Family Ties: A Close Look at the Influence of Static Features on the Precision of Malware Family Clustering

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institute imdea software

BforeAI

Gen™

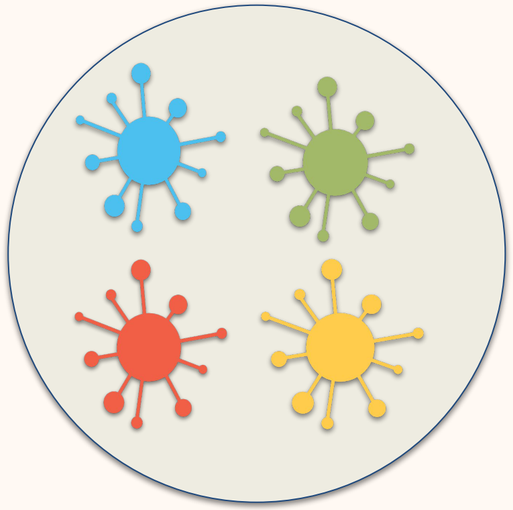
Malware Explosion

Millions of new malware daily

Polymorphism create many variants

Impossible to manually analyze all

Malware Family Clustering



Malware Family

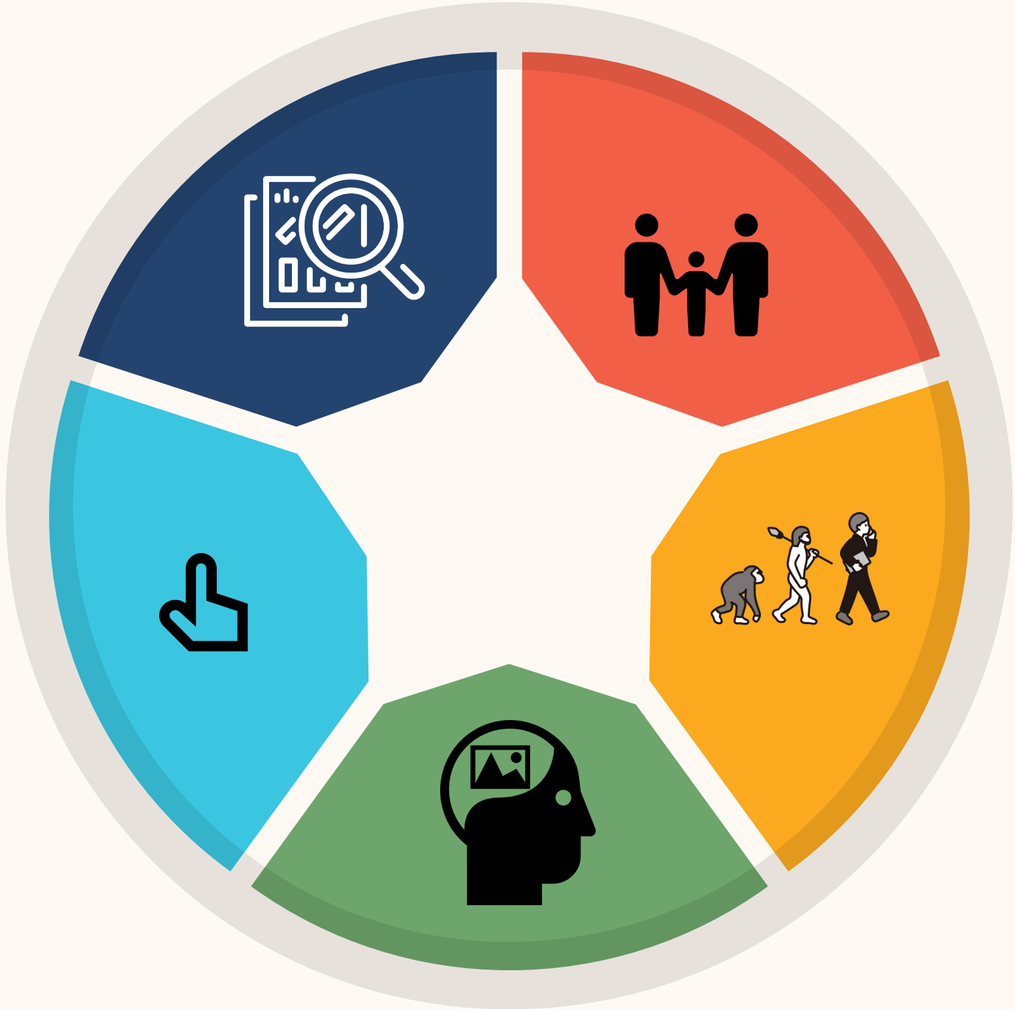
- Samples derived from same code base
- Share common:
  - Characteristics
  - Behavior
  - Attribution to same authors

- **One representative sample is often enough to understand the family's behavior**

Family Clustering Use Cases

Analysis Reduction

Attribution



Lineage Reconstruction

Malware Evolution

Behavior Understanding

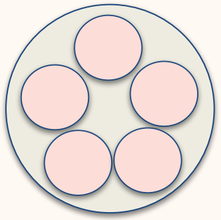
Clustering Accuracy

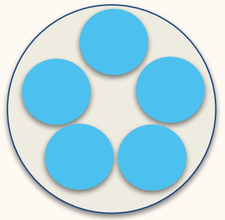
Malware Family A

Malware Family B

Precision

Recall



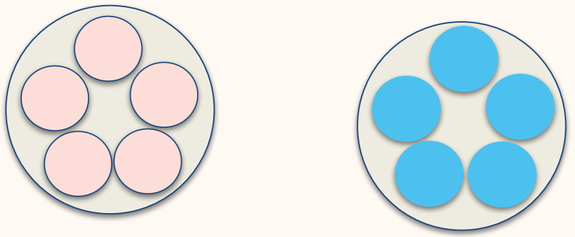


Clustering Accuracy

Malware Family A

Malware Family B

Precision Recall



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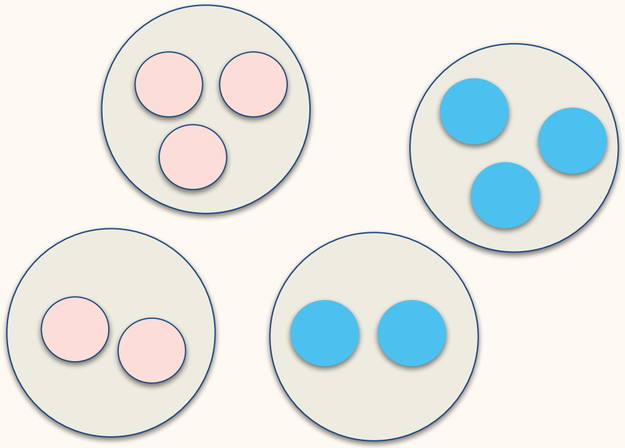

