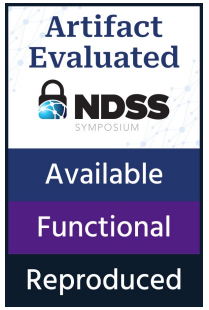

Detecting Ransomware Despite I/O Overhead: A Practical Multi-Staged Approach

Christian van Sloun, **Vincent Woeste**, **Konrad Wolsing**, **Jan Pennekamp**, and **Klaus Wehrle**
RWTH Aachen University

Christian van Sloun, sloun@comsys.rwth-aachen.de
32nd NDSS Symposium, February 2025
San Diego, California, USA

What is Ransomware and why do we care?

Ransomware 2nd biggest threat [ENISA 2024]

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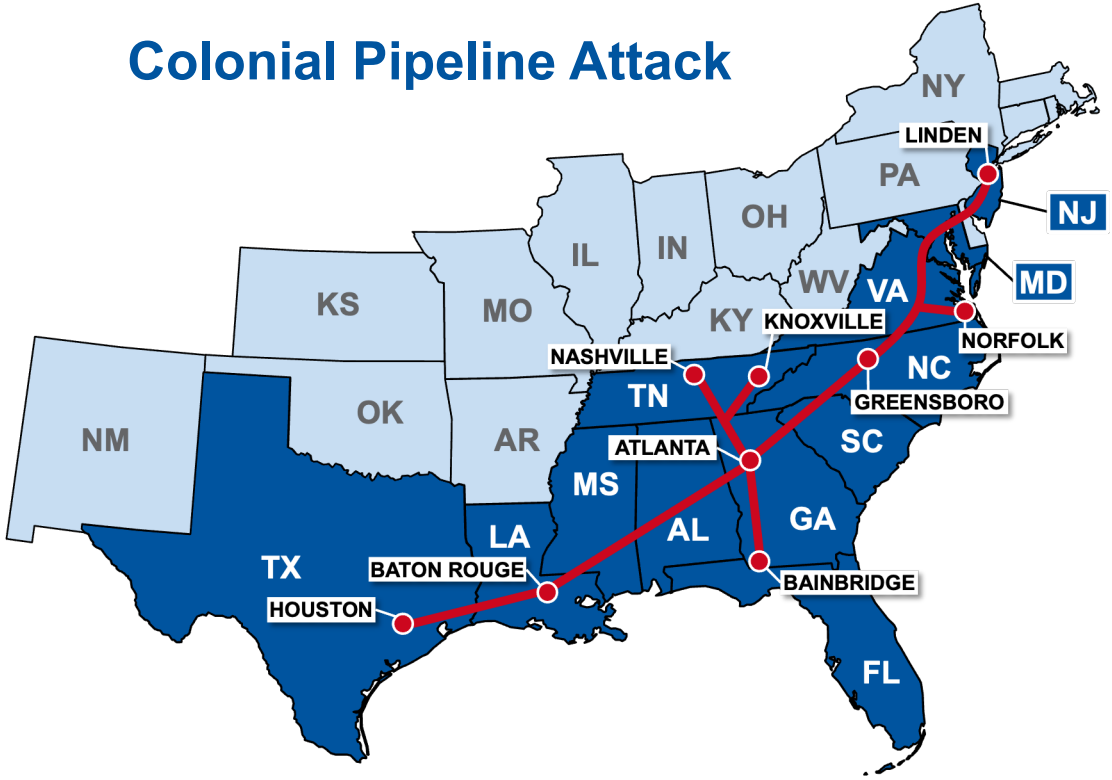
Colonial Pipeline Attack



What is Ransomware and why do we care?

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Cryptographic ransomware

- Encrypts user's files to prevent access
- Ransom demand to unlock files

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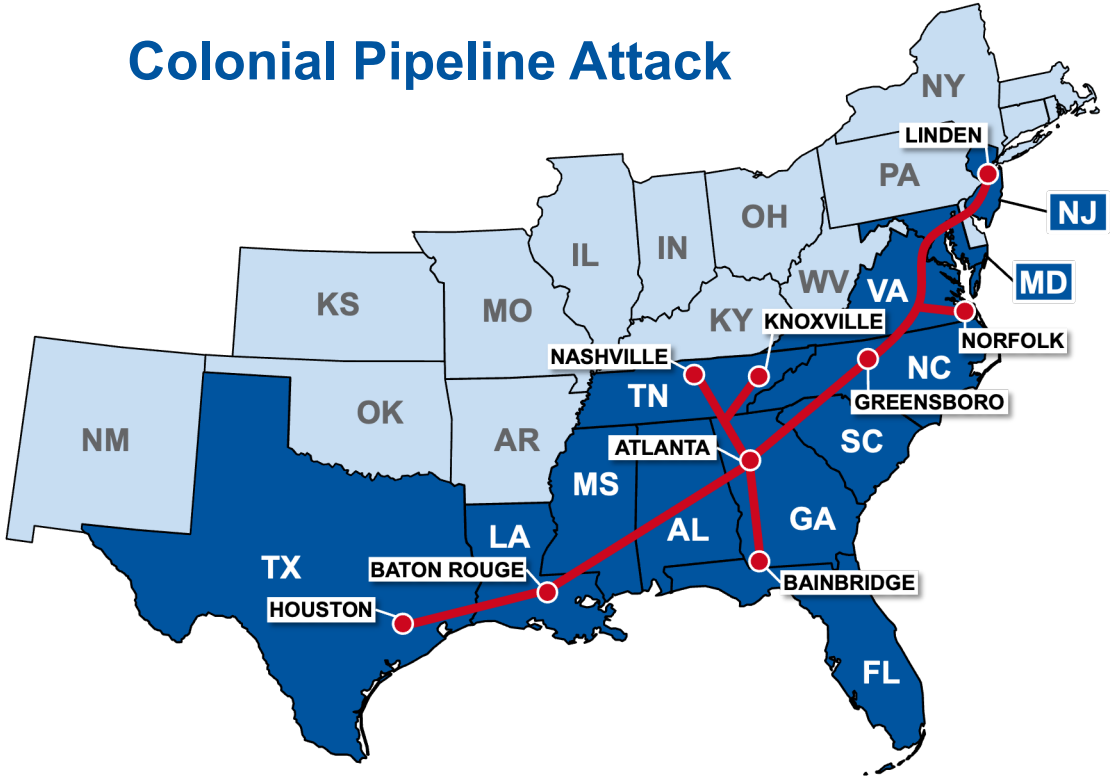

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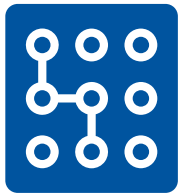
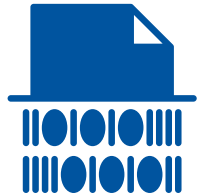


Access Patterns

- overwrite & encrypt
- read, write/encrypt, delete
- Read, encrypt, overwrite

File types

- Reads/Writes specific files (PDF, PNG, etc.)



