A Layered Architecture for Detecting Malicious Behaviors

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RAID 2008

The arm-race of malware and malware detectors

- Even the most effective malware detectors fail to detect more than 30% of malware seen in the wild
- More than five million active, distinct, bot-infected machines (Symantec report about the first half of 2007)

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Malware detectors have a finite set of syntactic signatures, but malicious programs have infinitely mutable syntax

Behavior-based malware detection

- Detect high-level actions that financially motivate malware development & distribution
  - keystroke logging
  - data leaking
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There are a finite number of ways to achieve each action
The models can encode all such ways

Semantic gap between models and monitored events

- Monitor execution of the program using an emulator (or similar)
- Lowest level events in behavior specifications are system calls
- Malicious behaviors are described as sequences of essential actions

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There is a semantic gap between the stream of events generated by a program and the actions of behavior specifications [Chen & Noble '01]

Outline

Our solution

- Complex & high-level behaviors are decomposed into multiple layers
- The lowest layer represents system call invocations
- Upper layers have a richer semantics

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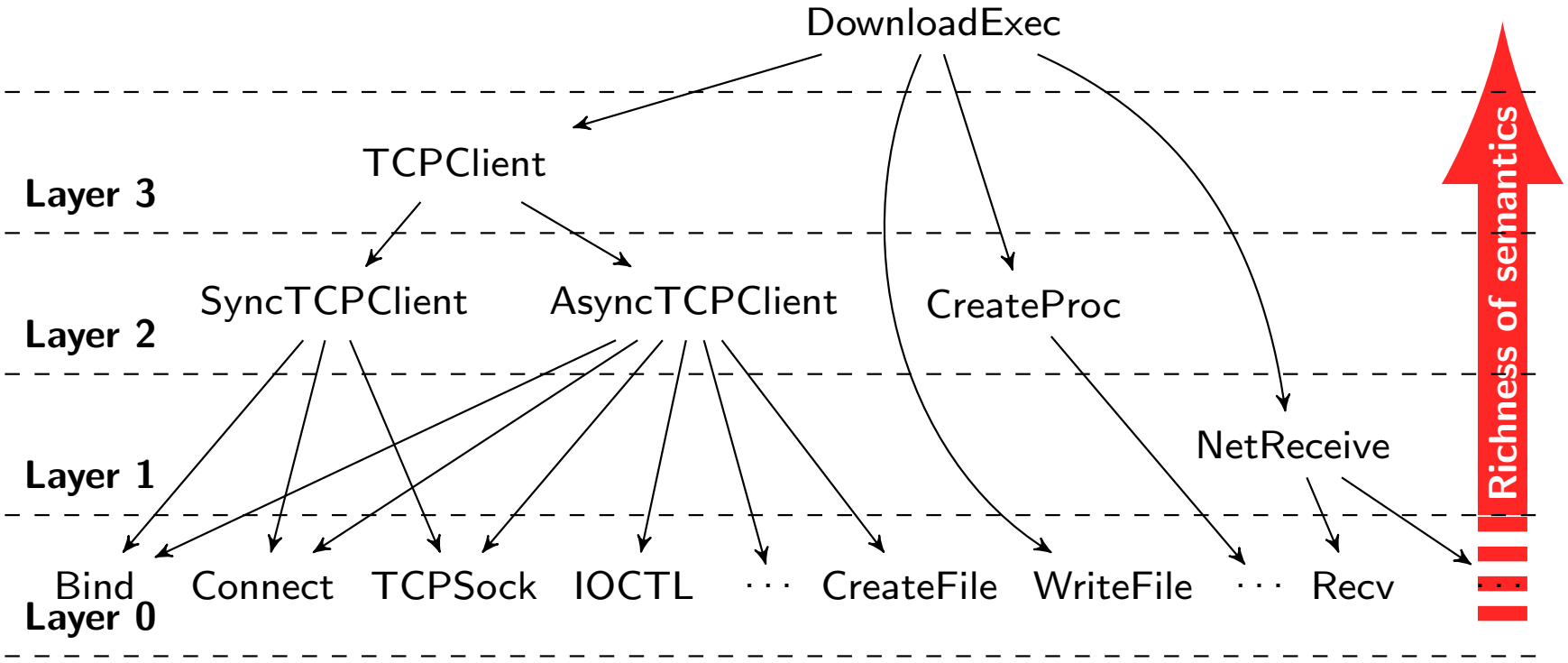

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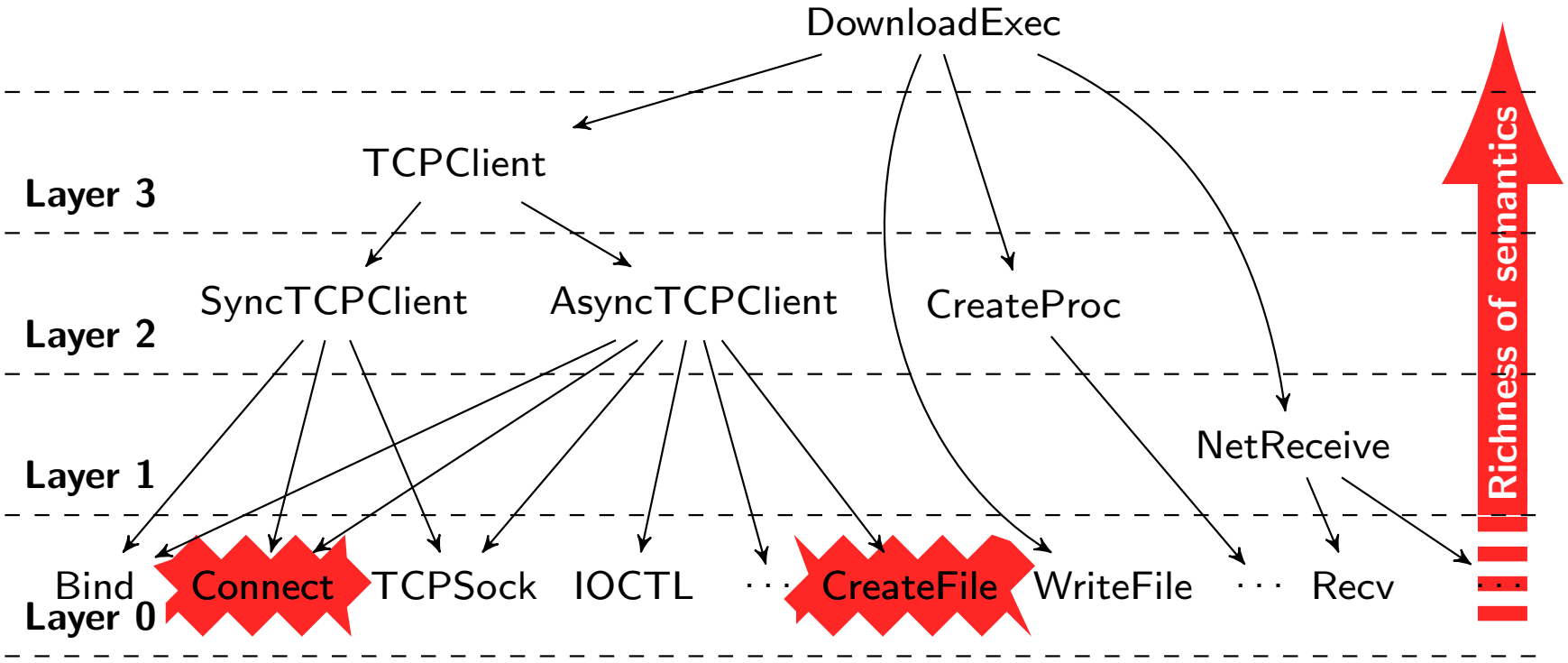

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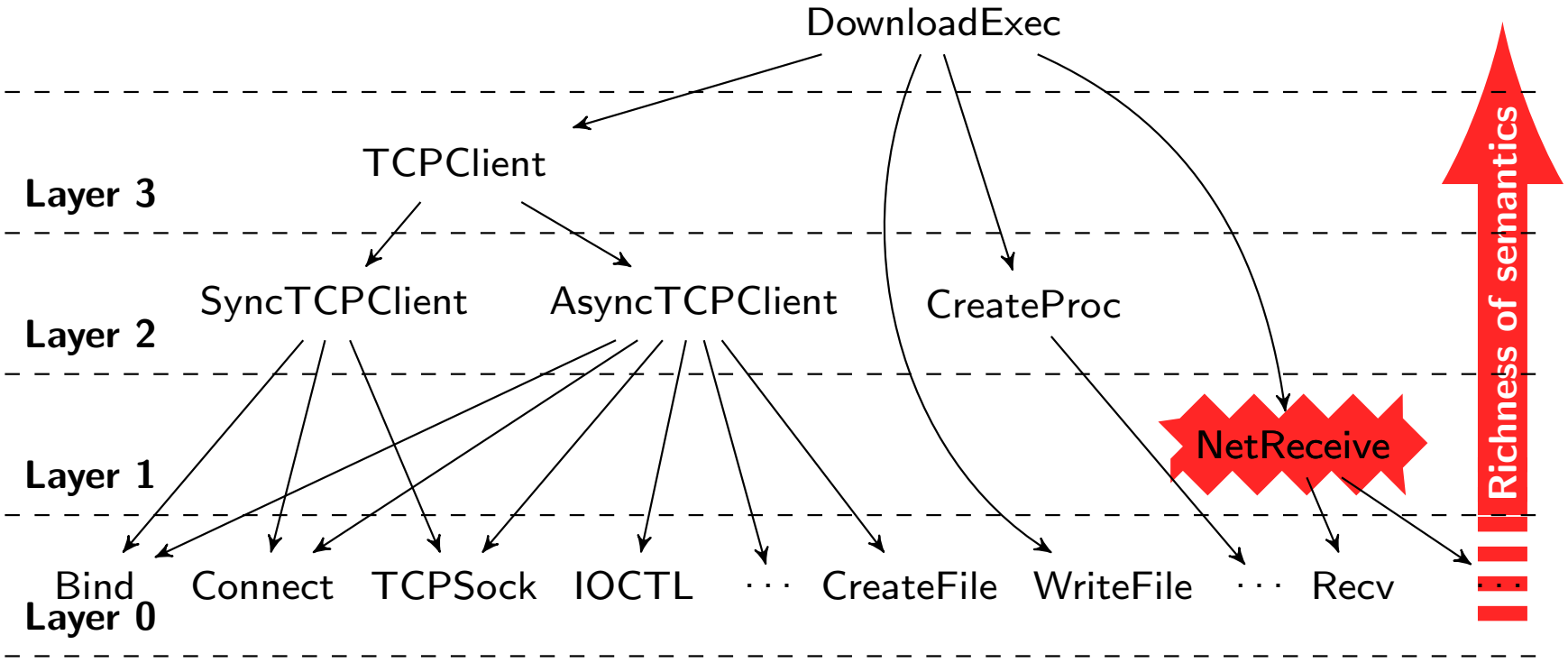

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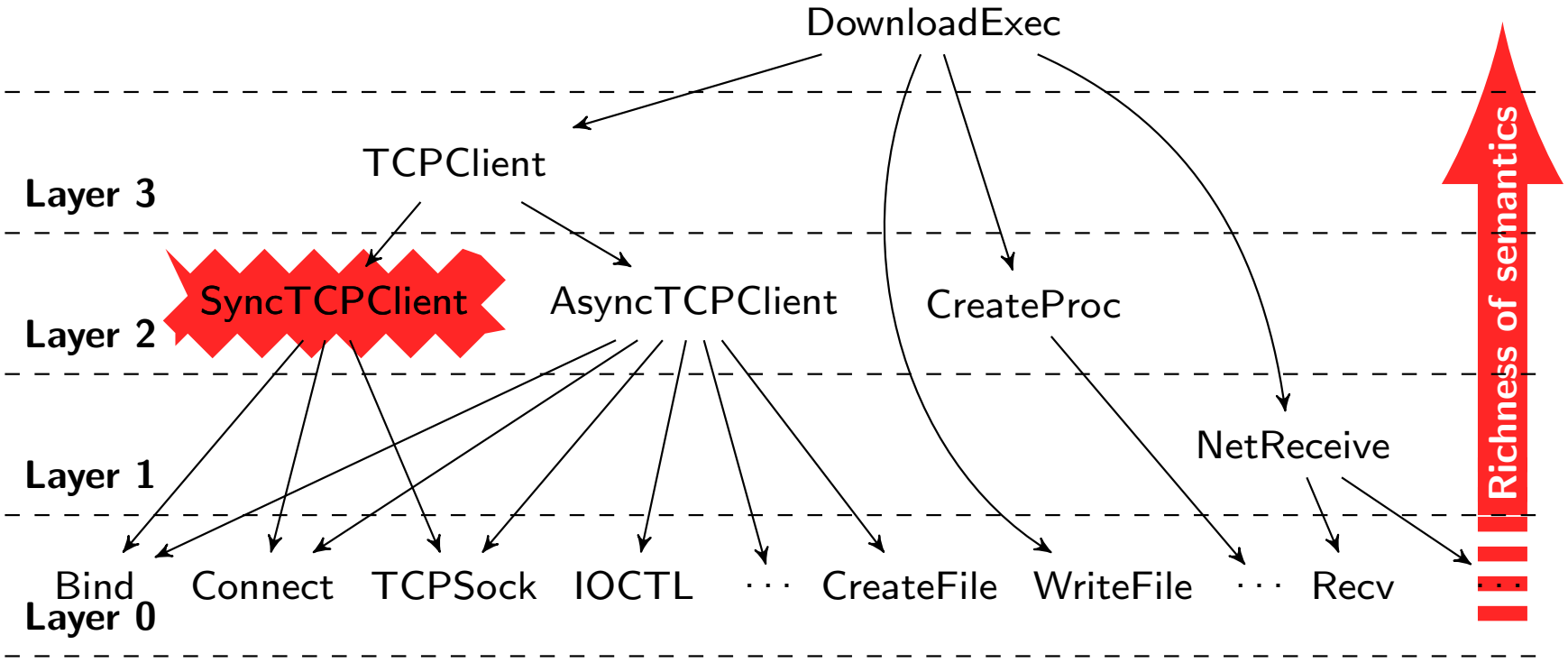