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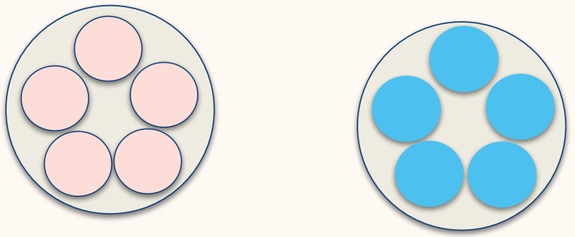

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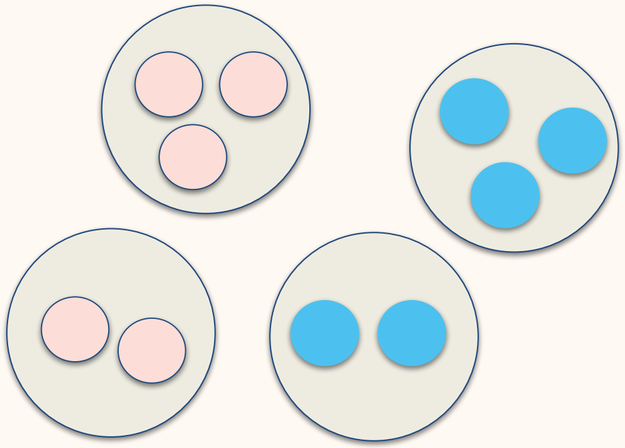

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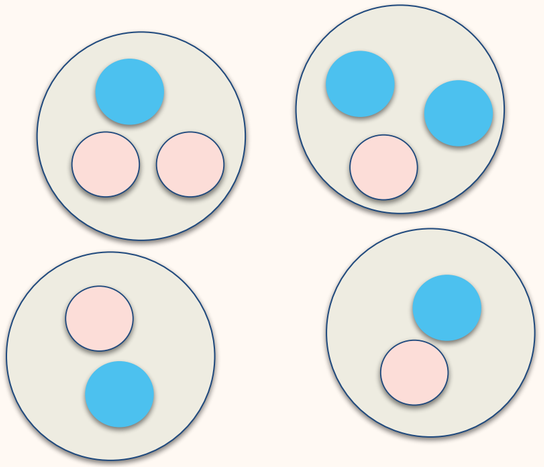

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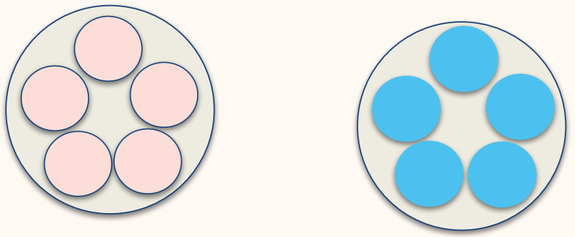

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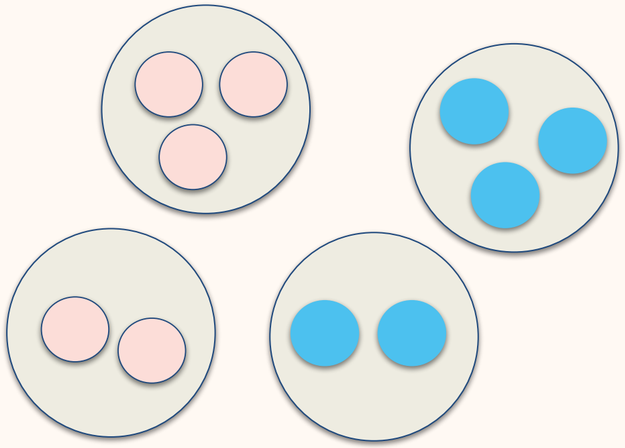
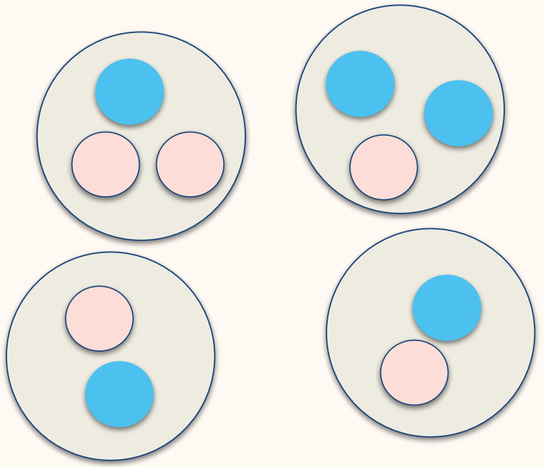
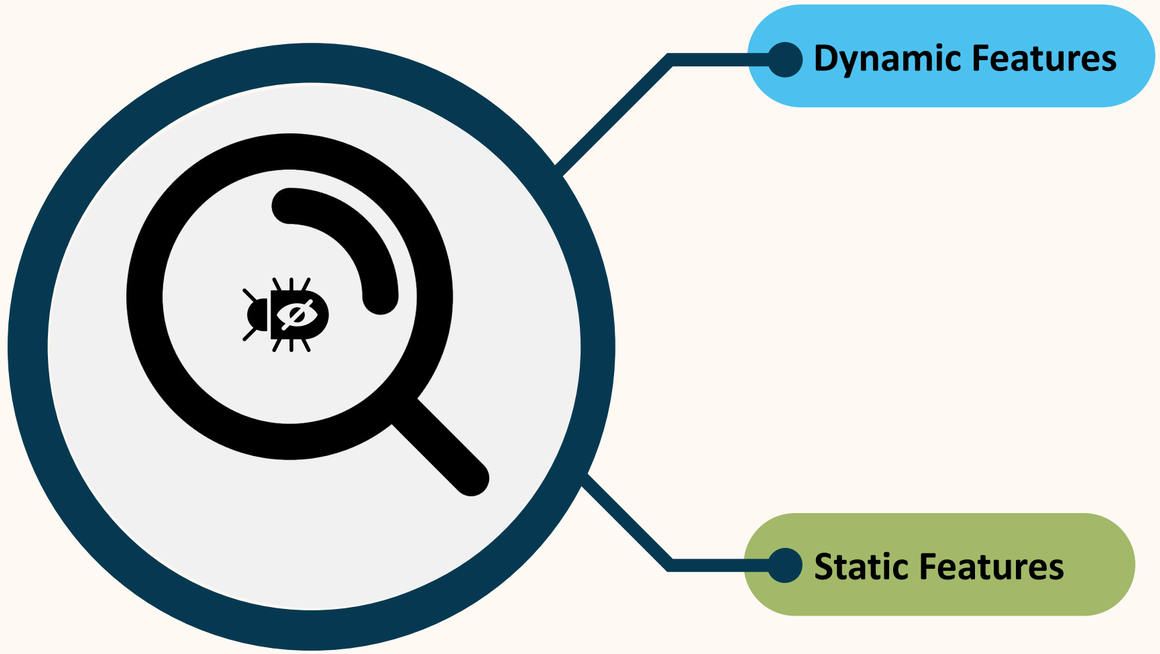