Data Entropy

- Most files have lower entropy
- Encryption creates **<u>high</u>**-entropy data

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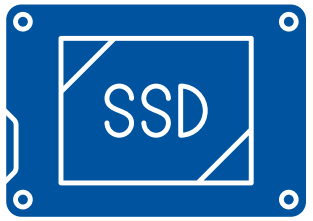

SATA SSD (sustained I/O) → **25%**

530 MB/s

Read/Write speed → **130 MB/s**

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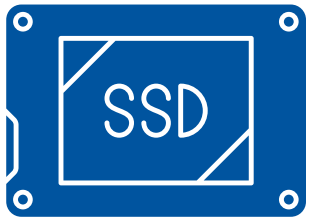

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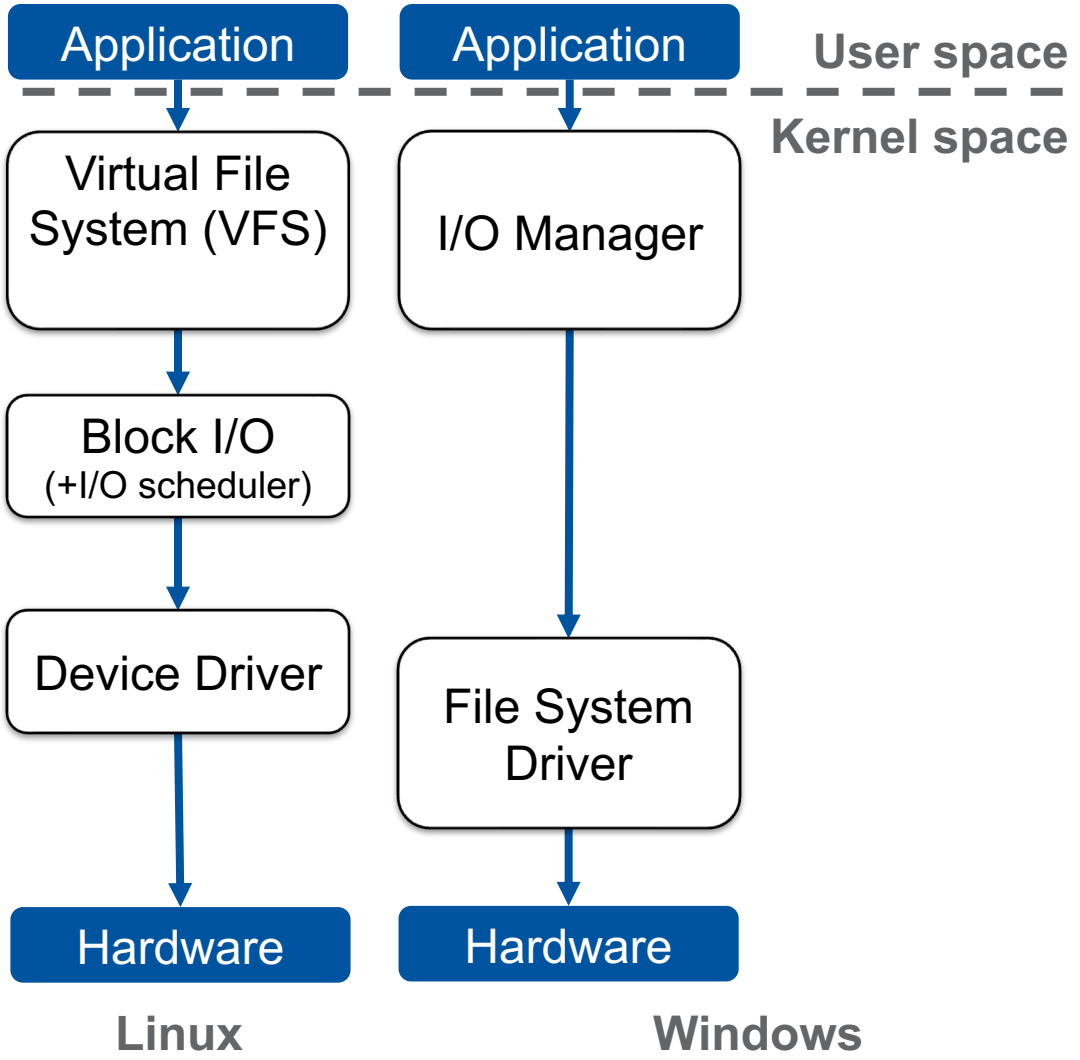
The impact of individual features on I/O overhead is unknown!

Quick Detour – Inner Workings of the I/O-Stack

- **Applications use OS functions to access the file system**
- **Hardware file layout abstracted through the file system**



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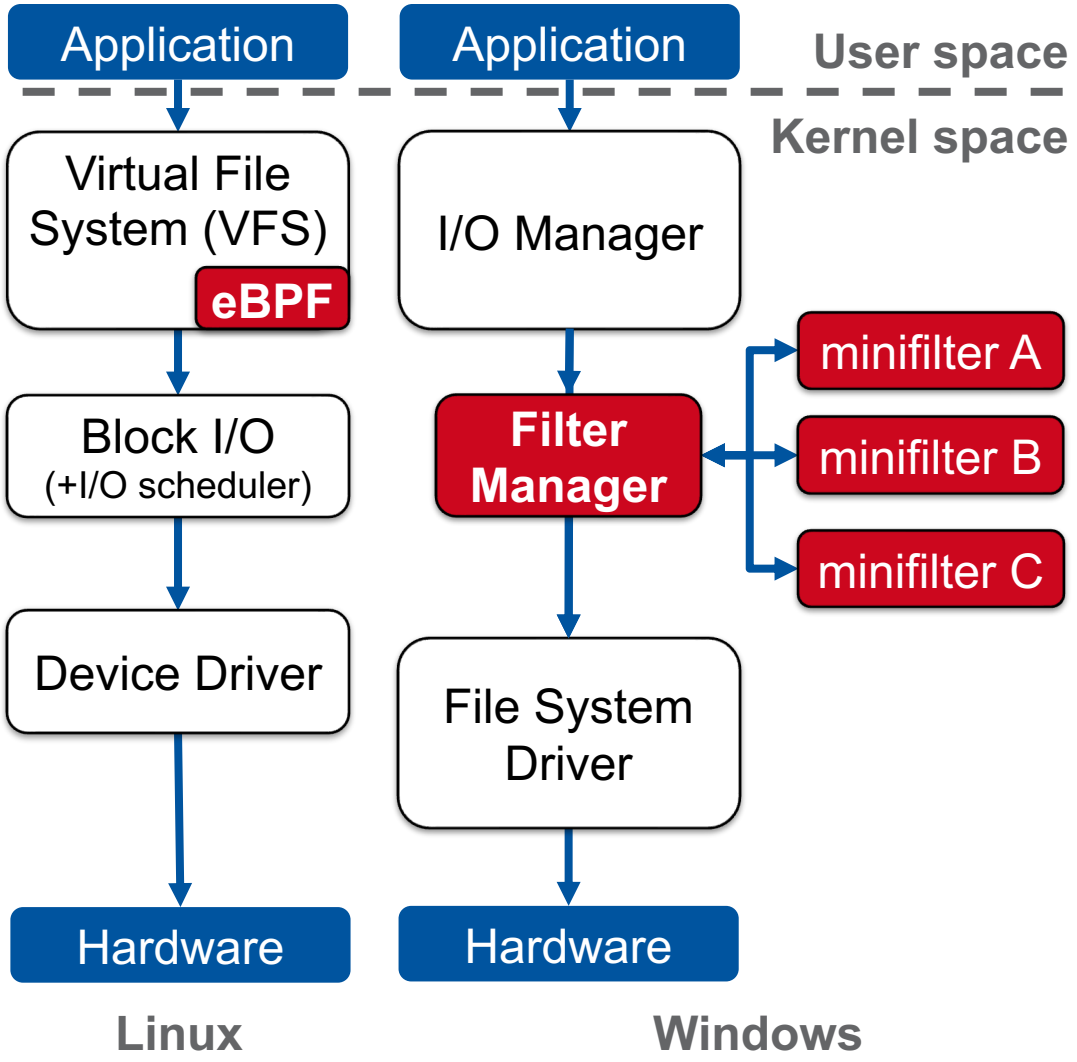