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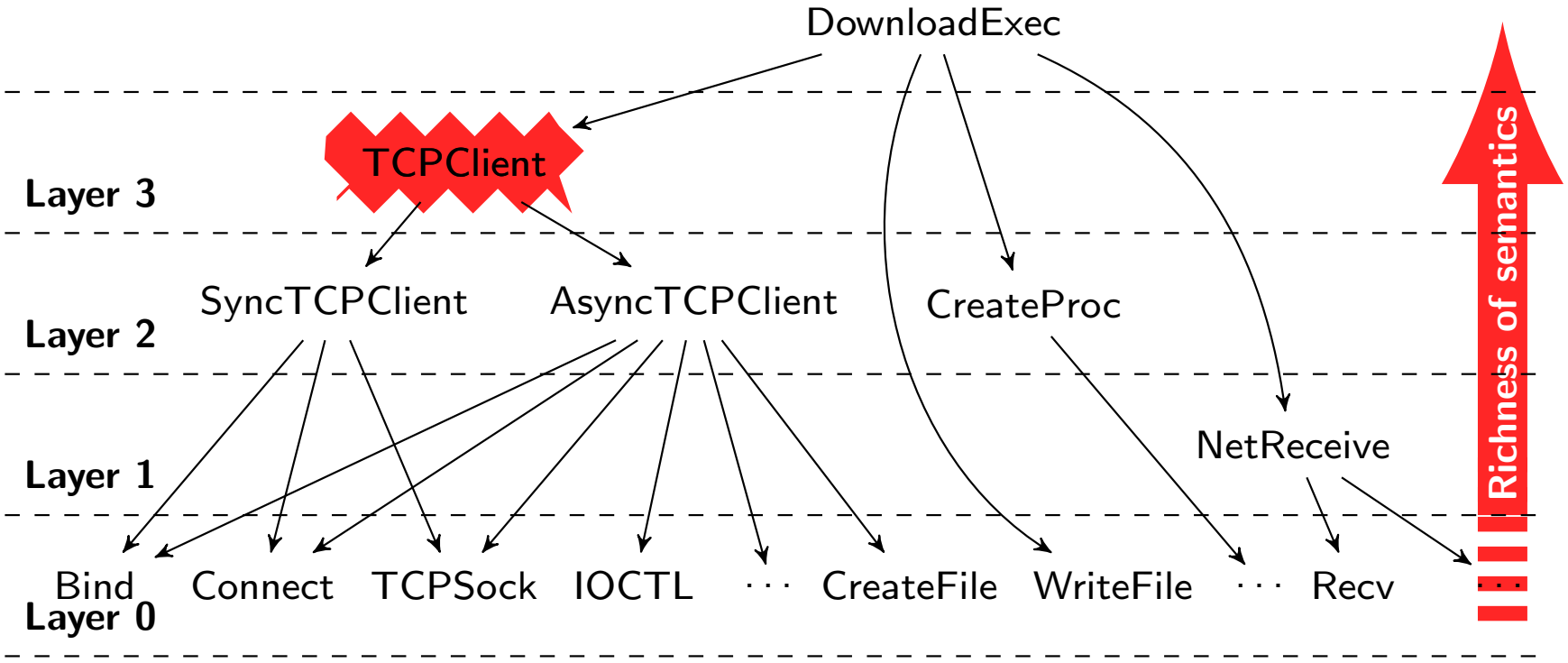

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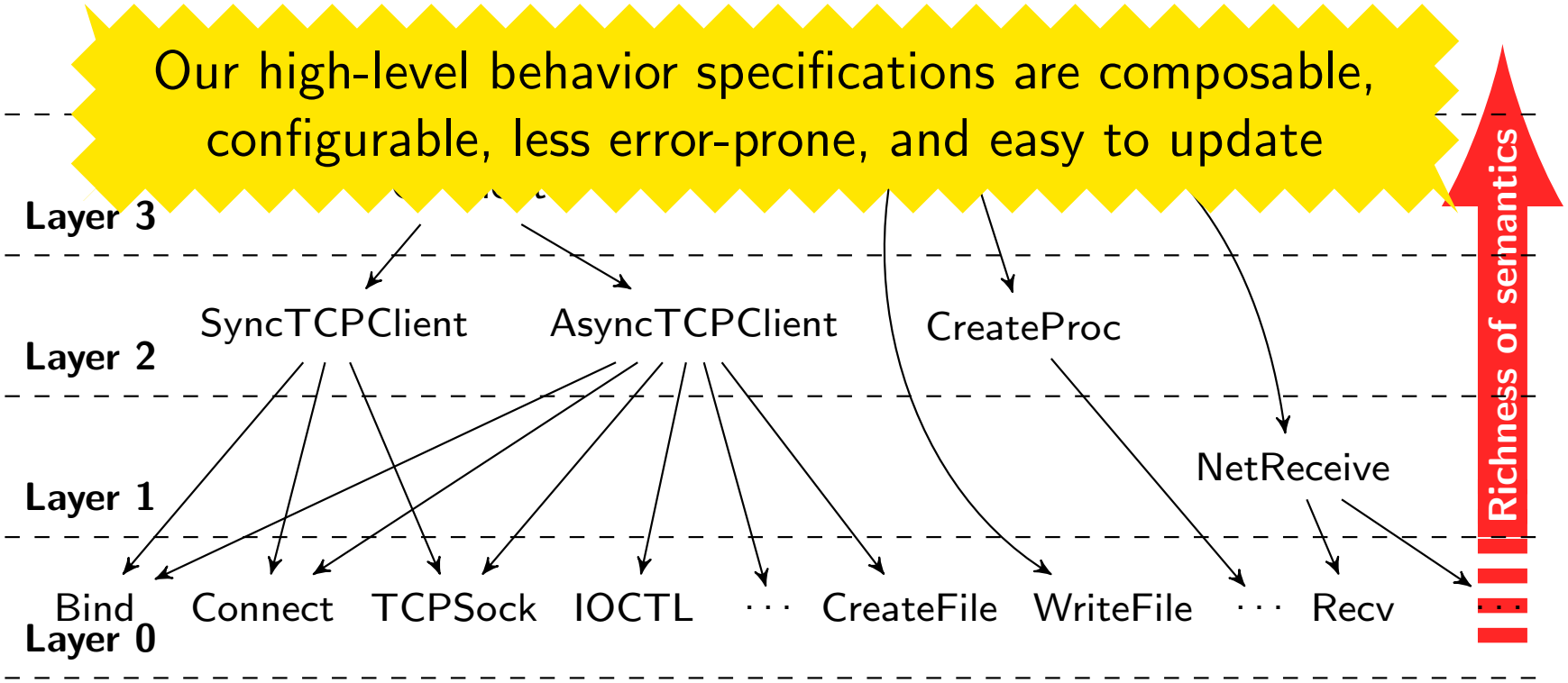


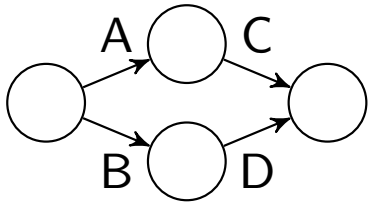
Technical challenges

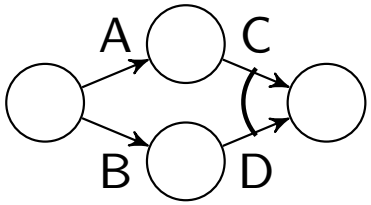
1. Find a good formalism to model complex high-level behaviors
2. Construct complete models of complex high-level behaviors

Technical challenges

1. *Find a good formalism to model complex high-level behaviors*

Behavior graphs (derived from AND-OR graphs)