Precision

Mixed clusters



Feature Types



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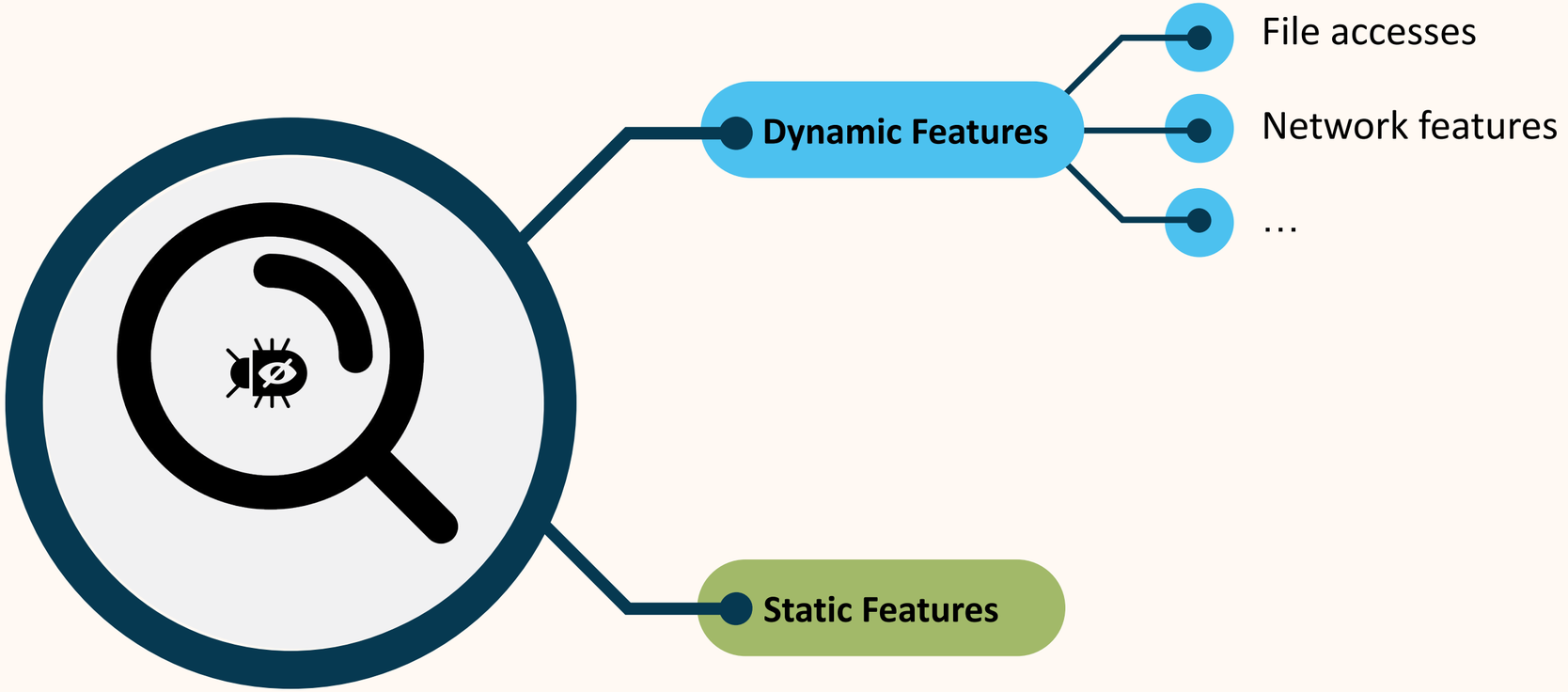

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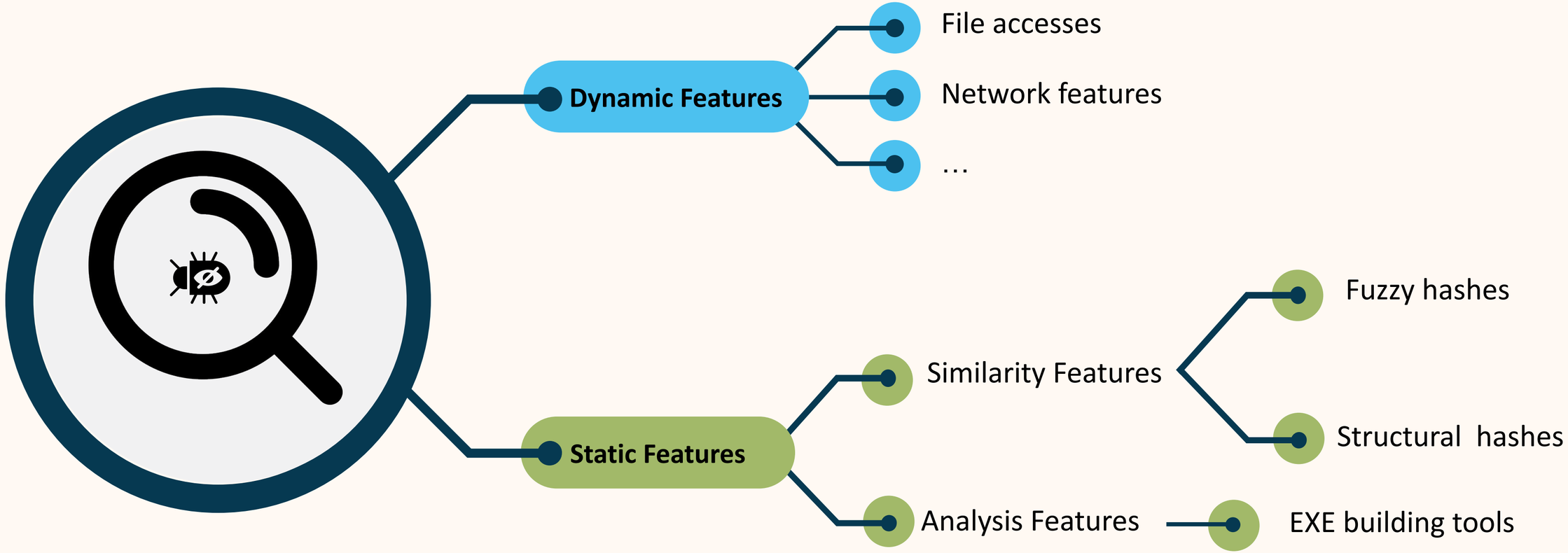