Quick Detour – Inner Workings of the I/O-Stack

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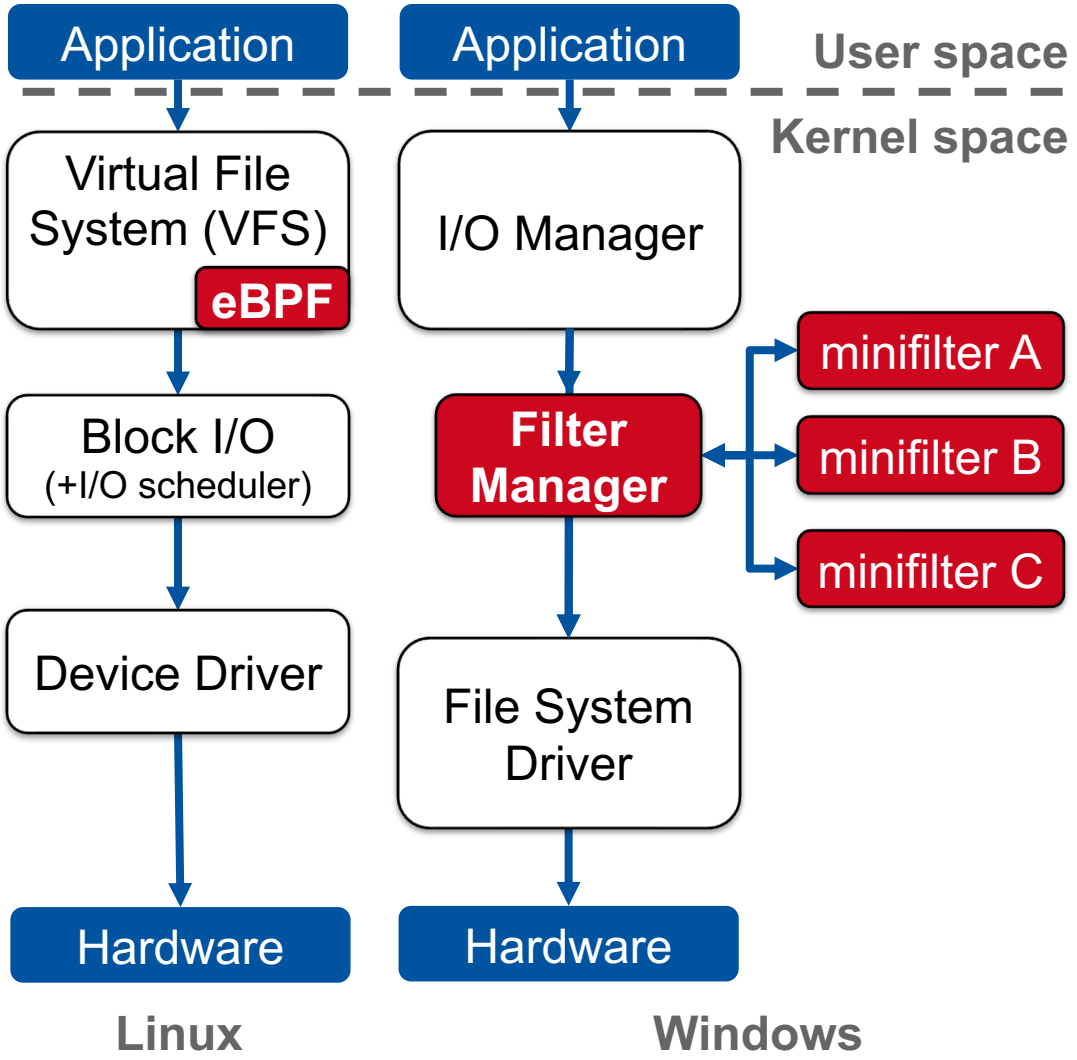
Work on improving filesystems and I/O stacks is ongoing

