmann, Giovanni Vigna