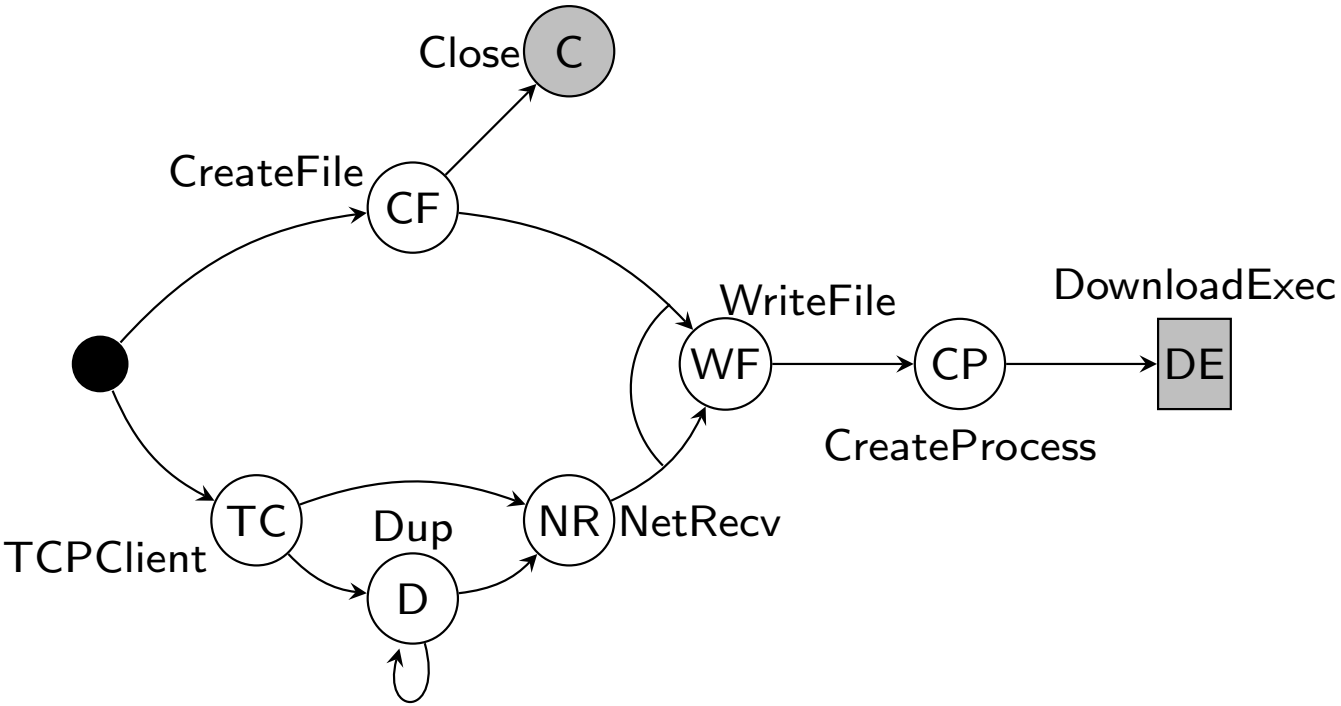
Technical challenges

2. *Construct complete models of complex high-level behaviors*

Manual analysis of execution traces & validation

Behavior graphs

Download & execute



Behavior graphs

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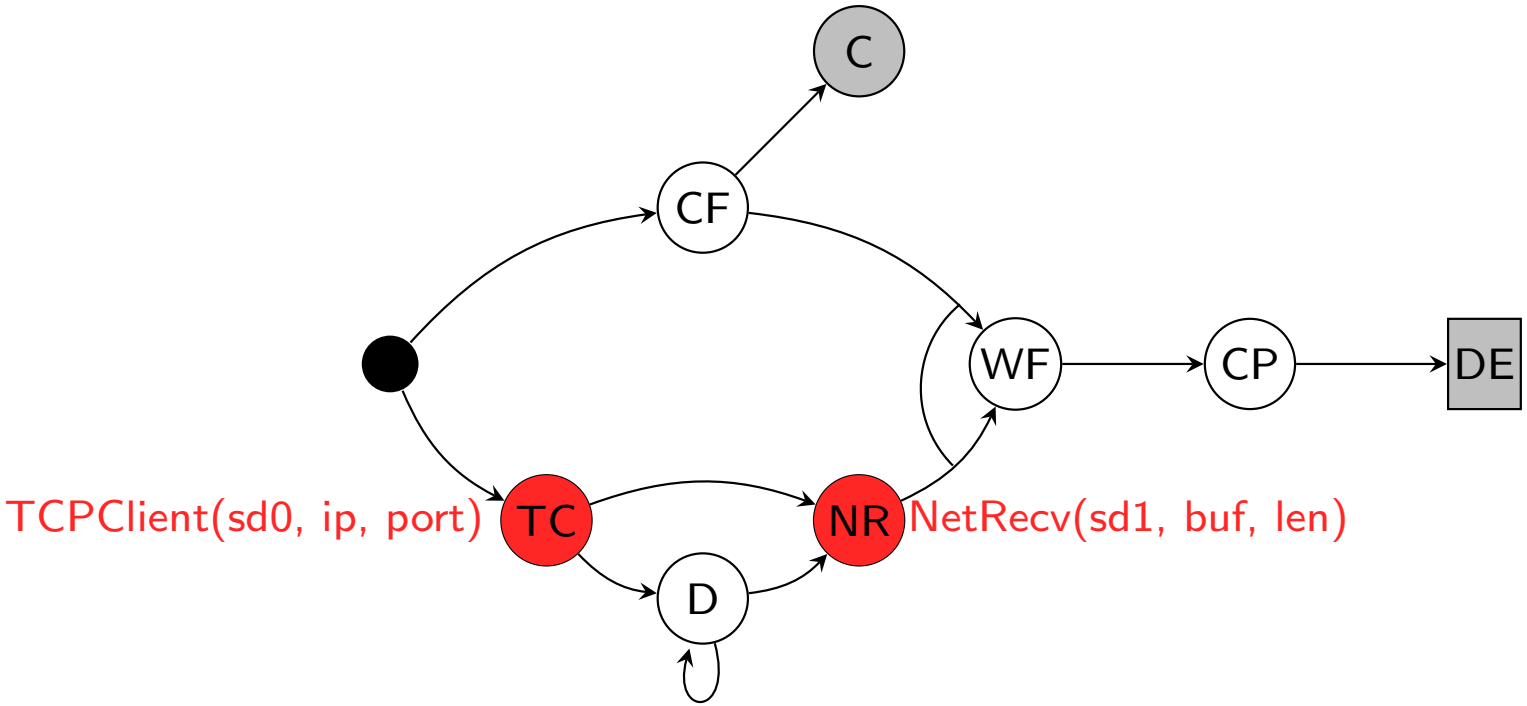
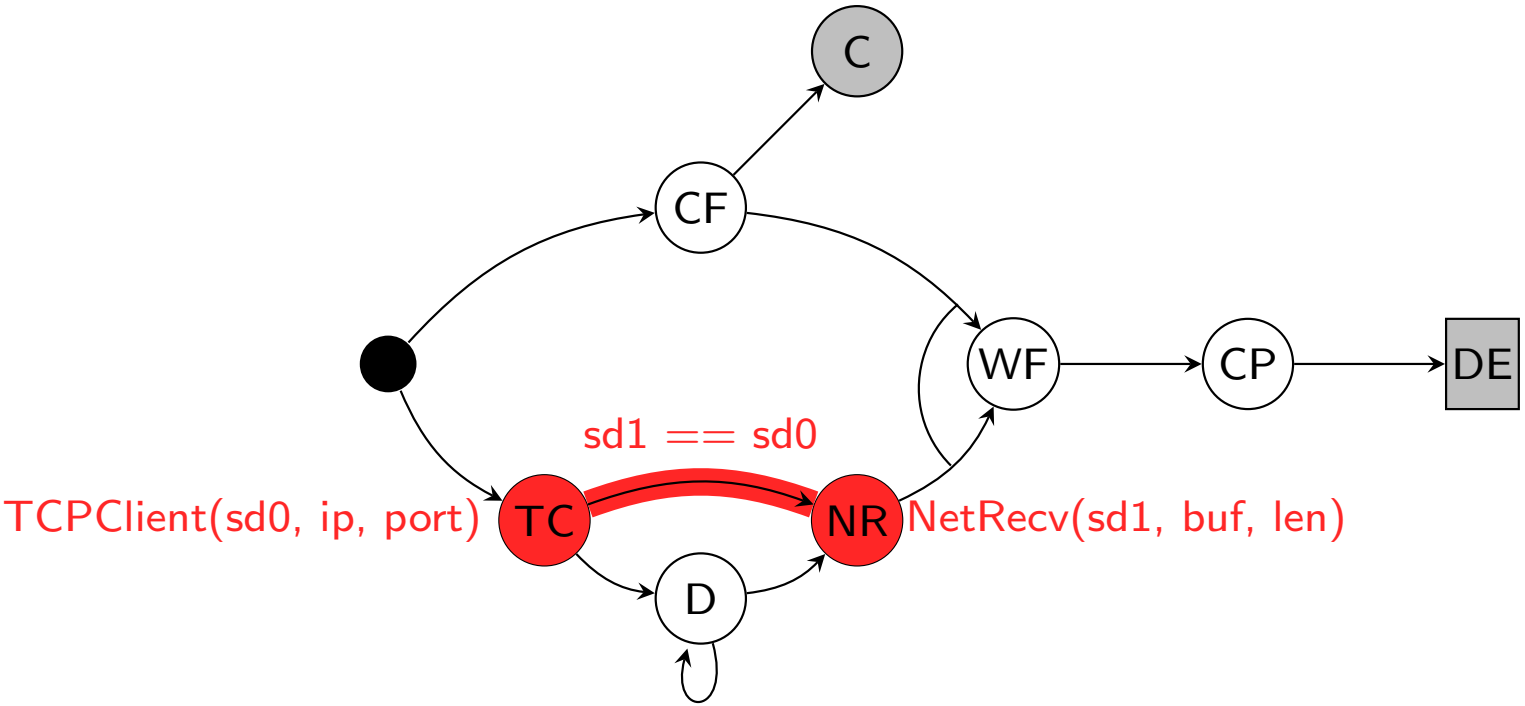


Internal nodes represent events (with formal parameters)

Behavior graphs

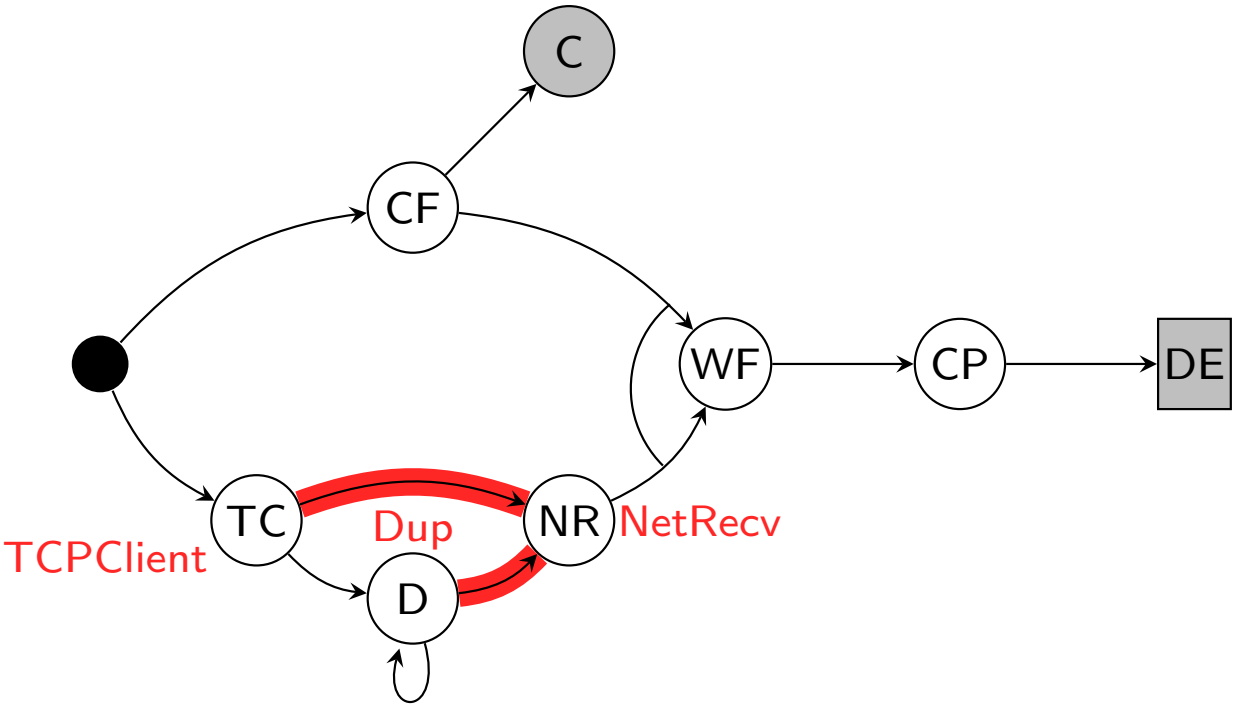
Download & execute



Edges represent predicates on events arguments

Behavior graphs

Download & execute



ORed edges represent events of which at least one has to occur

Behavior graphs

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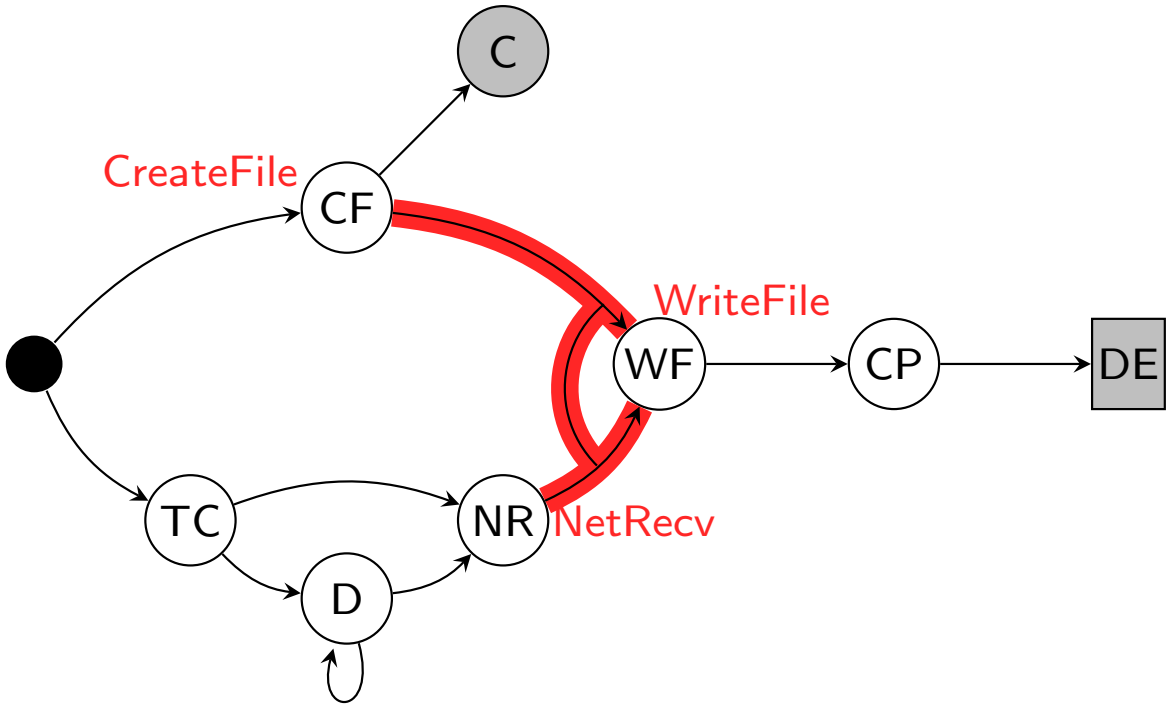

ANDed edges represent events that all have to occur (but can occur in any order)