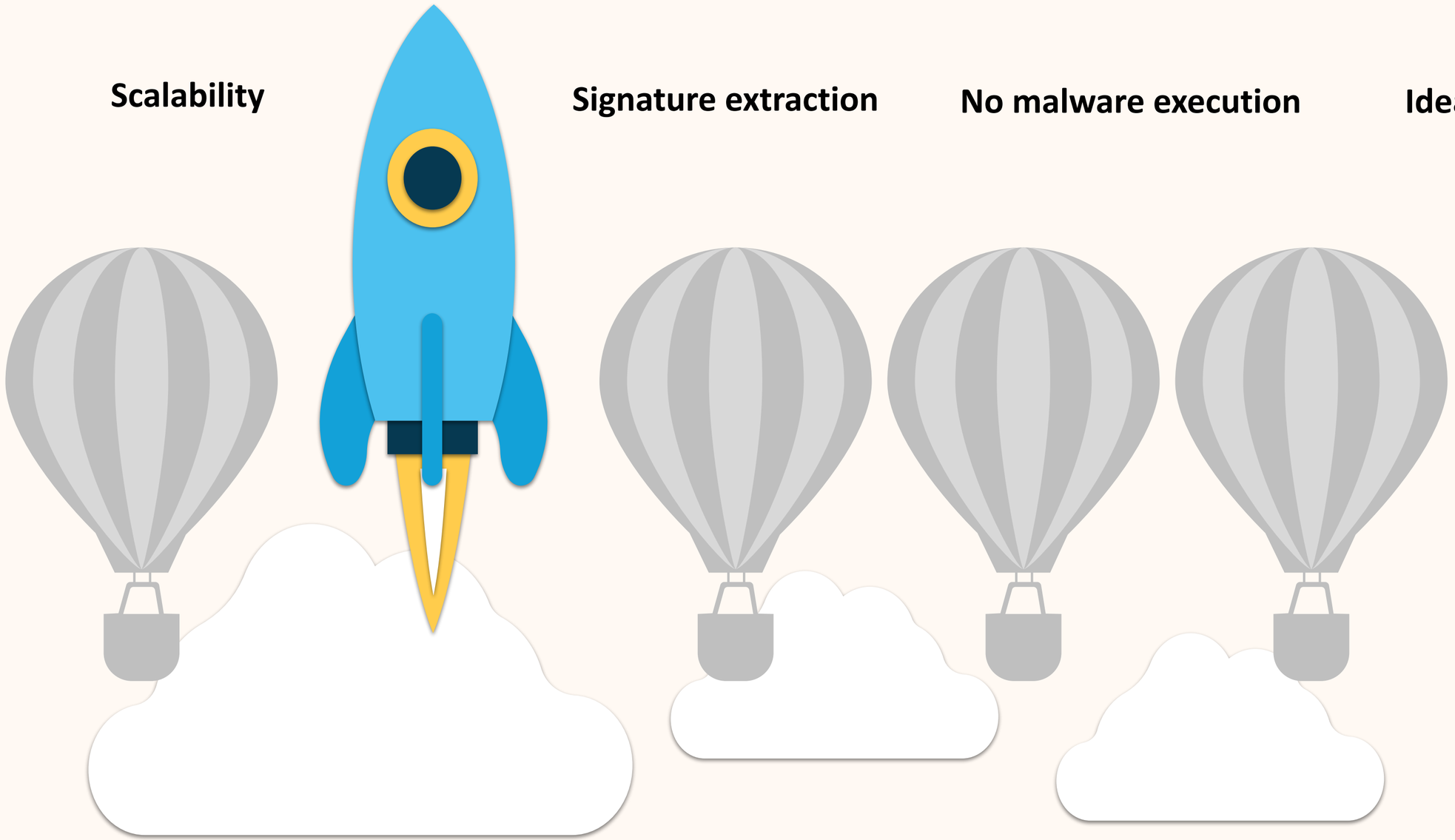
Static Feature Benefits

Scalability

Signature extraction

No malware execution

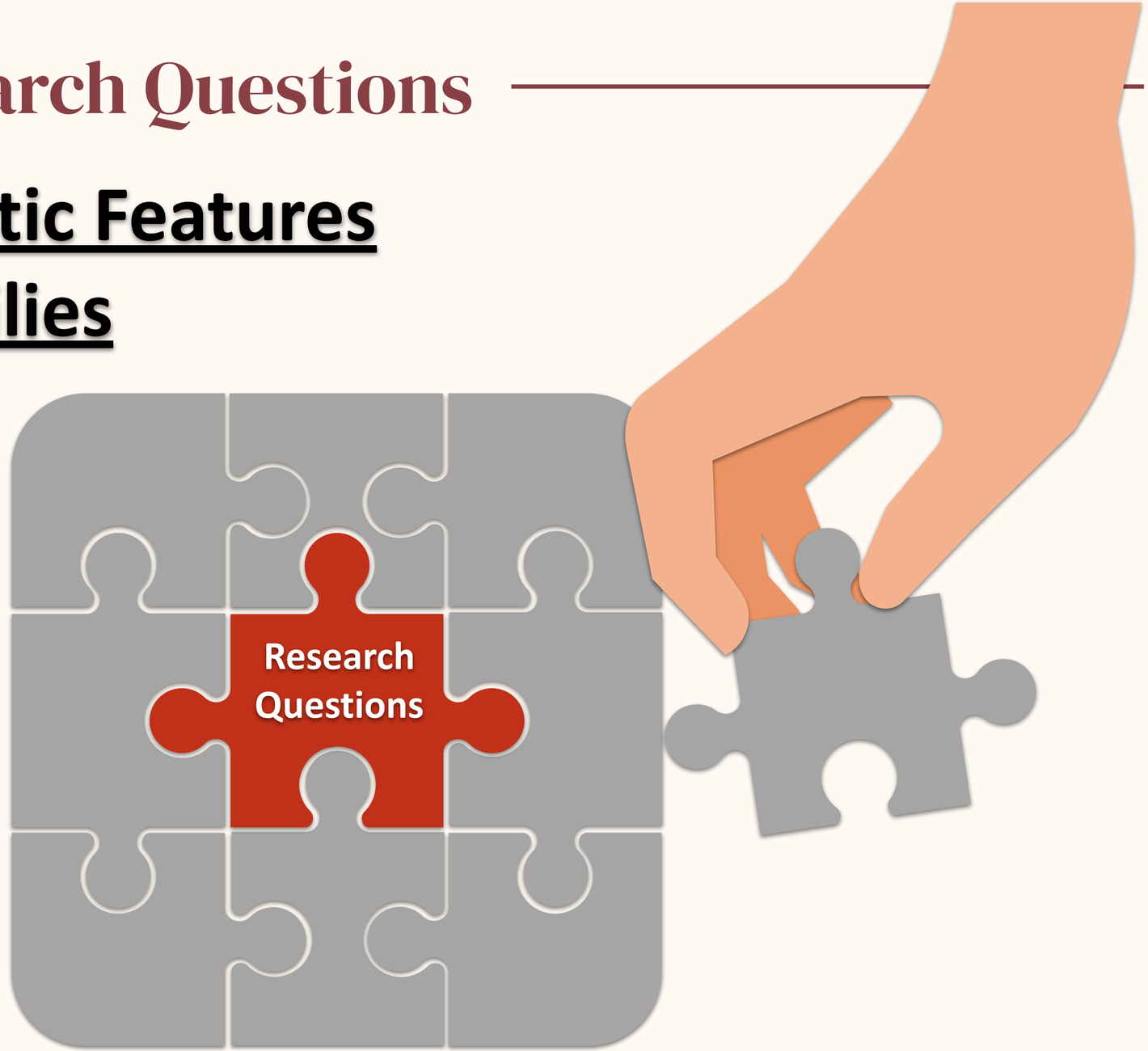
Ideal for large scale



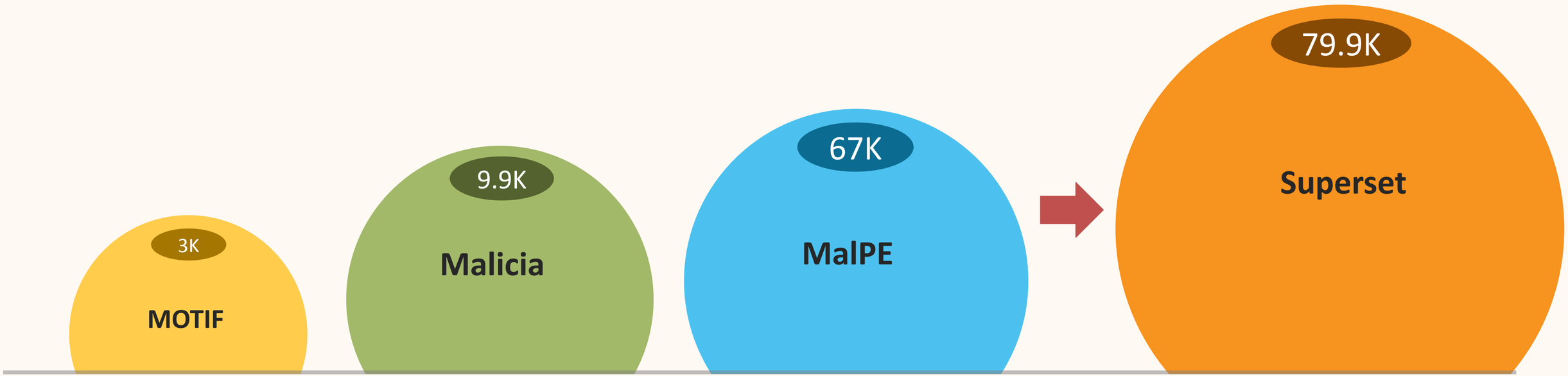
Research Questions

Precision Evaluation of Static Features in Windows Malware Families

- RQ1. Similarity Feature Precision
  - How often static features create mixed clusters?