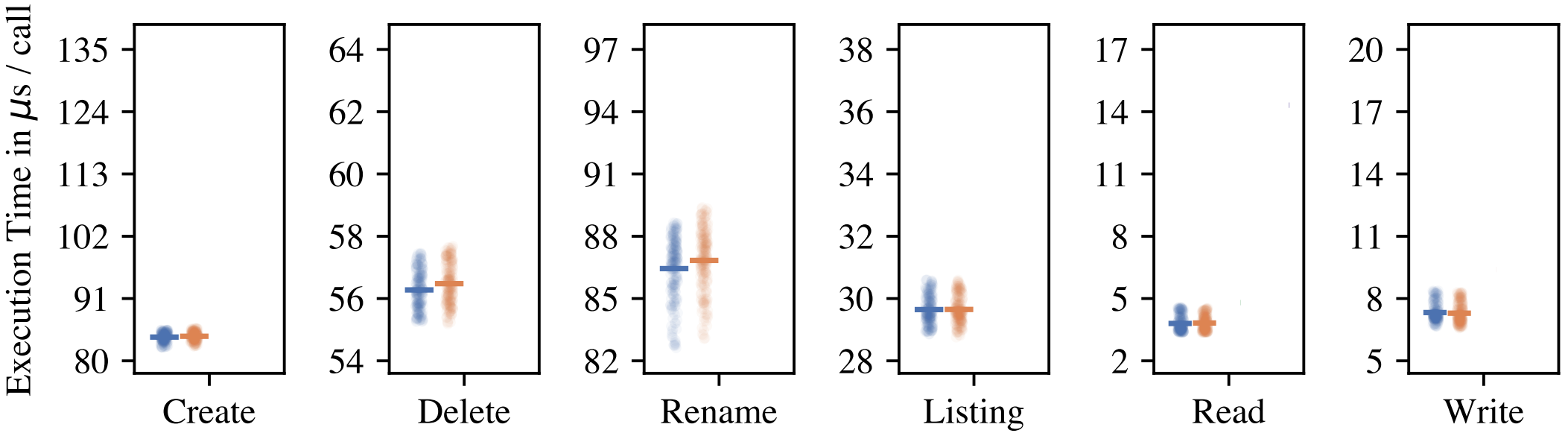
Microsoft FastIO

Microsoft DirectStorage 2020



I/O Overhead Measurements on Windows 11

Hardware: Intel i7 4770,
16GB RAM, 500GB SATA SSD



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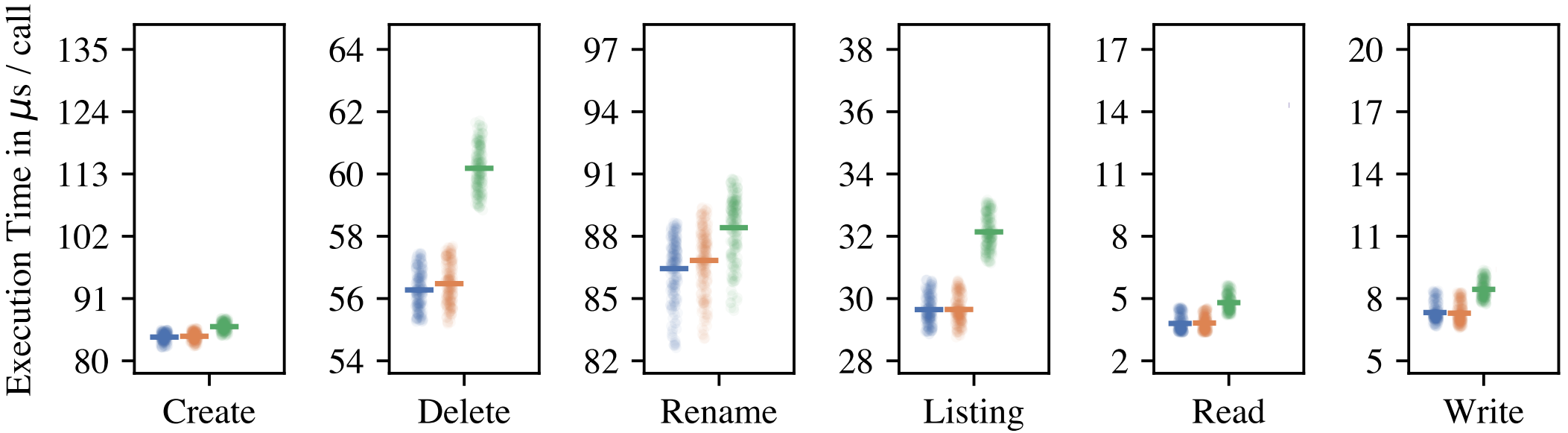

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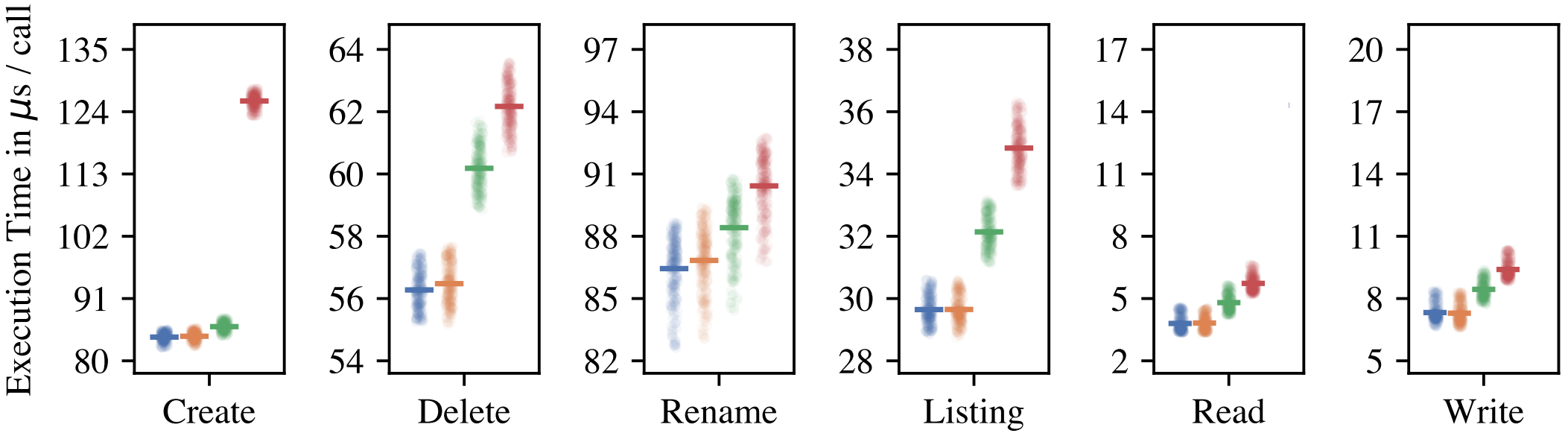

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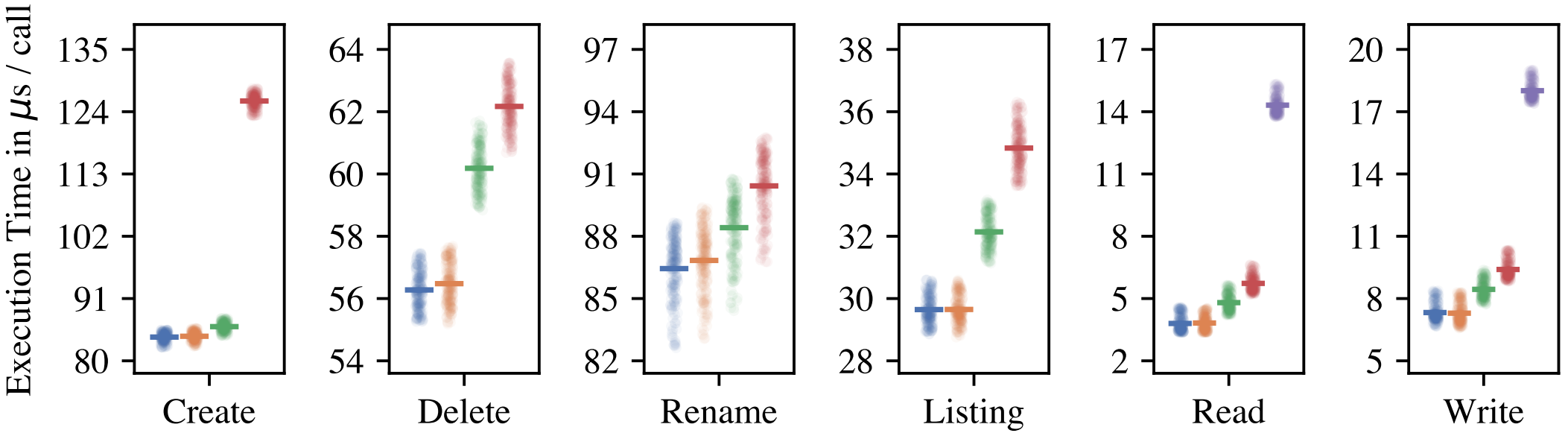