Behavior graphs

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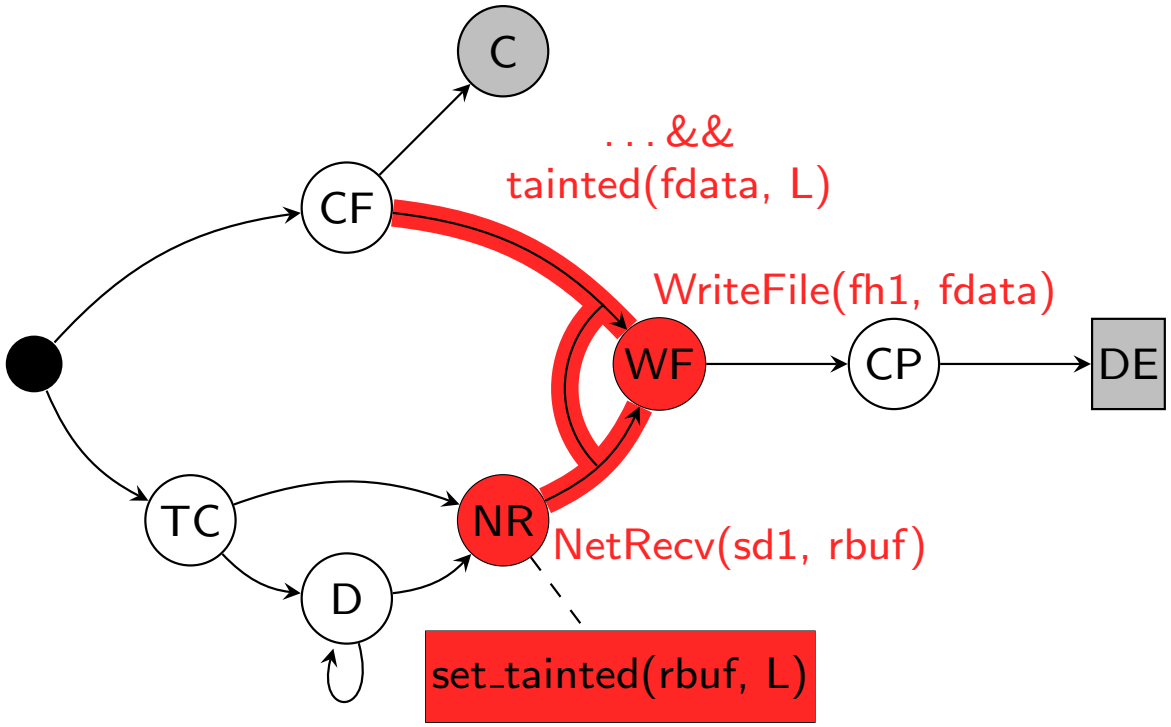
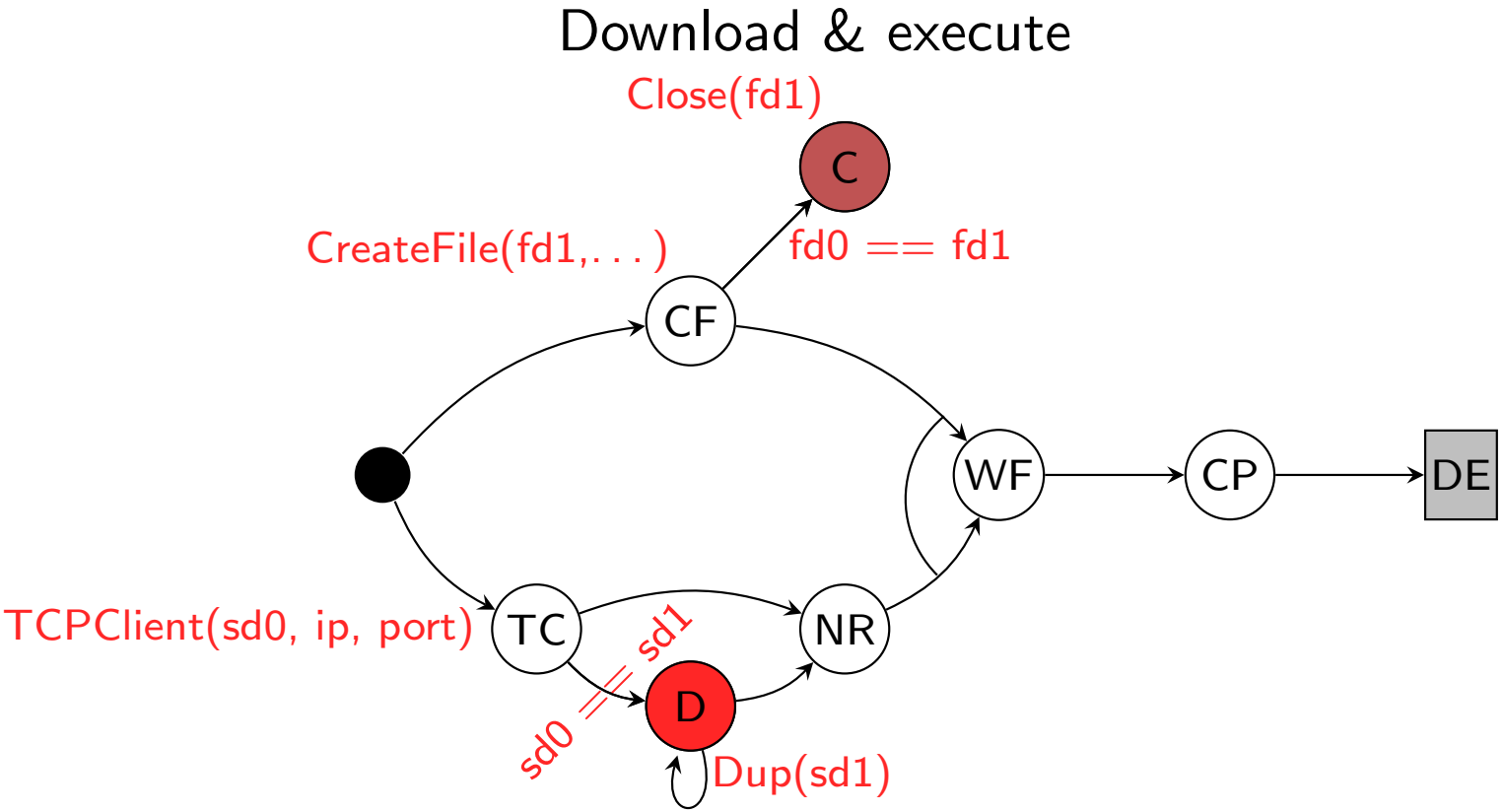


On-reach actions are actions performed by the monitoring system in response to reaching a given node

Behavior graphs



Annihilator and replicator nodes represent events that destroy and duplicate resources

Behavior graphs

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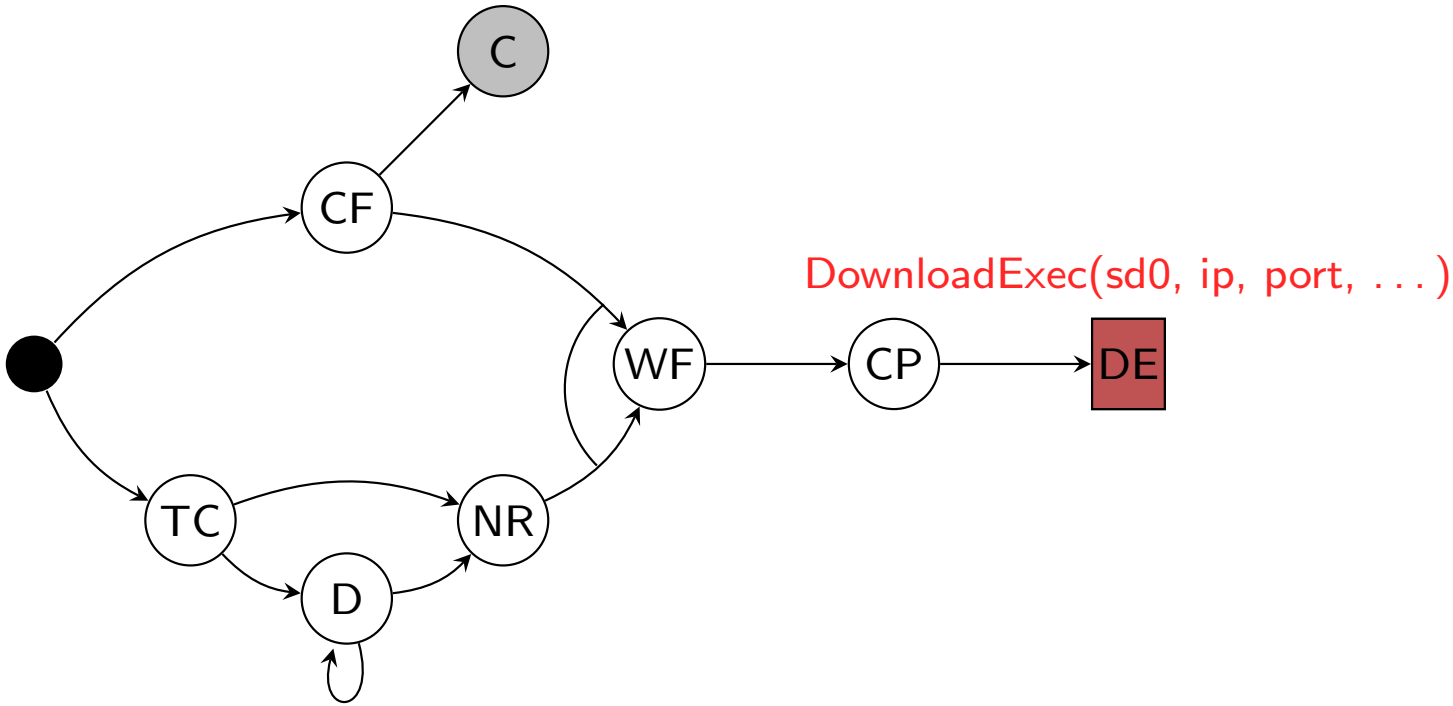
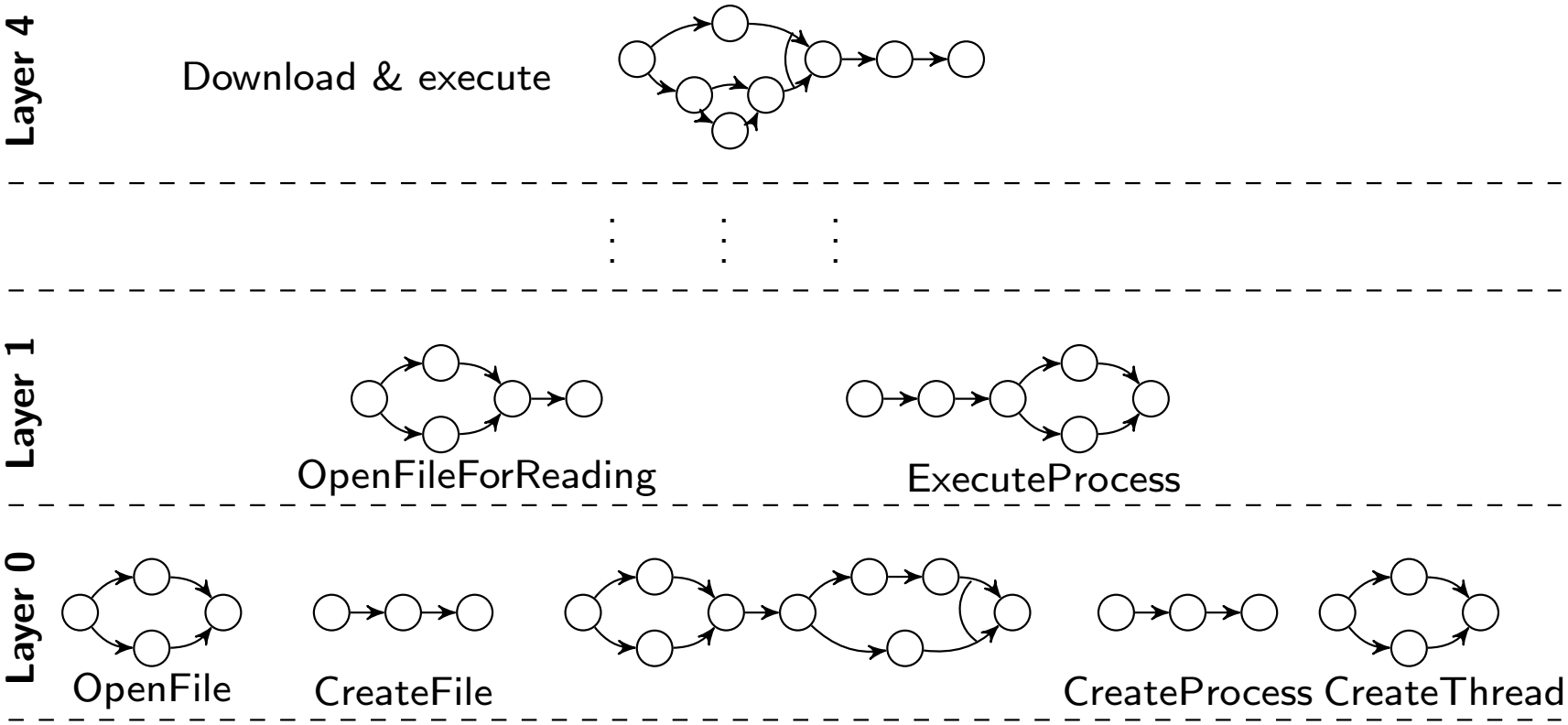