- RQ2. Similarity Feature Limits
  - Reasons for mixed clusters?



Windows Malware Datasets



454 families

- 2016 - 2020

53 families

- 2012 - 2013

670 families

- 2012 - 2022

1,1K families

- 2012 - 2022

Approach Overview

01 - Clustering samples using one similarity feature

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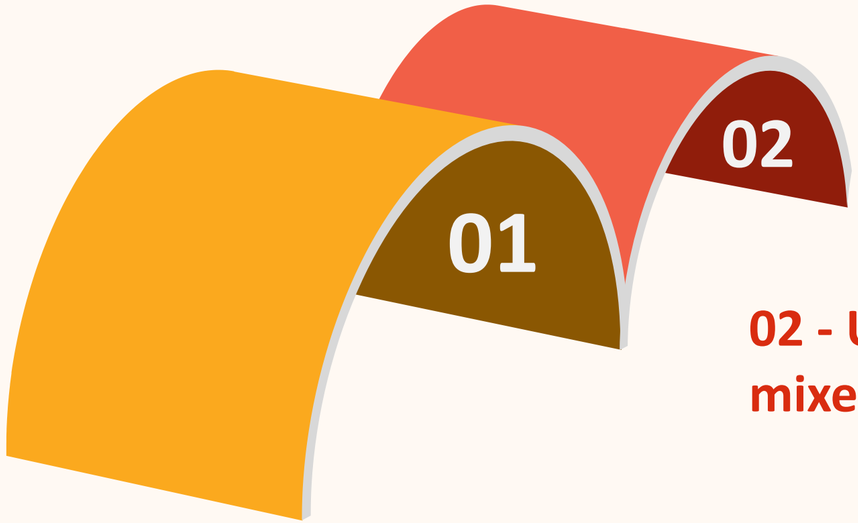