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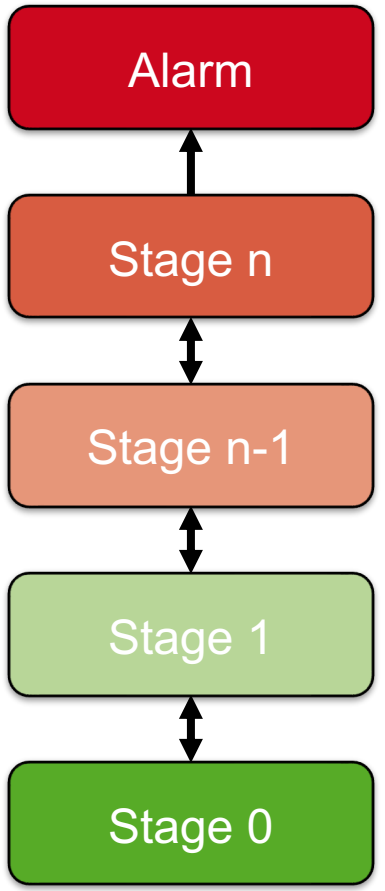
5. Record call, PID, arguments, resolve filename, calculate entropy (read/write)

Multi-Staged Ransomware Detection (MS-IDS)

- **Can we intelligently adjust real-time monitoring on a per-process level?**
  - Most processes are benign!
  - Why not monitor only what is required?
- **Add/remove features according to the process's behavior**



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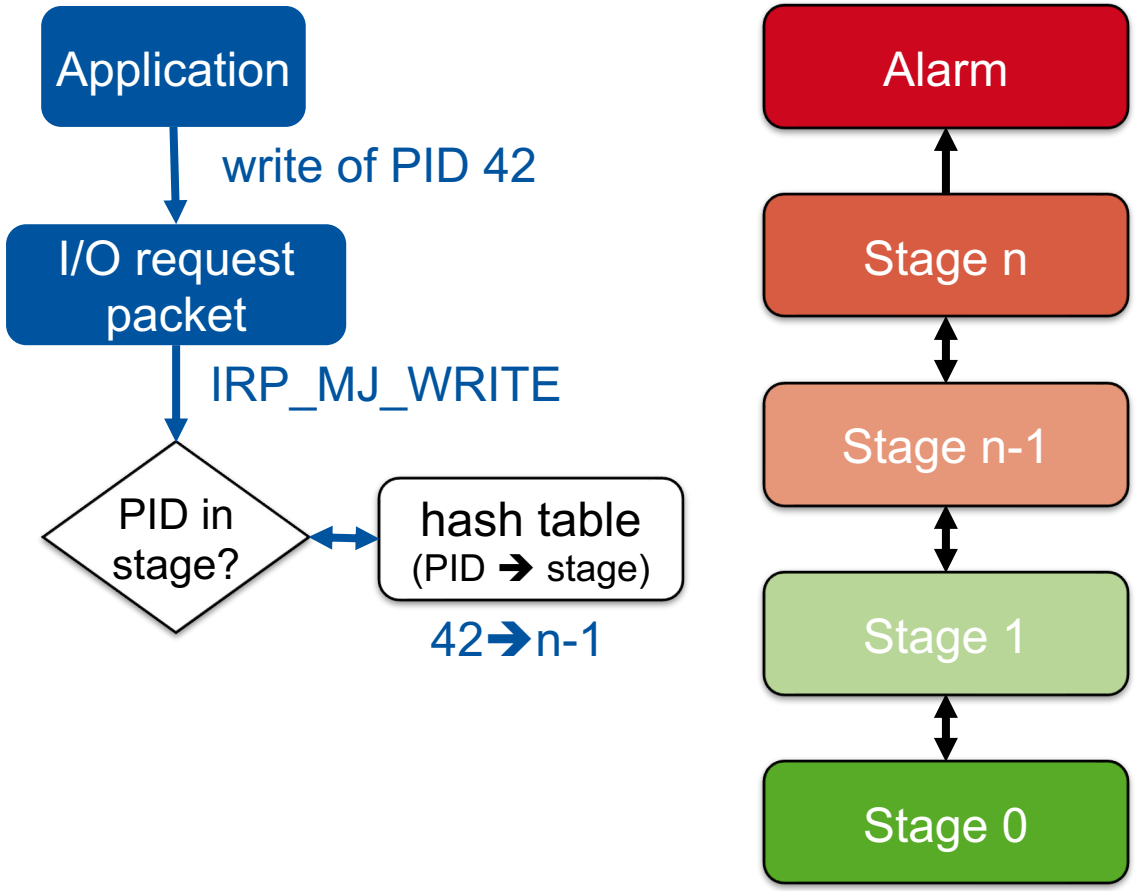