Acceptor nodes represent actions taken by our system when behaviors are matched

Matching malicious behaviors



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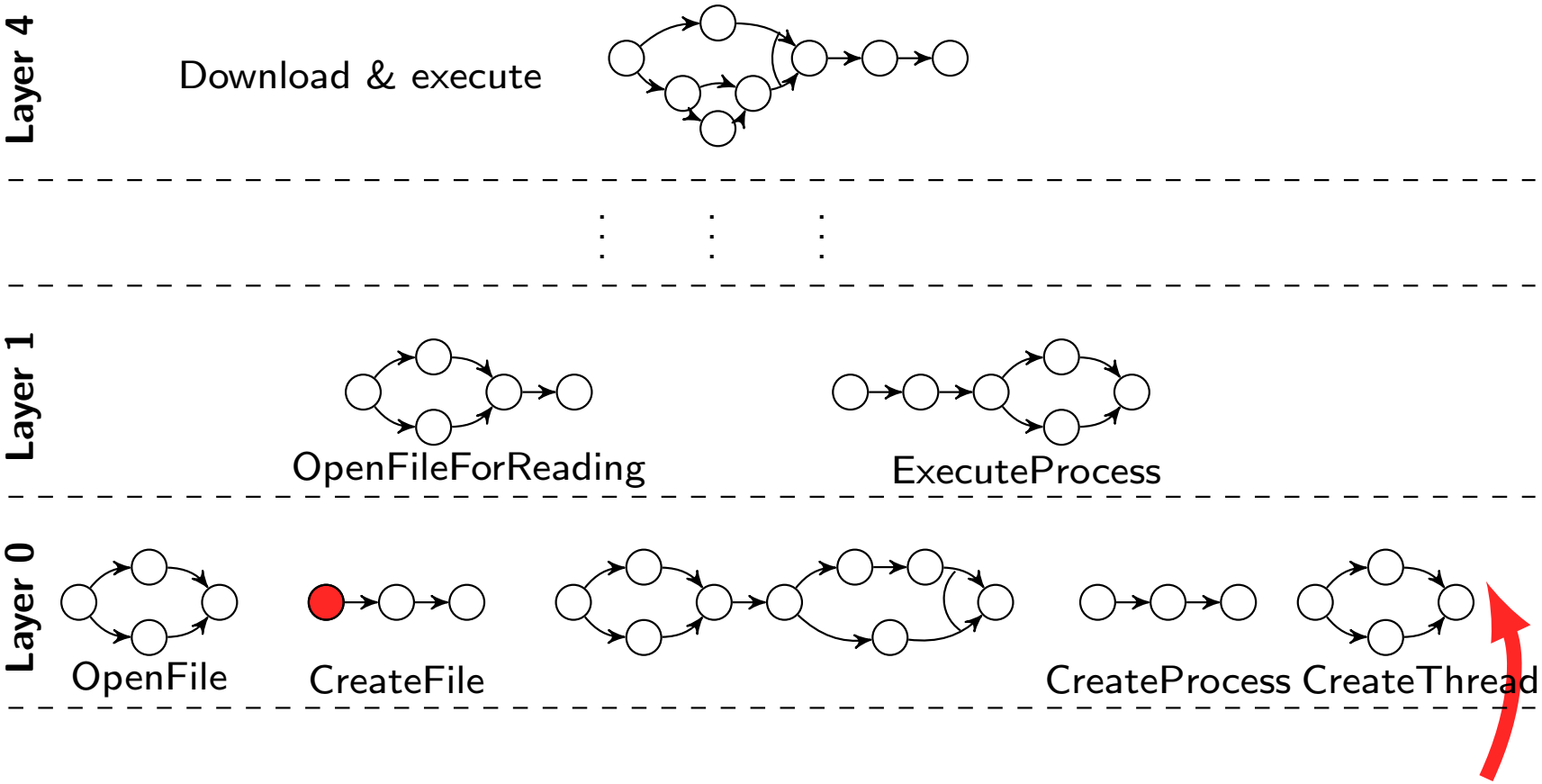

OS events are passed to the lowest layer

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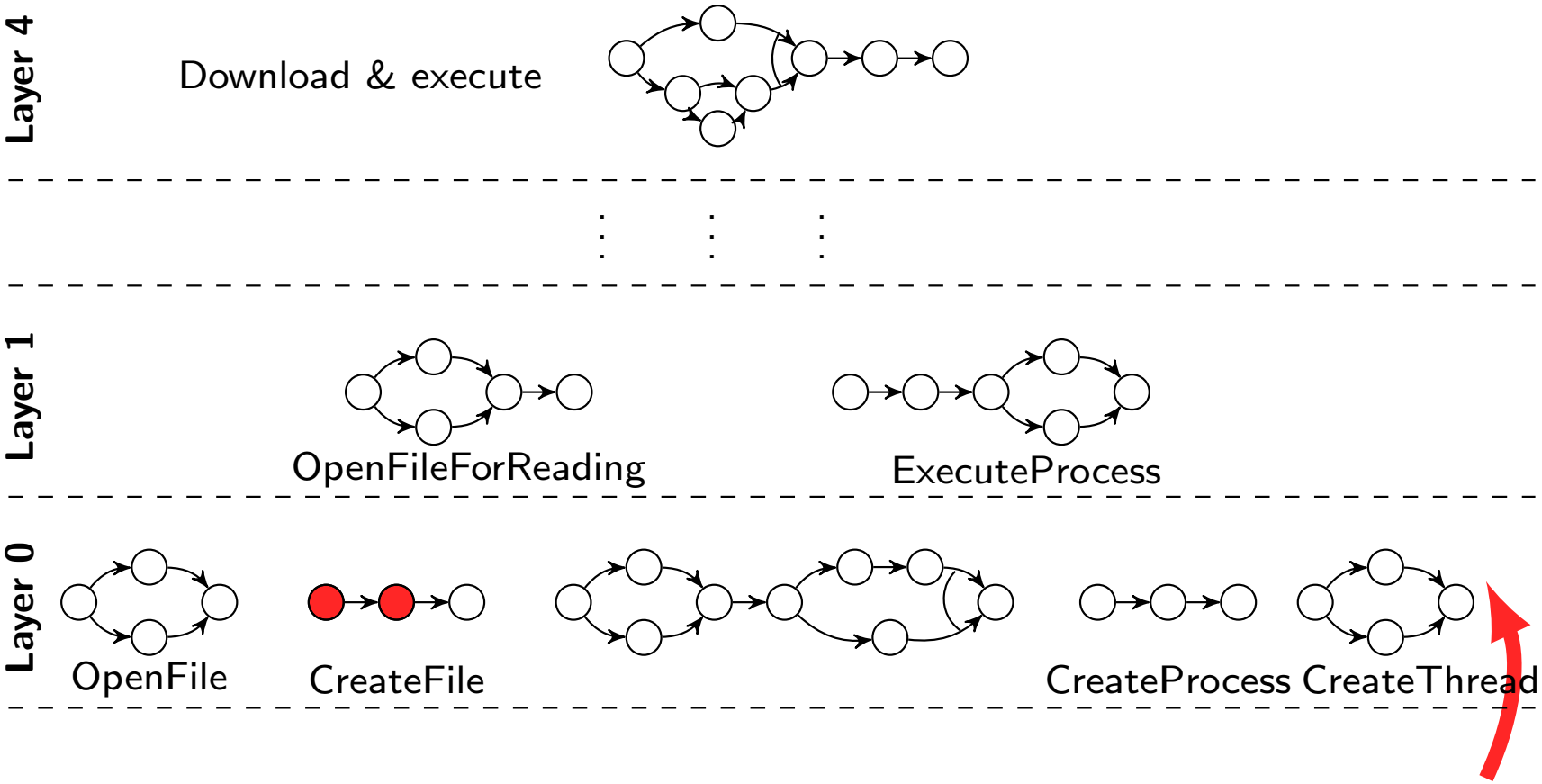

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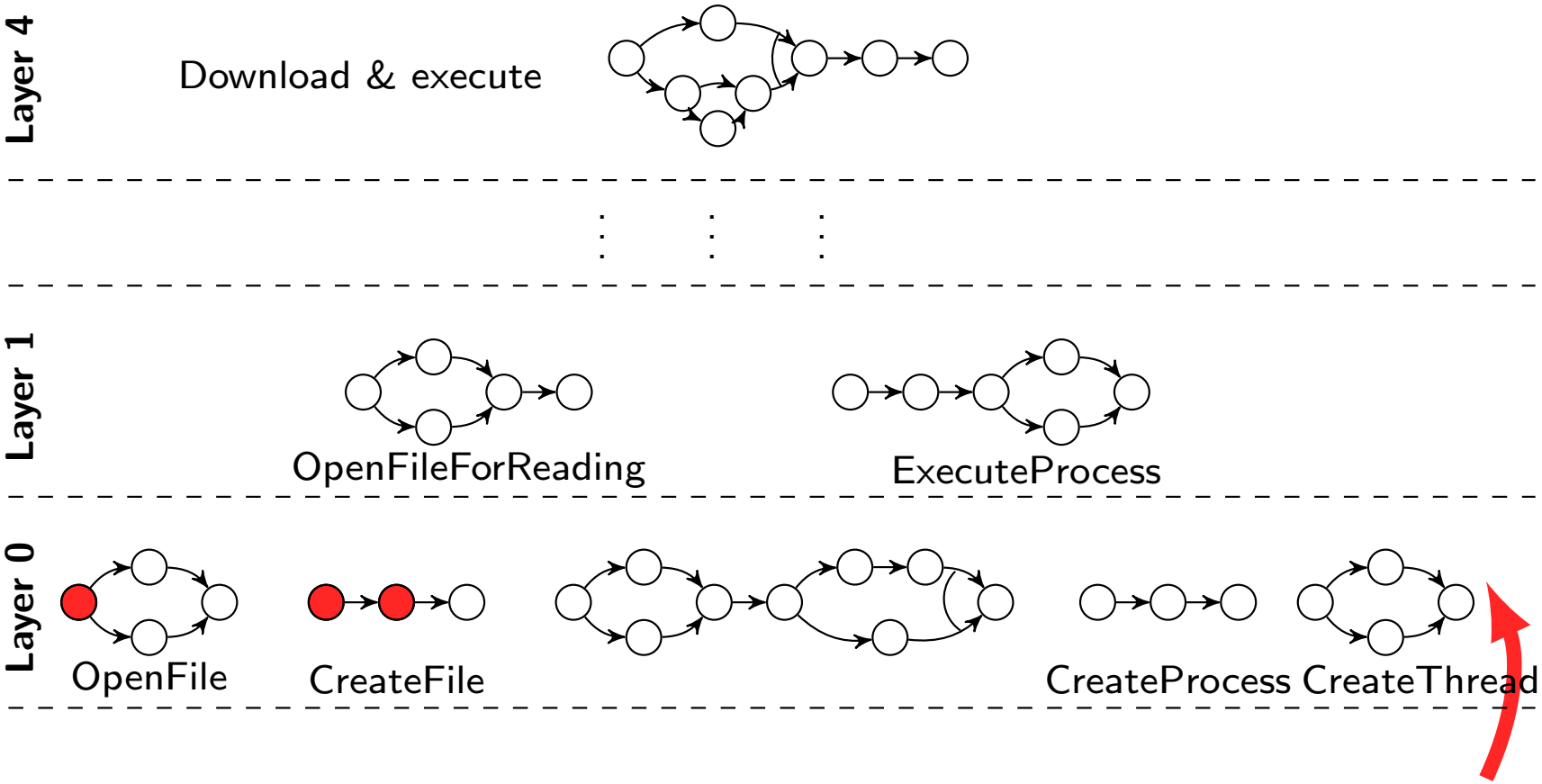

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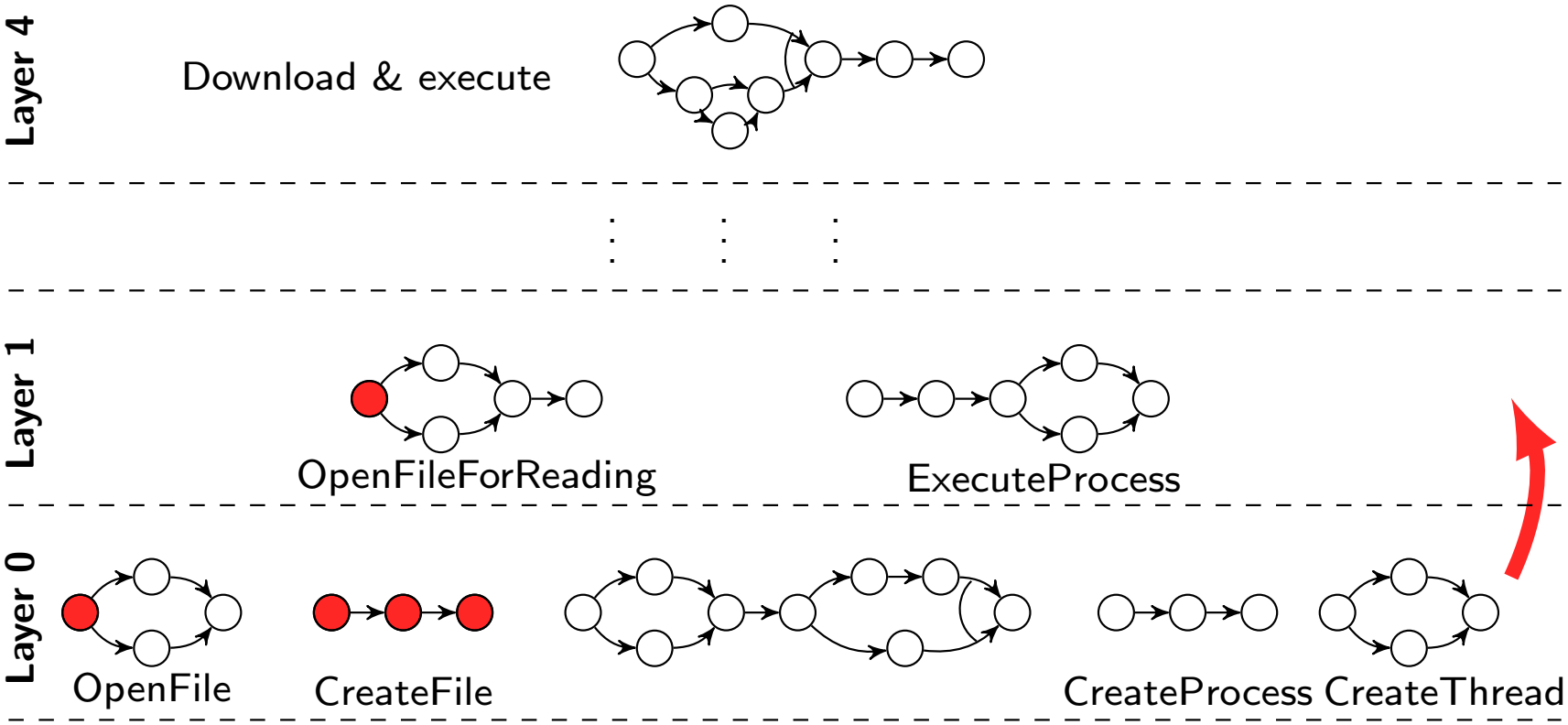