02 - Use dataset labels to identify mixed clusters

Approach Overview

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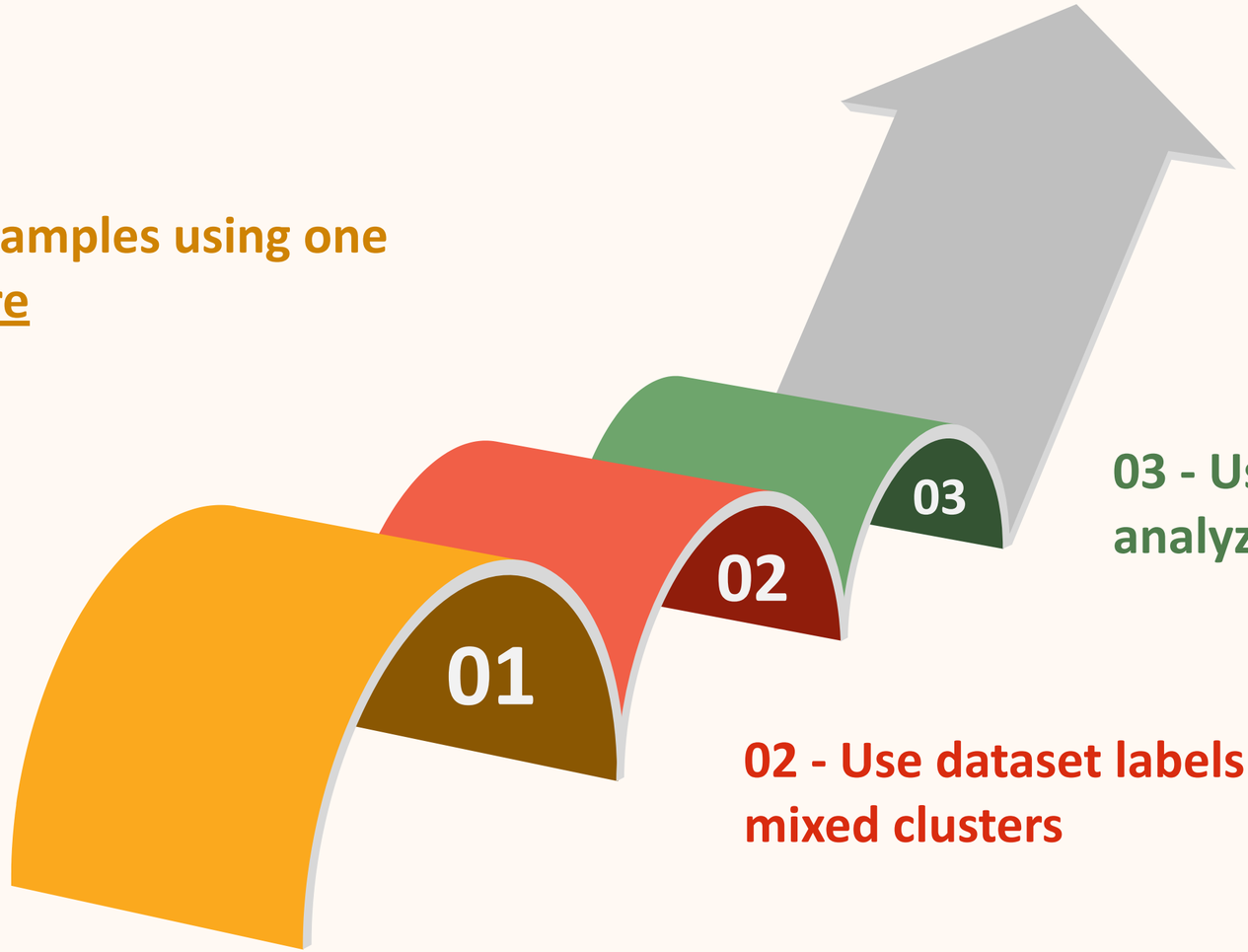

02 - Use dataset labels to identify mixed clusters

03 - Use analysis features to analyze mixed cluster

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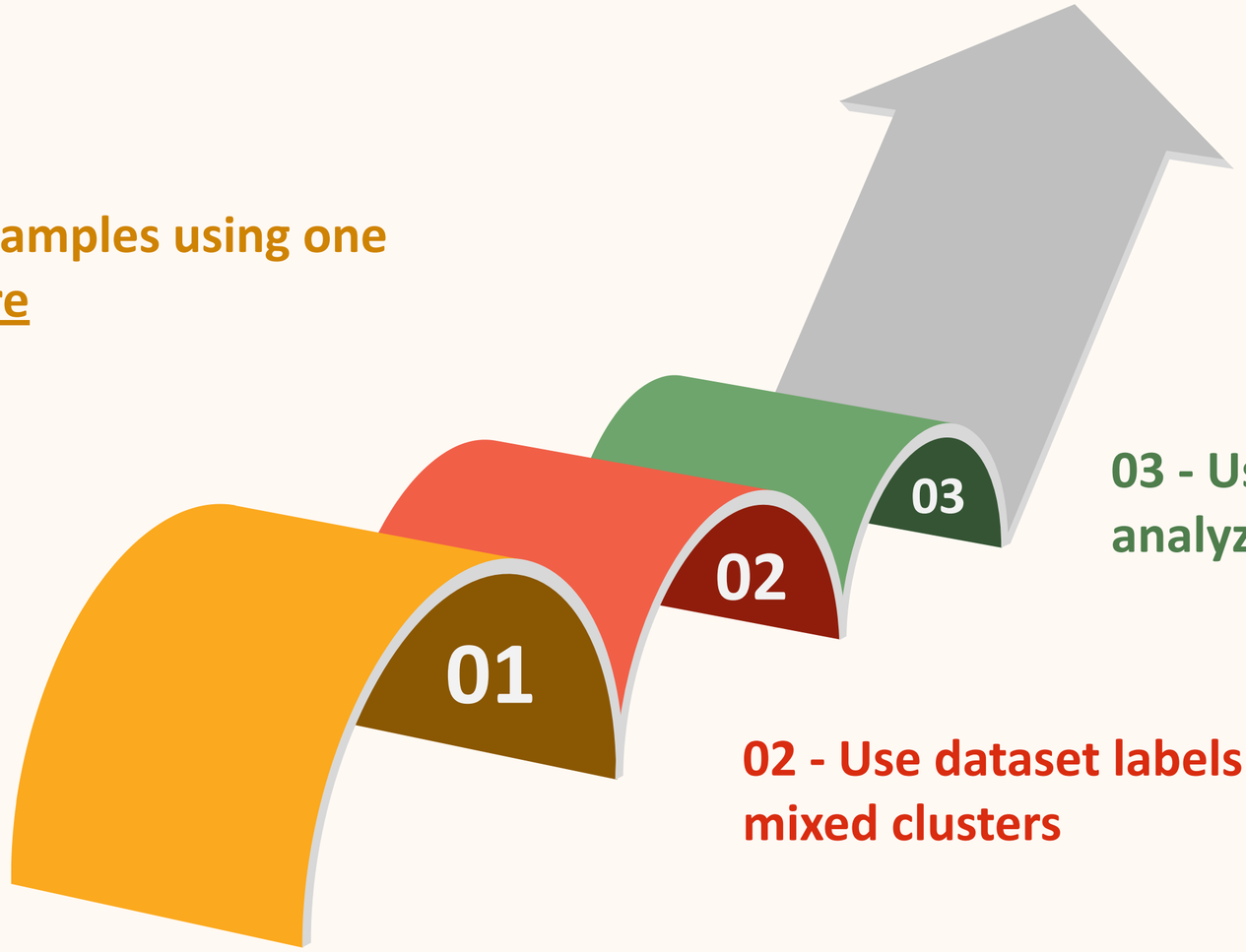