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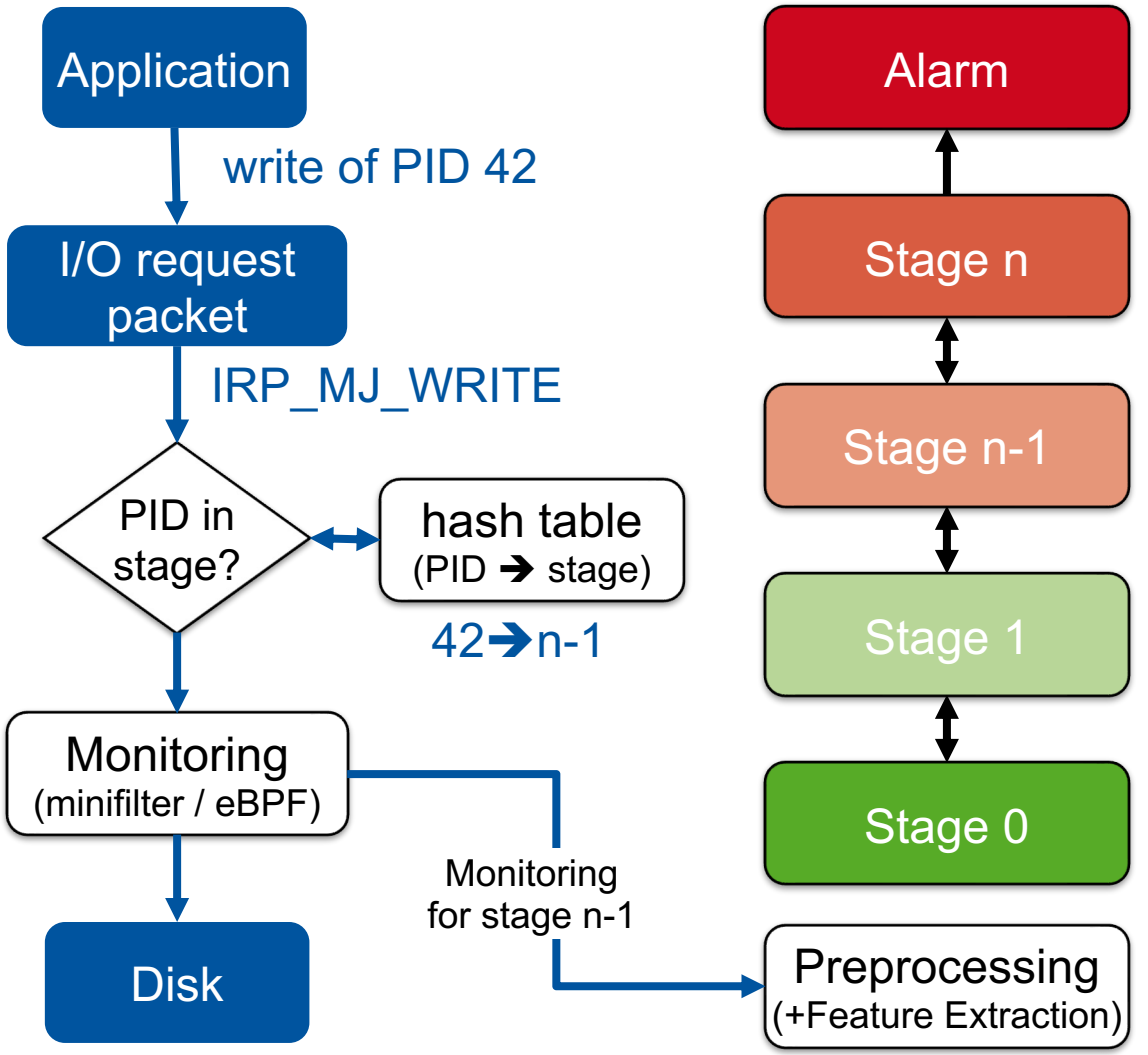

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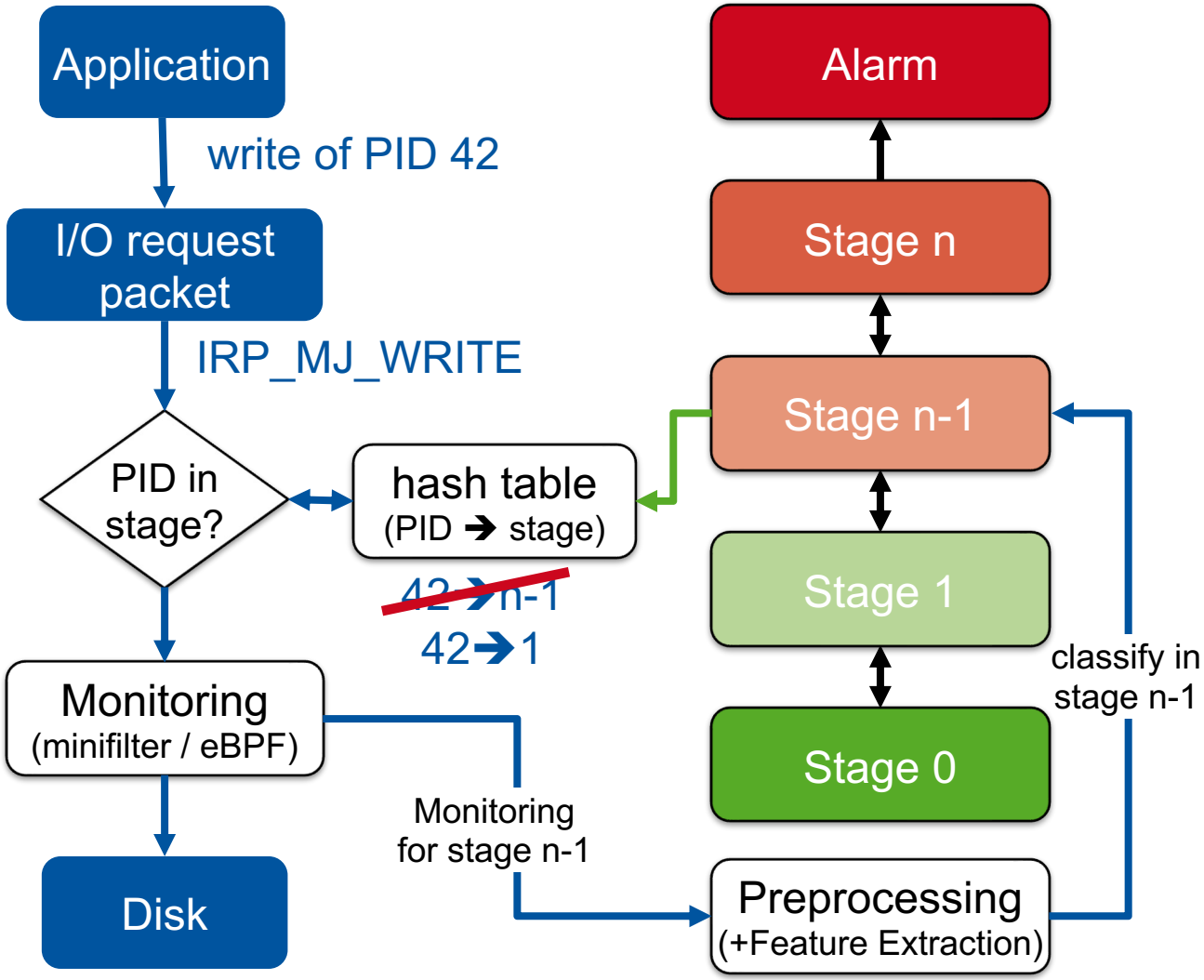