The low-level behavior is matched

The synthetic event (acceptor node) is passed to the upper layer

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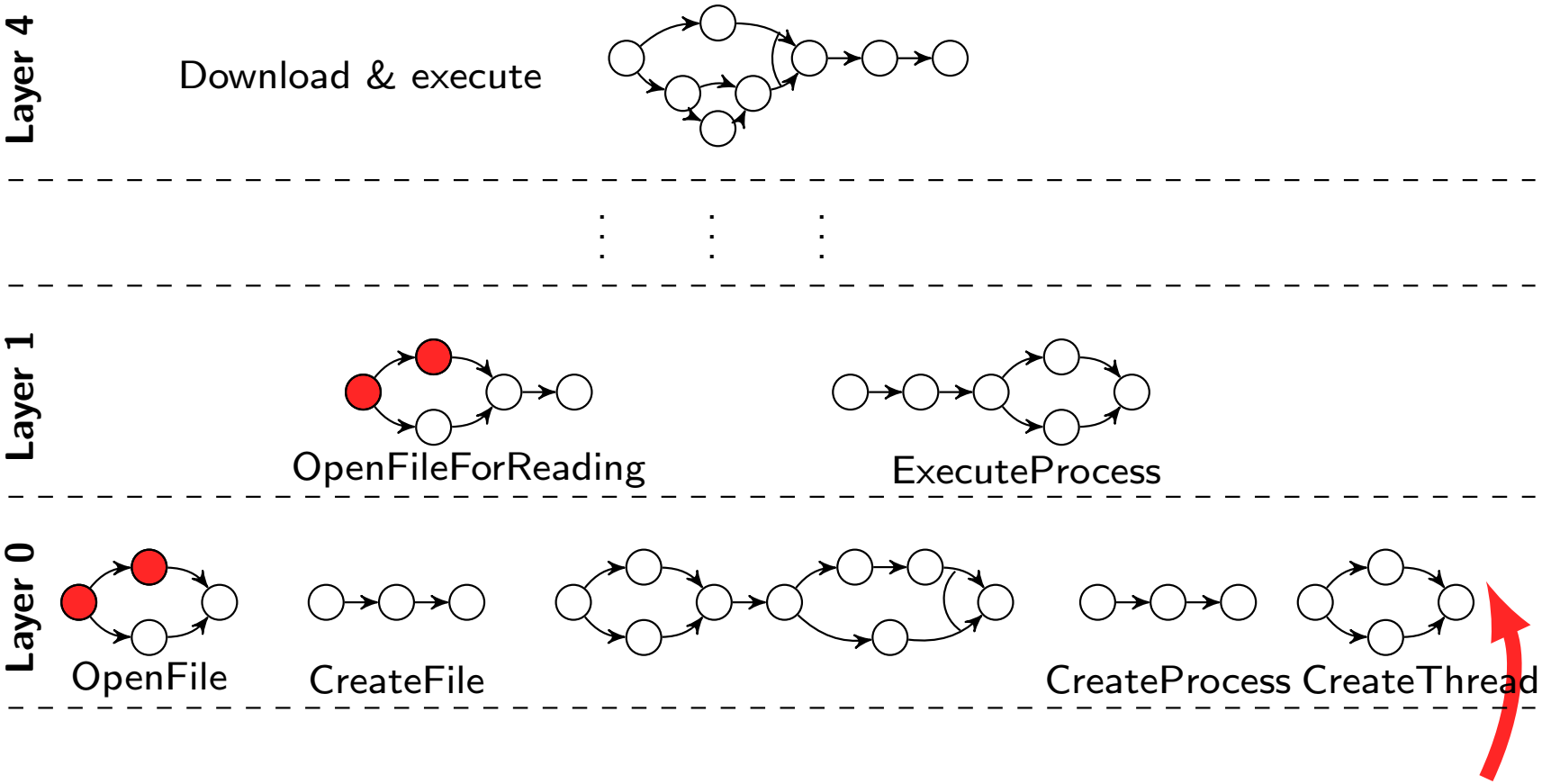

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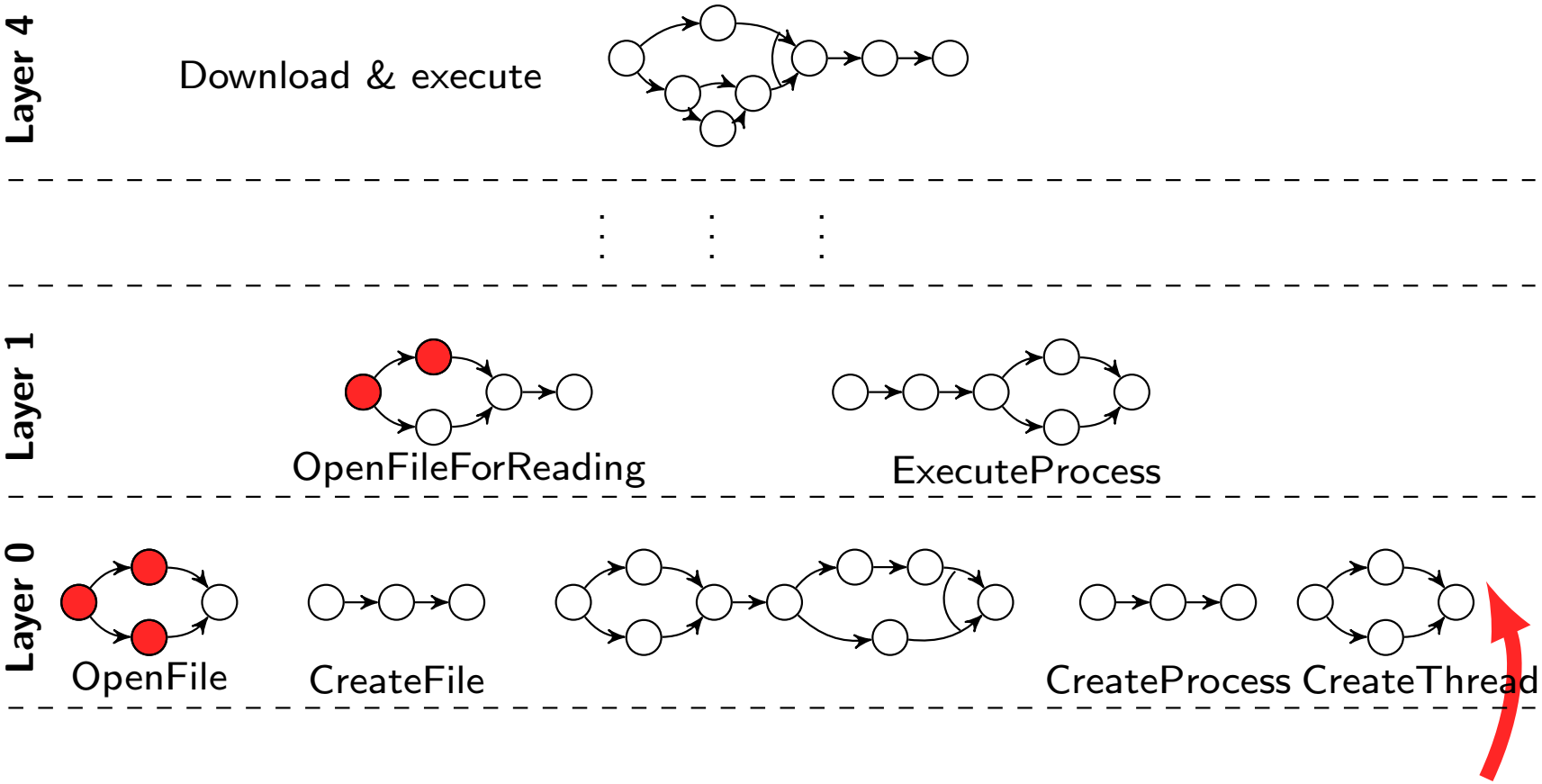

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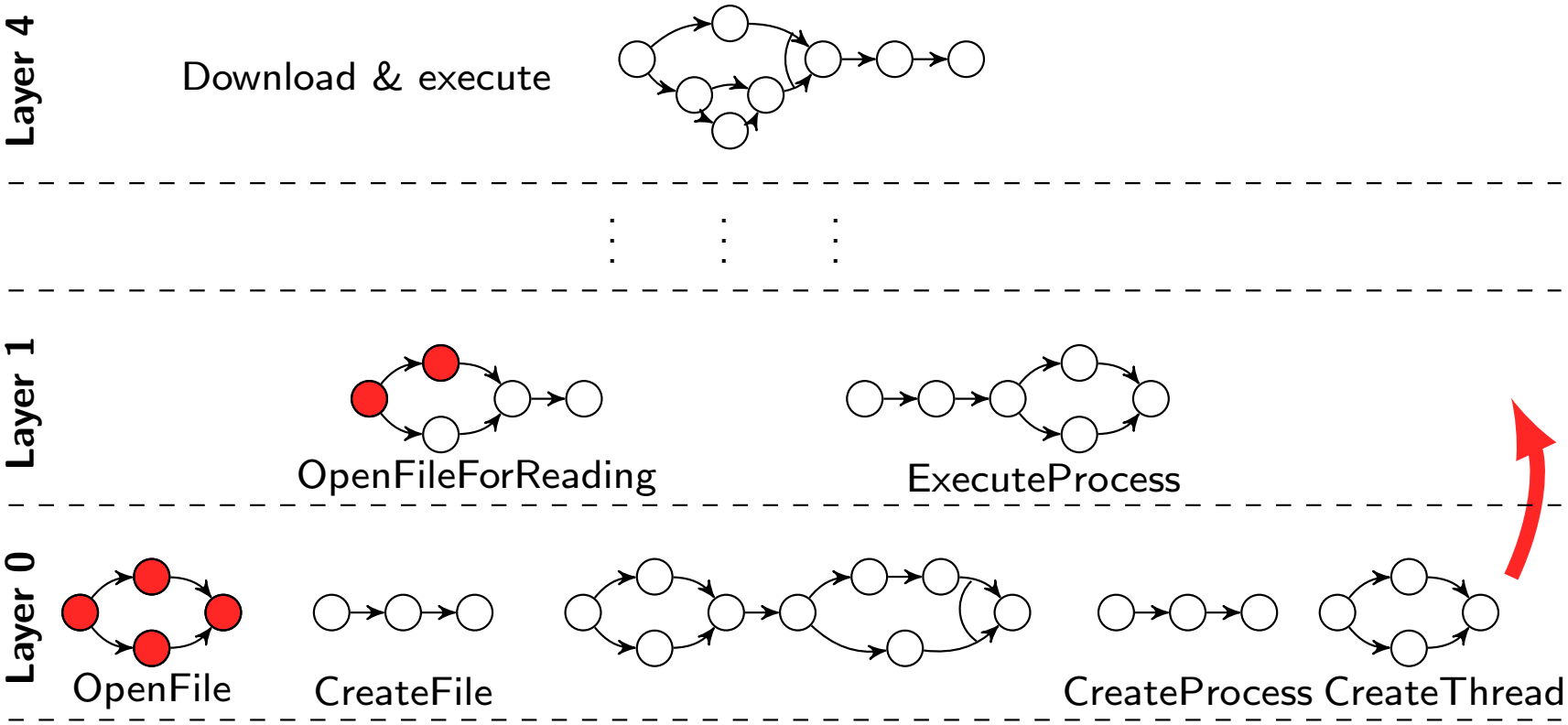