02 - Use dataset labels to identify mixed clusters

03 - Use analysis features to analyze mixed cluster

Our goal is not to develop a new family clustering approach, but to understand the limits of selected static features

Similarity Features

Structural hashes

Different input -> Different output

“hello” -> “5d4140…”
“hellp” -> “8e4d53…”

Equality comparison

- **Imphash**: Imported libraries
- **Pehash**: Program Executable header
- **Richpe:** Rich header (compiler metadata)
- **Certificate**: Thumbprint
- **Authentihash:** Exclude code signing fields
- **Icon hash:** Extracted icon
- **vhash:** VirusTotal’s propietary hash

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Fuzzy hashes

Similar input -> Similar output

“hello” -> “abcd…”
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Similarity comparison

Whole-file:

- **Ssdeep**
- **TLSH**

Extracted icon:

- **Dhash**

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Extracted icon:
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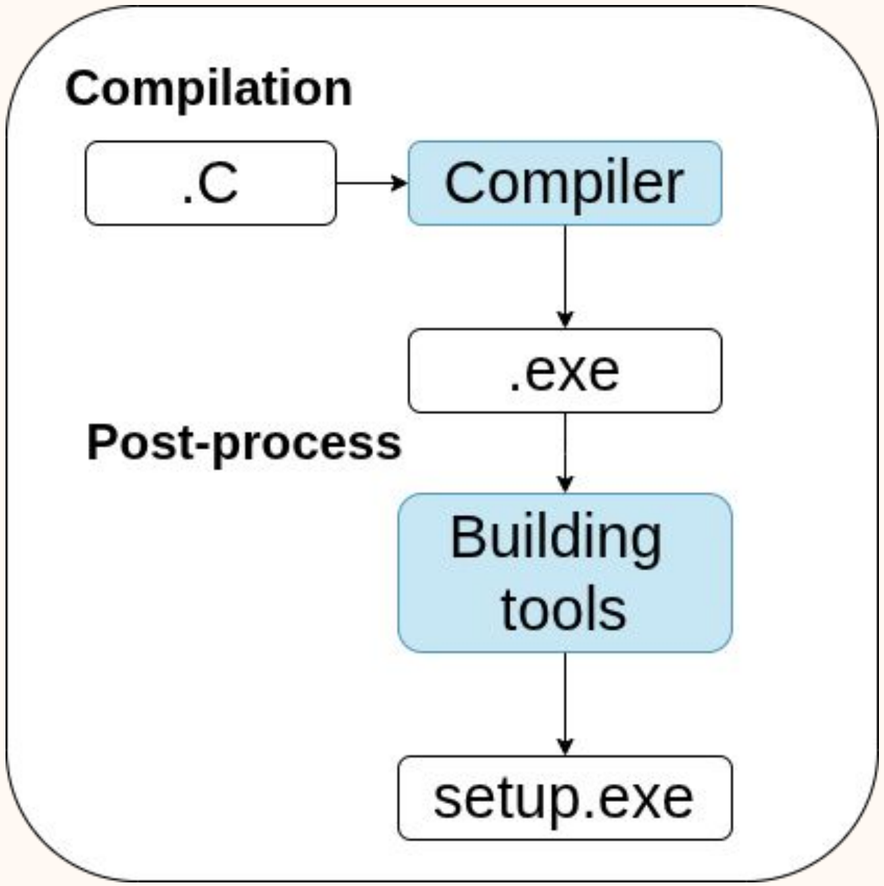
- **Proven effectiveness and interpretability**
- **Ease of extraction and reproducibility**

Analysis Features - EXE Building Tools



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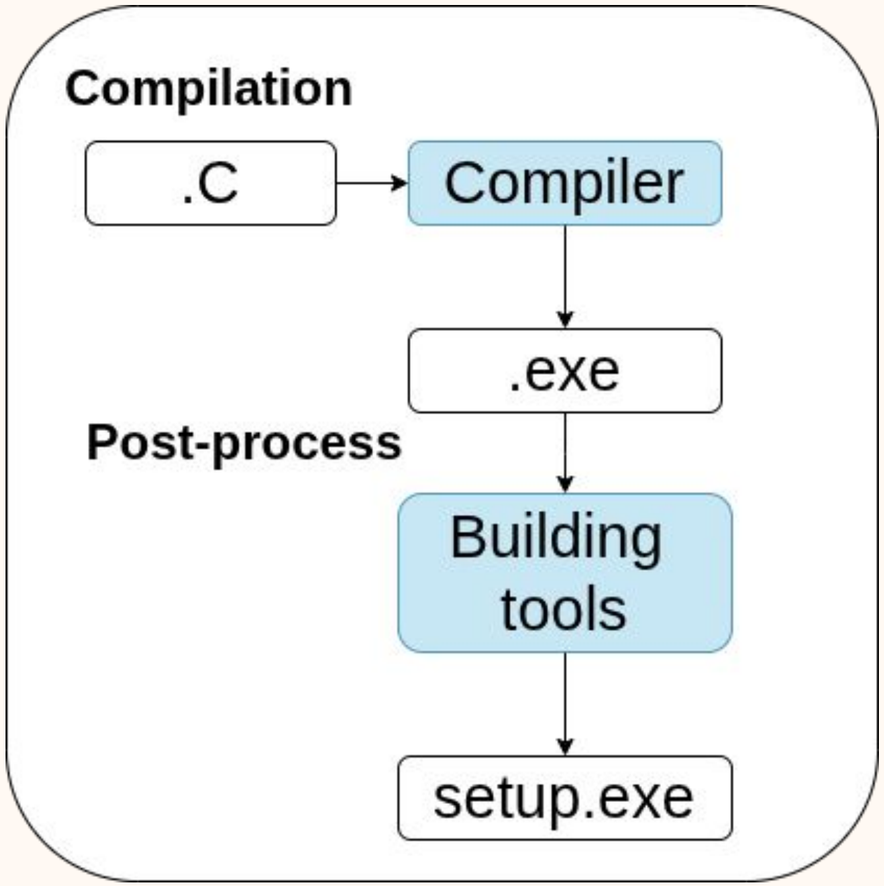