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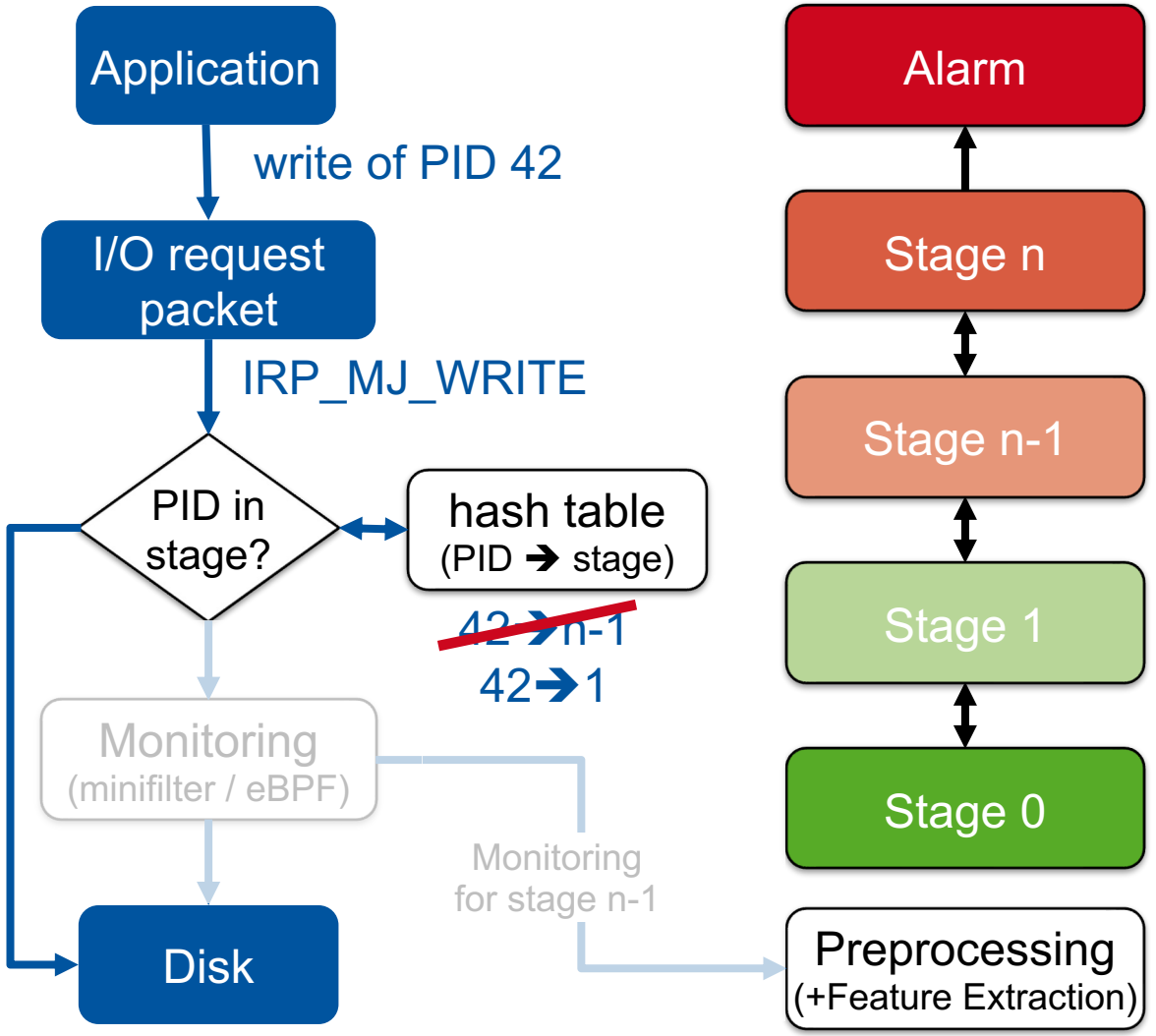

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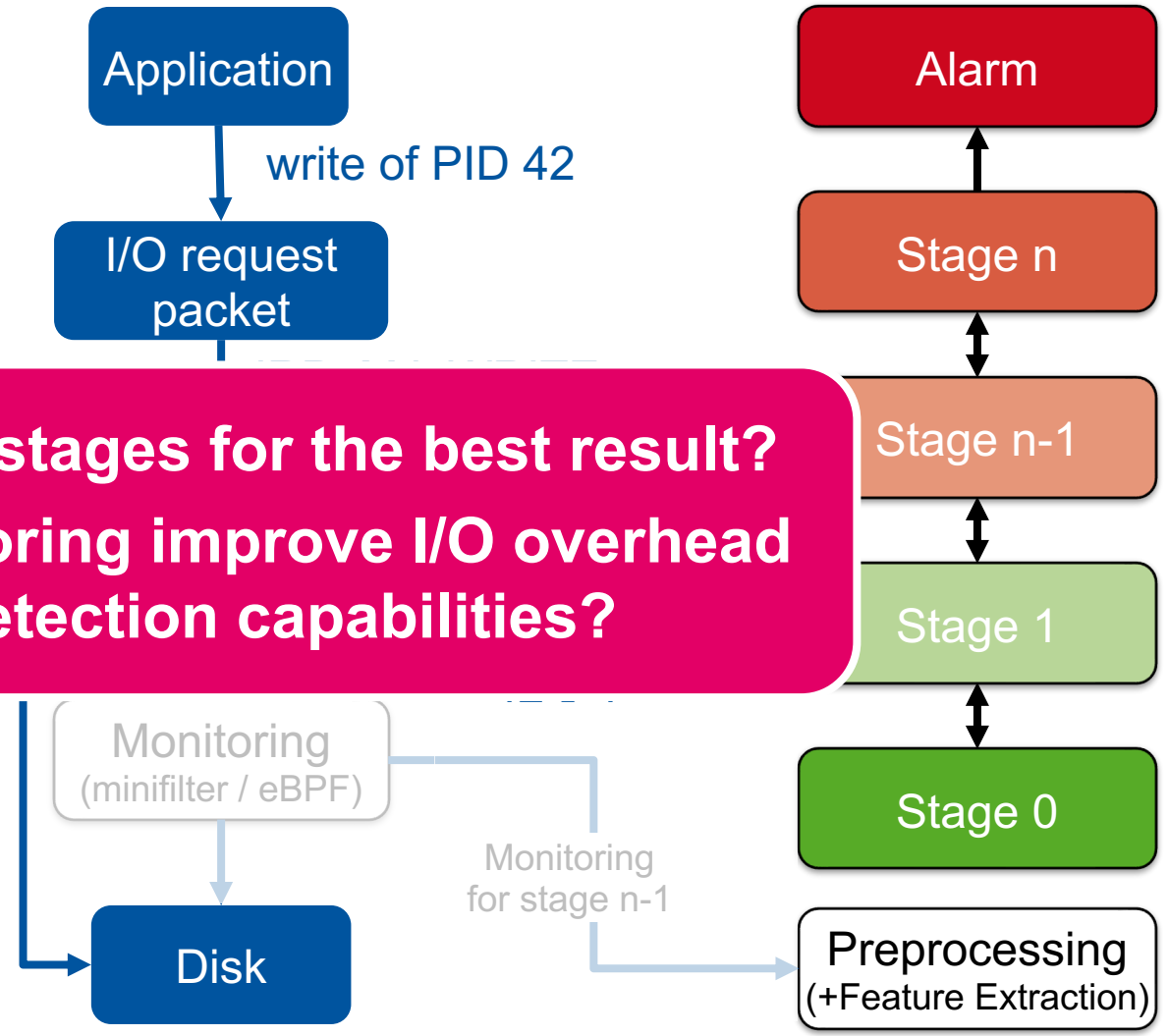