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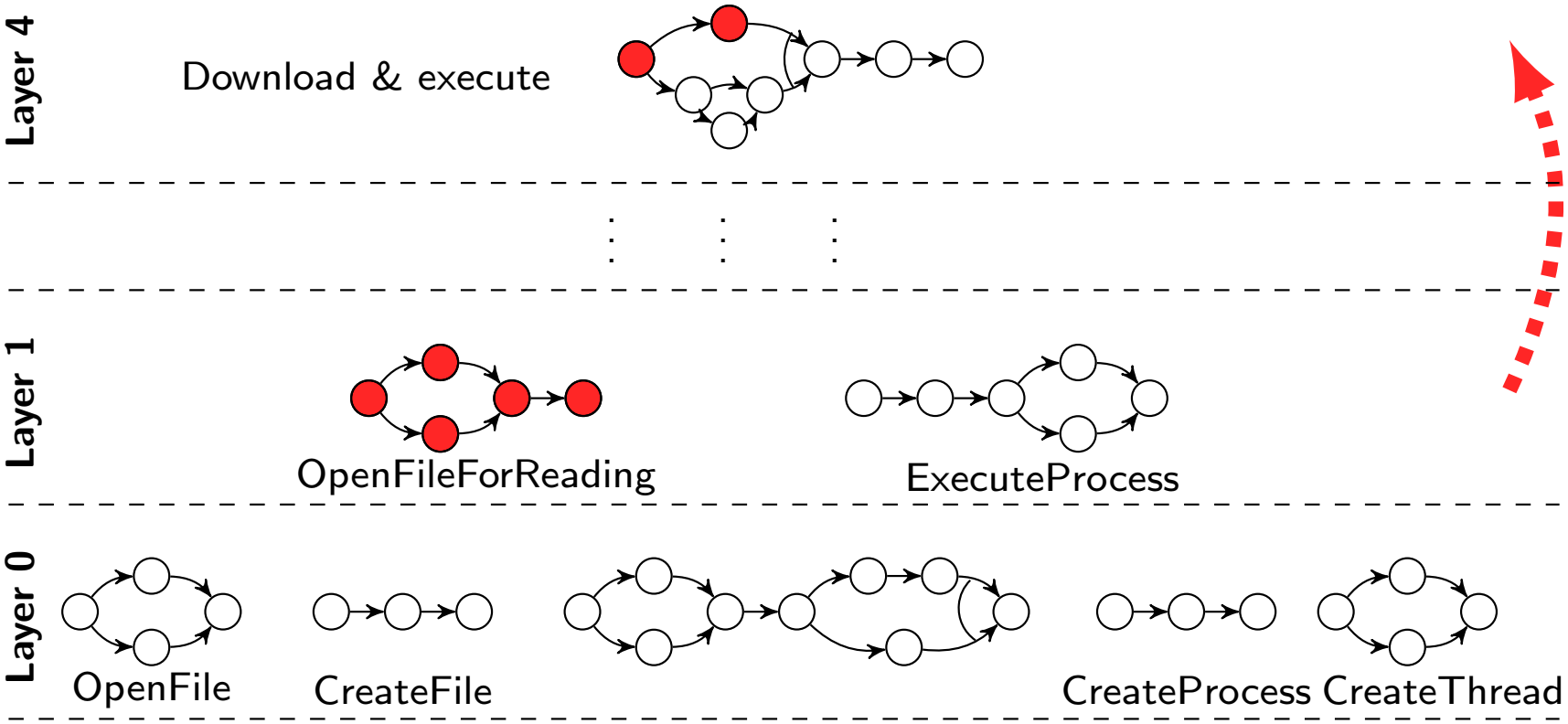
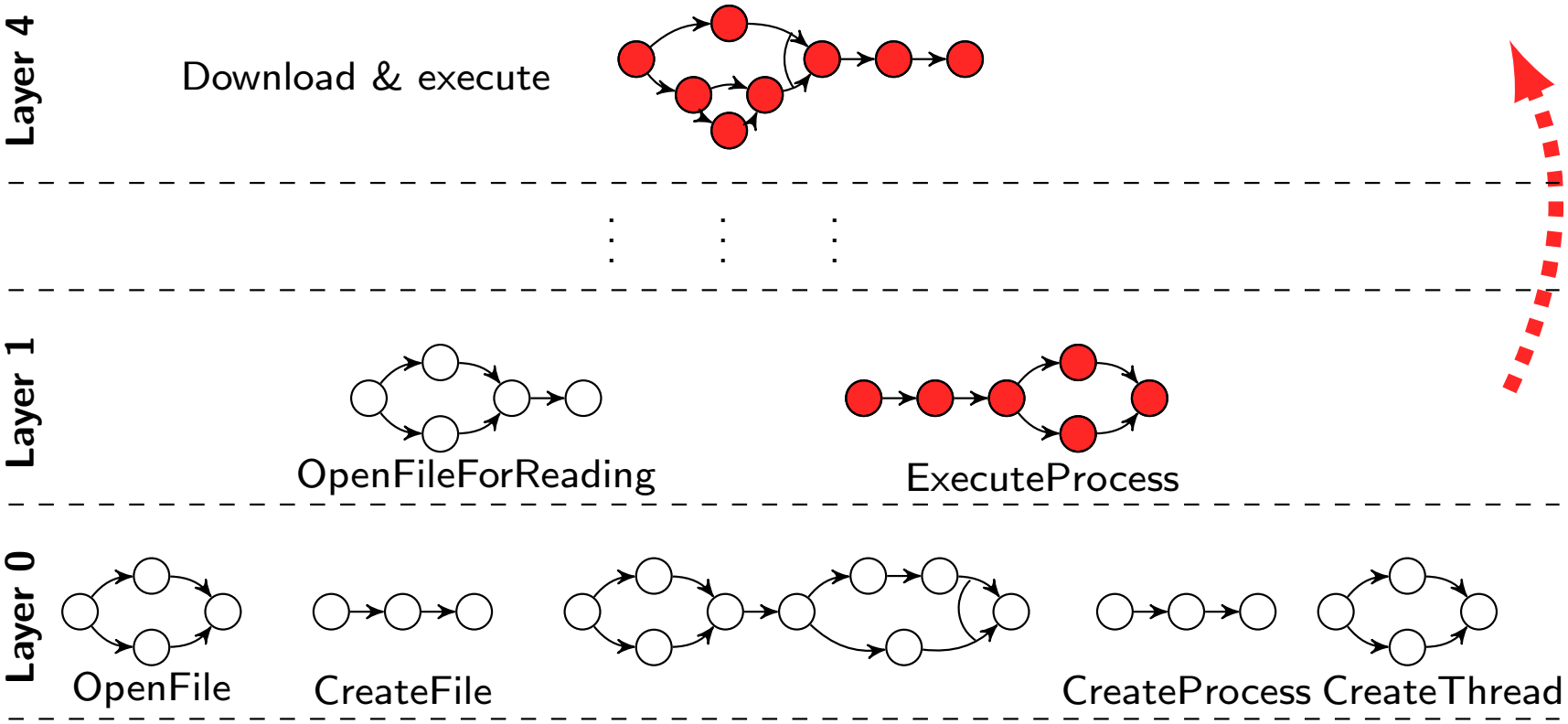


The middle-level behavior is matched

The synthetic event (acceptor node) is passed to the upper layer

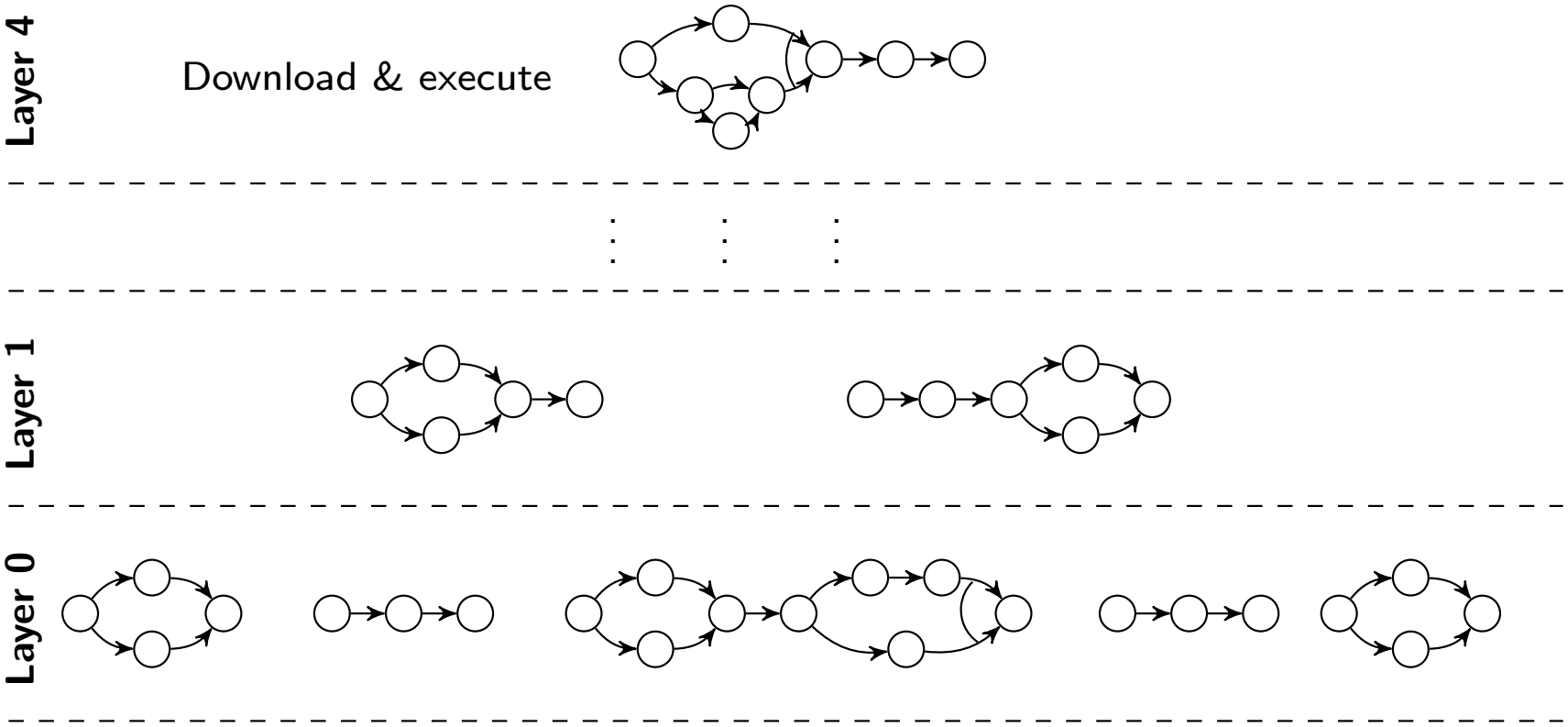
Matching malicious behaviors



The highest-level behavior is matched

The program is malicious

Are we managing the complexity?



