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A Runtime Environment for Online Processing of Operating System Kernel Events

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OS Kernel Event Tracing

- **Dynamic Analysis**

- **Usage scenarios**
  - System analysis
  - Debugging
  - Runtime-state monitoring

- **Problem identification**
  - Search “bad” patterns in the event stream
  - Adapt the system as reaction to “bad” pattern

Advantages of event tracing

- **Detailed information**
- **Hints for solution might be available in trace**

- **… under the assumption that**
  - Meaningful set of events is monitored
  - System is usable with activated tracing

Limiting aspects

- **Problem identification**
  - Experienced administrators
  - → Pattern description
- **Huge logfiles**
  - Detailed event information requires space
  - → Online processing of events
- **Offline/Post-Mortem analysis model**
  - Activate tracing – deactivate – (reboot?) – analysis
  - → Execute callbacks / scripts when a pattern is detected

Agenda

- → **Pattern description**
- → **Online processing of events**
- → **Execute callbacks / scripts when a pattern is detected**

Pattern specification

- **Similar to regular expressions**
  - Sequence `[a, b, c]`
  - Alternative `(a | b | c)`
  - Negation `~a`

  - Simple events `event:name`
  - Arrays of events `event[>4]:name`

  - Conditions `WHERE`
  - Timeframe `WITHIN`
  - Result data `RETURN`

Example

Import Event Types

Rule Name

Event Pattern

```
EVENTS “wmkevents.h”

RULE nosyscallexit
  PATTERN {
    [syscall:a, ~(syscallexit|threadtermination), syscall]
  }
  WHERE  { [ProcessId],
           [ThreadId],
           a.SyscallNr < 300 }
  RETURN { a.SyscallNr,
           a.TimeStamp }
```

Conditions

Return Values

Join fields in **WHERE** statement

- **Abbreviated form ...**

```
PATTERN {
  [syscall:a, ~(syscallexit|threadtermination), syscall]
}
WHERE  { [ProcessId],
         [ThreadId] }
```

- **... instead of**

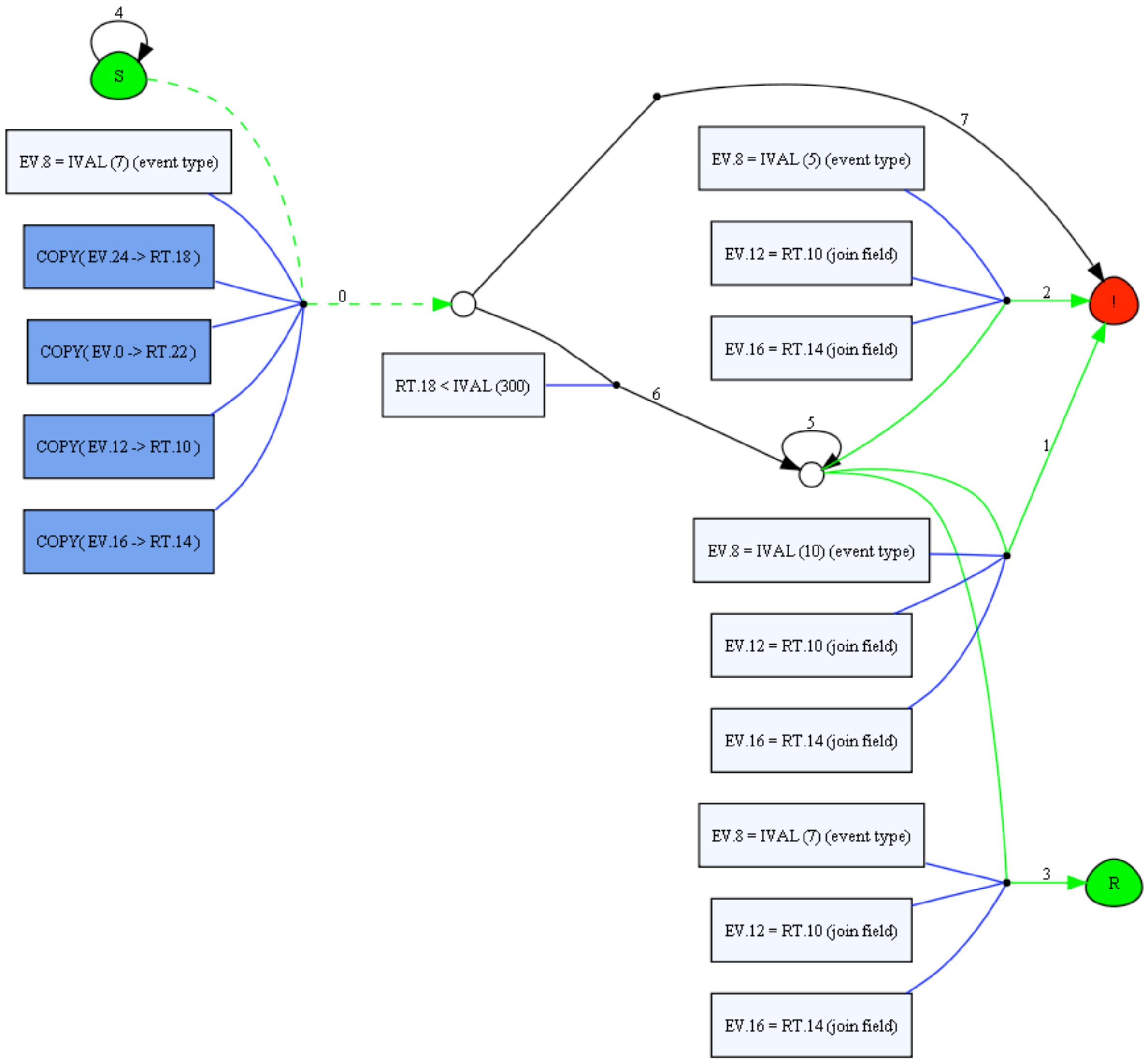
```
PATTERN {
  [syscall:a, ~(syscallexit:b|threadtermination:c), syscall:d]
}
WHERE  { a.ProcessId == b.ProcessId,
         a.ProcessId == c.ProcessId,
         a.ProcessId == d.ProcessId,
         a.ThreadId == b.ThreadId,
         a.ThreadId == c.ThreadId,
         a.ThreadId == d.ThreadId }
```