- **How to connect the stages for the best result?**
- **Can dynamic monitoring improve I/O overhead while maintaining detection capabilities?**

Stage Designs Considerations

1. **Classification Performance**
   - Balance precision/recall per stage individually
   - Low stages require high recall, but **not** high precision

2. **Overhead / Classification Frequency**
   - Frequency influences overhead
   - Only recorded calls can trigger classification

3. **Detection Latency**
   - More stages ➔ higher latency to detect attacks
     - Minimize “shortest path to alarm”

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Paper: Details on stage-transitions and features per stage

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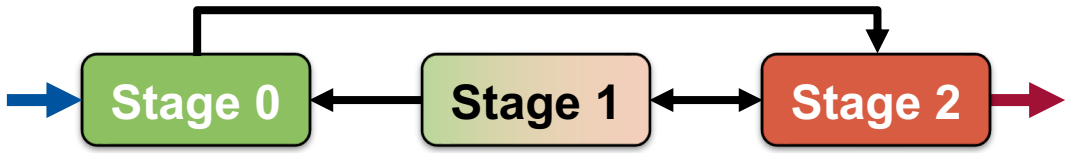
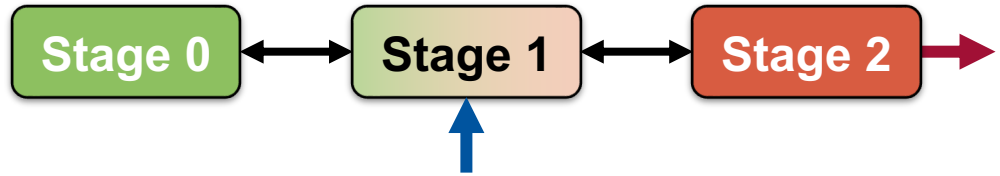
Naïve Monitoring (N)

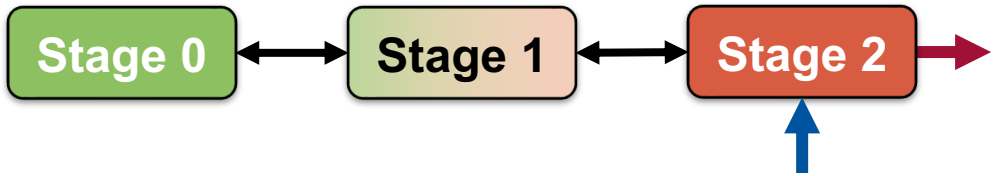
Reduced Monitoring (RM)



Initial Monitoring (IM)



Suspicious Monitoring (SM)



Evaluation Results

Excludes processes with insufficient IO operations to raise false alarms

#Stages	Architecture	TN	FP	FN	TP	F1
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3	Naïve Monitoring	2693	3	0	91	0.98
	Reduced Monitoring	2694	2	0	91	**0.99**
	Initial Monitoring	11638	9	0	91	0.95
	Suspicious Monitoring	12749	7	0	91	0.96
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Evaluated on ShieldFS dataset (2016)

- Real-world data of user sessions from 11 machines
- Over 380 distinct ransomware samples of 6 ransomware strains (91 contained in test set)

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Even the naïve models detect all samples

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No increase in false-positives for suspicious monitoring

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Evaluation against novel ransomware (2020-2023)

Unmodified models with data from 2016:

- MS-IDS detects 12 out of 47 samples **(~25%)**
- Single-Stage IDS detects 12 samples

Manual adjustment of hyperparameters:

- MS-IDS detects 18 out of 47 samples **(~38%)**

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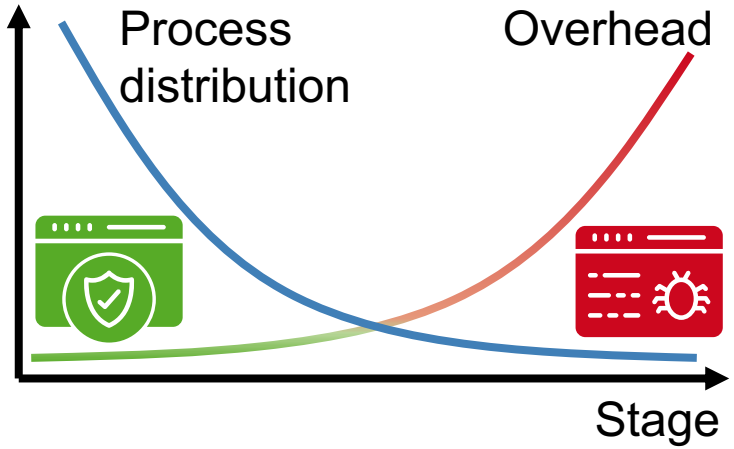

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Paper: Details on detection latency and I/O distribution across stages

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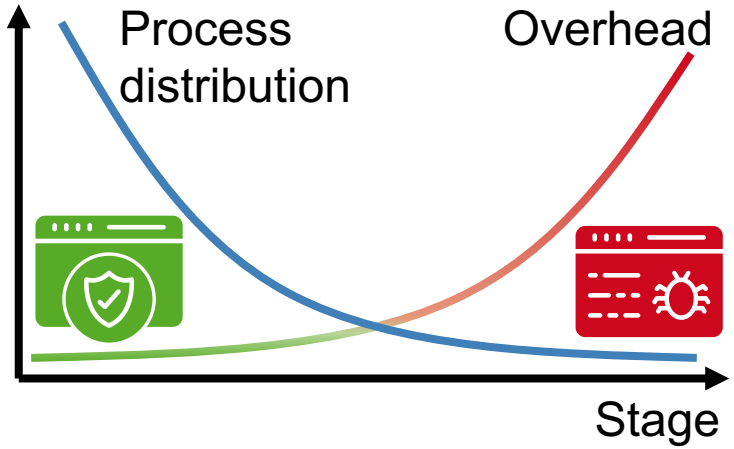

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- **An MS-IDS starting with <u>all</u> features already decreases average overhead by 10x**
  - Other architectures reduce overhead by a further factor of 2x

Conclusion

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Thank you for your attention

Check out our code