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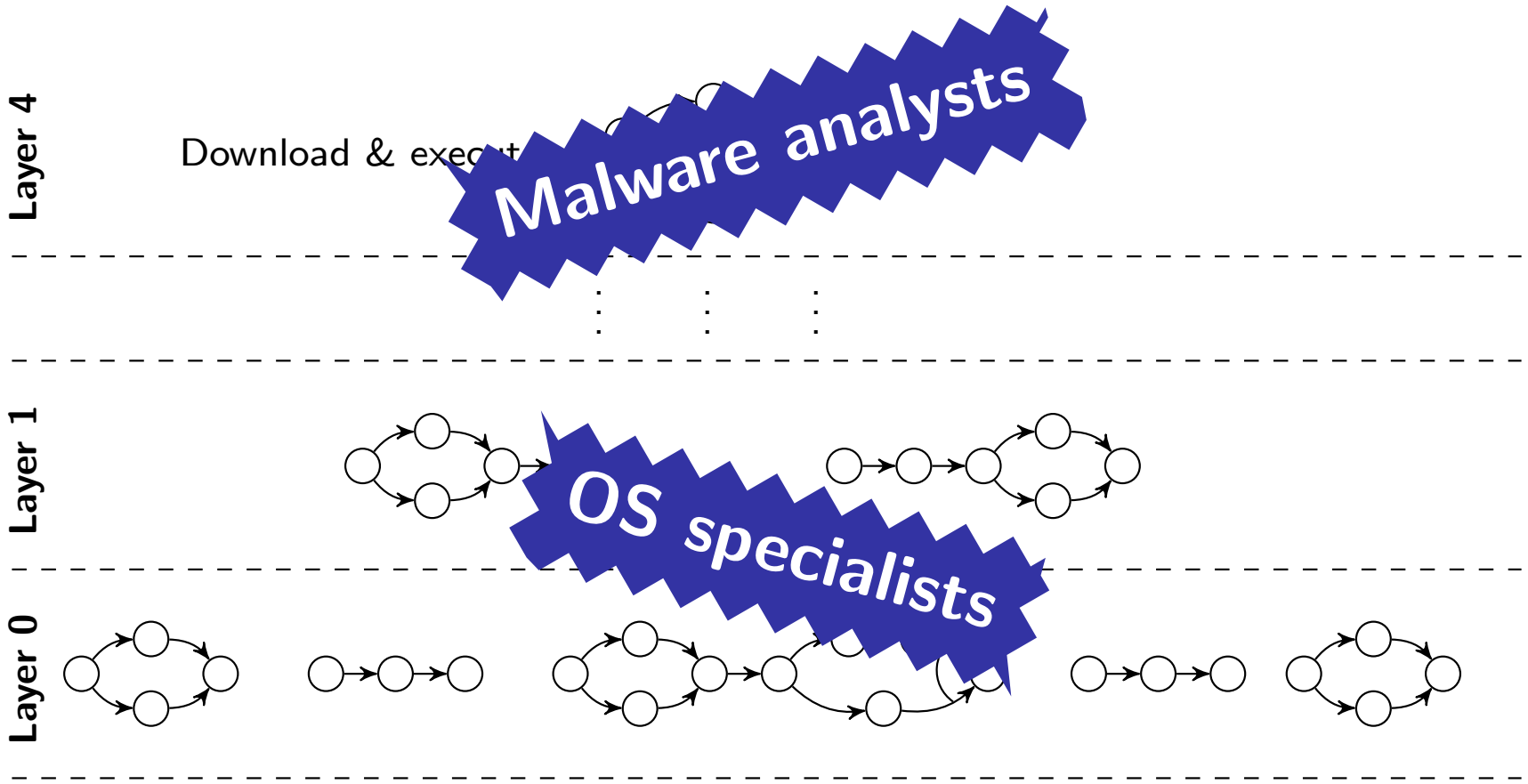
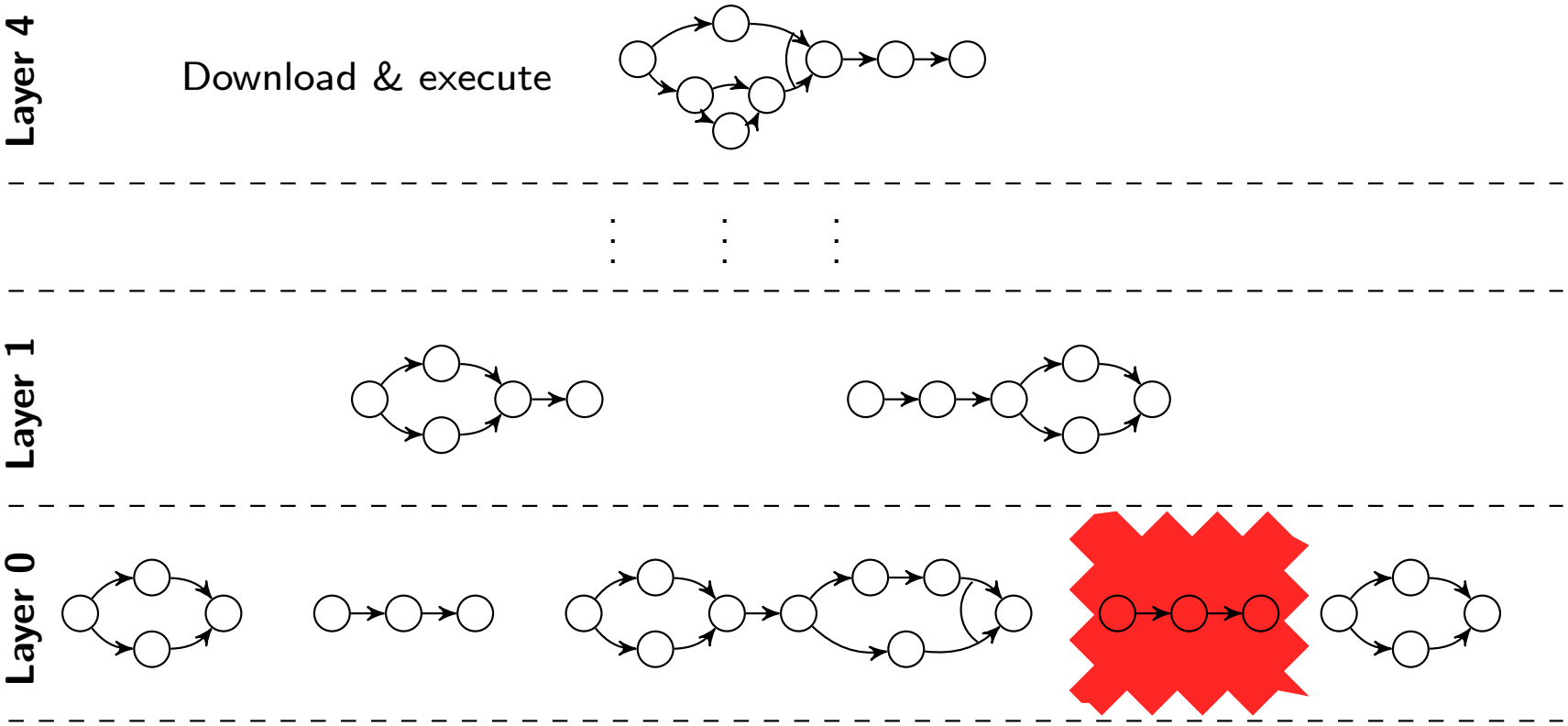


Imagine how easy it is to manage our models of malicious behaviors

Are we managing the complexity?



A behavior graph can be easily extended or replaced without needing to change the upper layers

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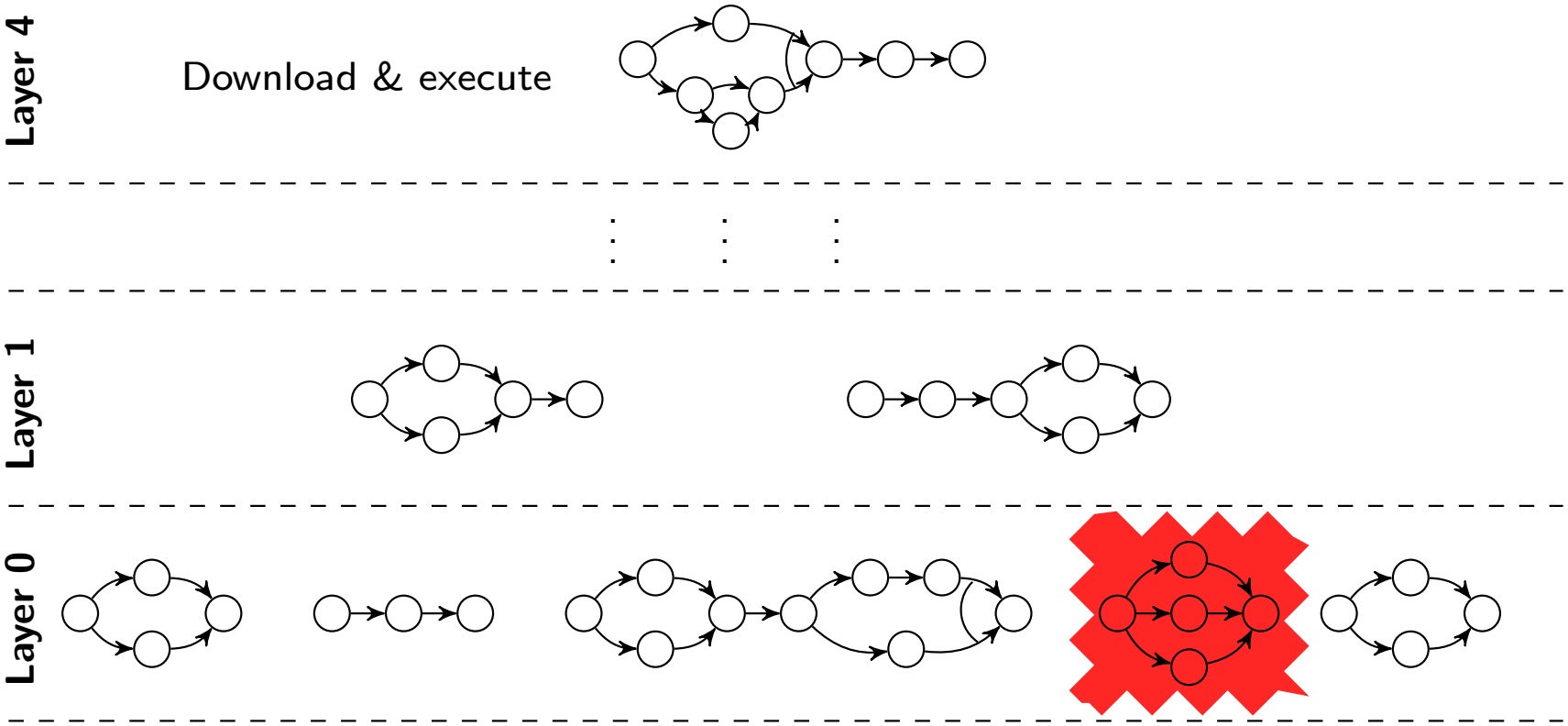

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Construction of behavior graphs

- Native API are not documented! We analyzed tens of gigabytes of execution traces of various applications to build the most complete behavior graphs
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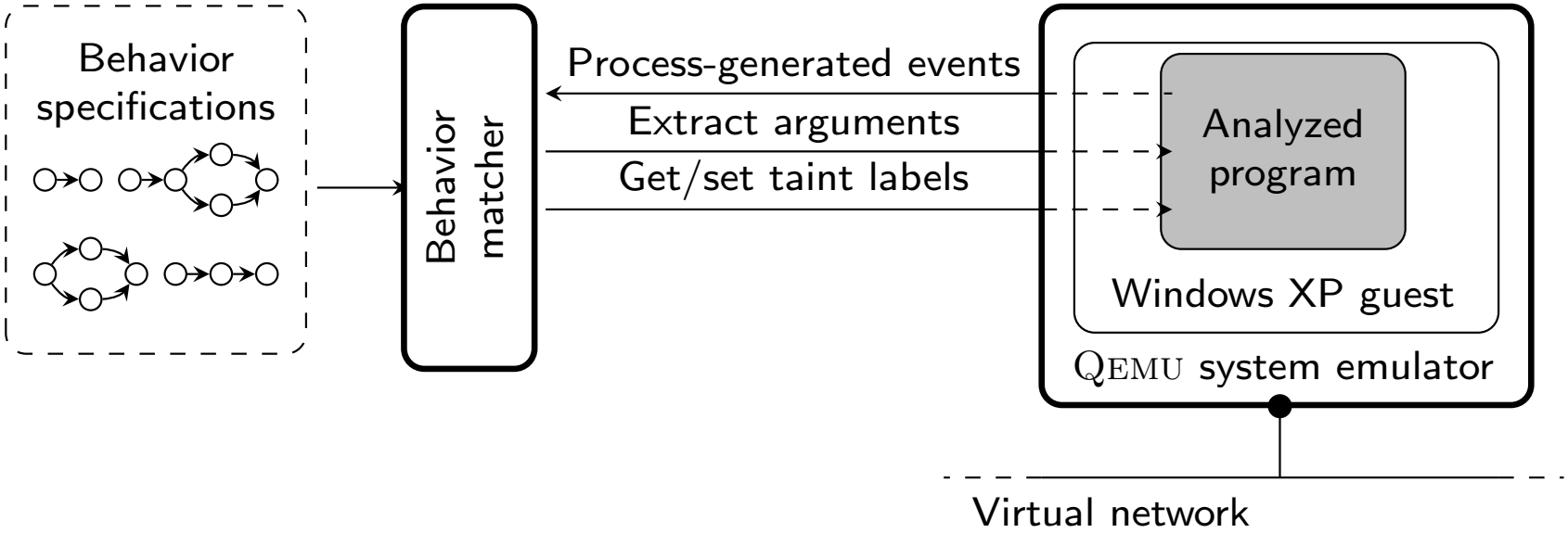
- We currently have more the 40 behavior graphs (for WinXP)
- Some primitives of our language resulted from this effort:
  - TCPClient (8 graphs)
  - TCPServer (6 graphs)
  - TCPProxy (21 graphs)
  - NetDownload (15 graphs)
  - SendEmail (12 graphs)
  - KeyLogging

It becomes very easy, using our primitives, to model new behaviors (e.g., a malware that acts as a SMTP relay or that sends copies of itself via email)

Architecture of the system



- Customized QEMU that instruments the guest code to monitor system call invocations, to perform taint analysis, and to track local user input
- A behavior matcher that receives events in real-time and tries to match each behavior graph loaded

Evaluation

1. Do our behavior specifications adequately cover semantically-equivalent but programmatically-different execution paths?
2. Are our behavior specifications good for detecting bots and other kinds of malware?
3. Do our behavior specifications report any benign program as malicious?
4. What is the performance impact of the system?

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Our graphs have a very good coverage

Evaluation

2. *Are our behavior specifications good for detecting bots and other kinds of malware?*

The system and the behavior specification were tested against 7 well known bots and 7 malware:

Behaviors:

- Remotely initated (RI) sendto
- RI create and execute file
- RI net download
- RI send email
- RI TCP proxy
- Keylogging
- Data leak
- Self propagation via email

Bots & other malware:

- rBot
- Agobot
- SpyBot
- ...
- Banker
- Delf
- Bagle

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A single behavior graph (signature) can be used to identify the same malicious behavior in a variety of malware

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User input tracking is very important to distinguish between behaviors triggered by the user and behaviors triggered automatically:

- ∼25% FP without user input tracking
- ∼9% FP with user input tracking (Data leak is too coarse)

Evaluation

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User input tracking is very important to distinguish between behaviors triggered by the user and behaviors triggered automatically:

- ∼25% FP without user input tracking
- ∼1% FP with user input tracking (Outlook)

Evaluation

4. *What is the performance impact of the system?*

Wallclock time between visible events for various configurations of the system:

	Tainting	**RICE**	**RISE**	**KL**
Internet Explorer	5.25	11.53	7.19	5.64
pSCP	7.32	8.08	19.62	7.42
Agobot	3.01	16.40	23.73	16.84
rBot	9.50	11.20	11.08	9.62

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The overhead introduced does not allow real-time analysis, but . . .

Usage scenarios

. . . there are many others alternative usage scenarios:

- Off-line detailed analysis
- Provide support to domain experts
- Distributed analysis

Take away

We have developed an effective framework for managing the semantic gap problem in behavior-based malware detection:

- Hierarchical behavior graphs allow to easily describe novel semantically meaningful behaviors
- The behavior graphs we have developed are good behavioral signatures for malware detection

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Thank you!
Any questions?