Compiler

- **Based on C++ version of Coco/R**
  - Parse event description and pattern definition
  - Generate …
    - Deterministic Finite Automata (DFA) for pattern
    - Graphical (.dot) representation of DFA (for debugging)
    - DLL for console printing of rule results

- **Features**
  - Check `WHERE` conditions as early as possible
  - Save only the required parts of the event information
  - Compact binary representation of DFA

Deterministic Finite Automata



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Instrumentation framework

- **Windows Monitoring Kernel**
  - Static instrumentation
  - Based on Windows Research Kernel
    - Custom build Windows Server 2003 kernel
  - Usage similar to KLogger for Linux
  - Overhead ~ 1% for 13k events per second
  - Compiler parses C header file **`wmkevents.h`**
    - Get available event types
    - Read event type descriptions

DFA processing model

- **Runtime state (RTS) information**
  - Representation for single automata run
  - Data structure is generated by compiler
    - Current state
    - Event field information
    - Result information

  - Evaluate conditions for current state
  - Determine valid transition

  - Conditions evaluated based on event data and RTS
  - Actions copy event data to RTS

Current implementation

- **User-mode application**
  - Load rule representation
  - Read event stream from WMK logfile
  - Output:
    - Result information
    - Processing statistics

```
match #1
{ 106 485370171 }
match #2
{ 139 1320873480 }
match #3
{ 139 1350760491 }
match #4
{ 139 1351041183 }
```

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- → **Online processing of events**
- → **Execute callbacks / scripts when a pattern is detected**

React to detected patterns

- **Application domain**
  - Reconfiguration
    - Caching policy
    - Number of worker threads
  - → **Callback to application specific function**

- **System domain**
  - Reconfiguration
    - Prevent execution of malware pattern
    - Adapt thread/process priorities
  - → **Execute script in kernel mode**

Execute application specific callback

- **Programming interface for applications**
  - Control rule lifecycle (load-activate-deactivate-unload)
  - Callback
    - Registered for a specific rule
    - Implements reaction to detected pattern
    - Access to rule results (`RETURN` values)
    - Access to execution context information
  - Synchronous or asynchronous processing in user mode

Kernel mode scripting

- **Extend rule specification language**
  - Allow script definition: DO keyword
    - Access to (named) events and event data fields
    - Access to execution context information
    - Runtime environment exposes some kernel functions
  - Execute reactions directly in the kernel

Outlook

- **Kernel integration of runtime environment**
  - Efficient synchronization
  - Condition evaluation / transition search
- **Case studies**
  - Server applications – worker thread management
  - Deadlock detection / prevention
  - Context-oriented programming

Summary

- → **Pattern description**
  - Regular expressions
  - Compiled to Deterministic Finite Automata
- → **Online processing of events**
  - No logfile required
- → **Execute callbacks / scripts when a pattern is detected**
  - OS kernel integrated runtime environment