Packer

Code Shield

- Encrypt and decrypt at runtime
- Obfuscation oriented
- UPX, PECompact…

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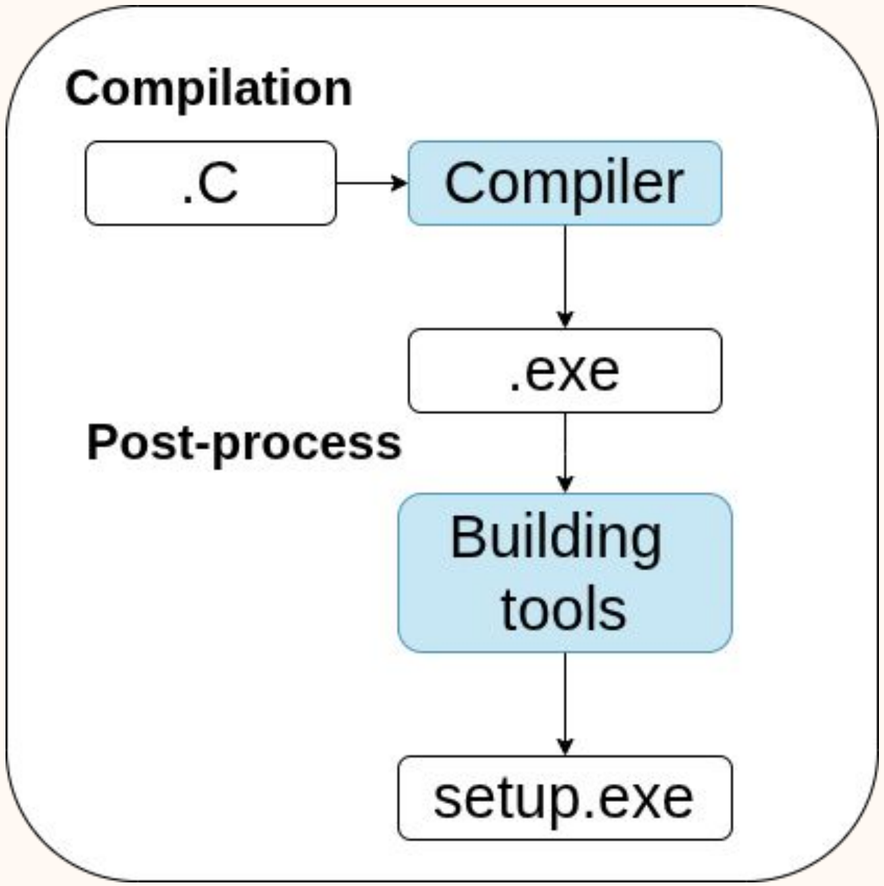

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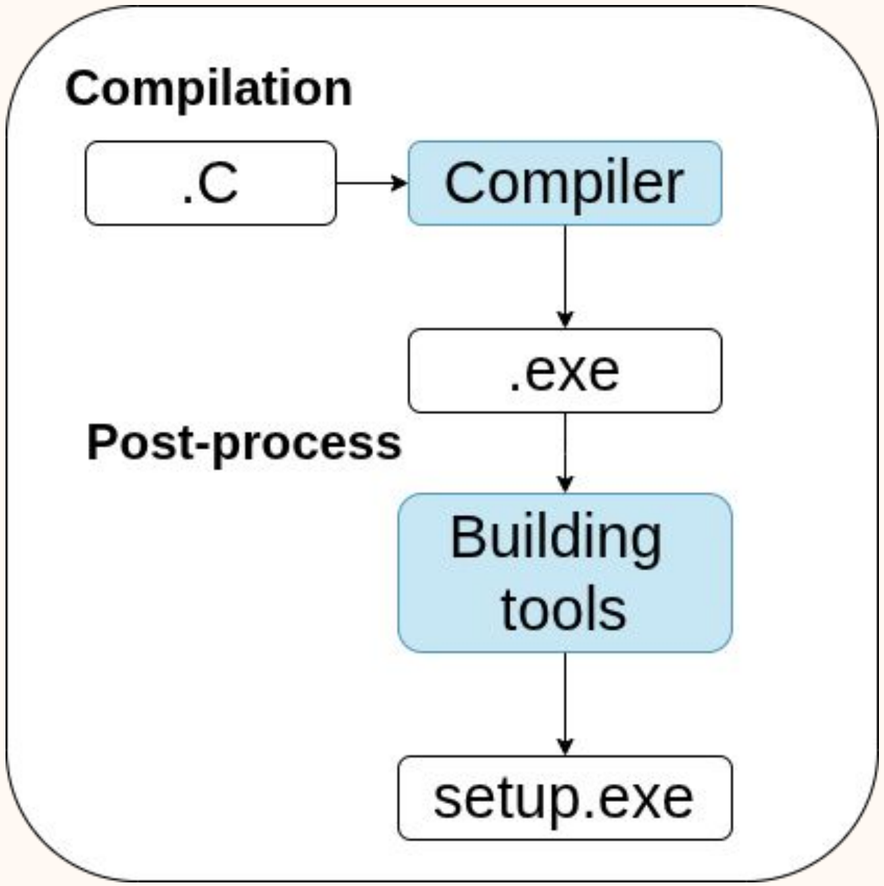

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Self-Extracting Archive

Auto Extract

- Self-extract compression
- 7-zip, WinRAR…

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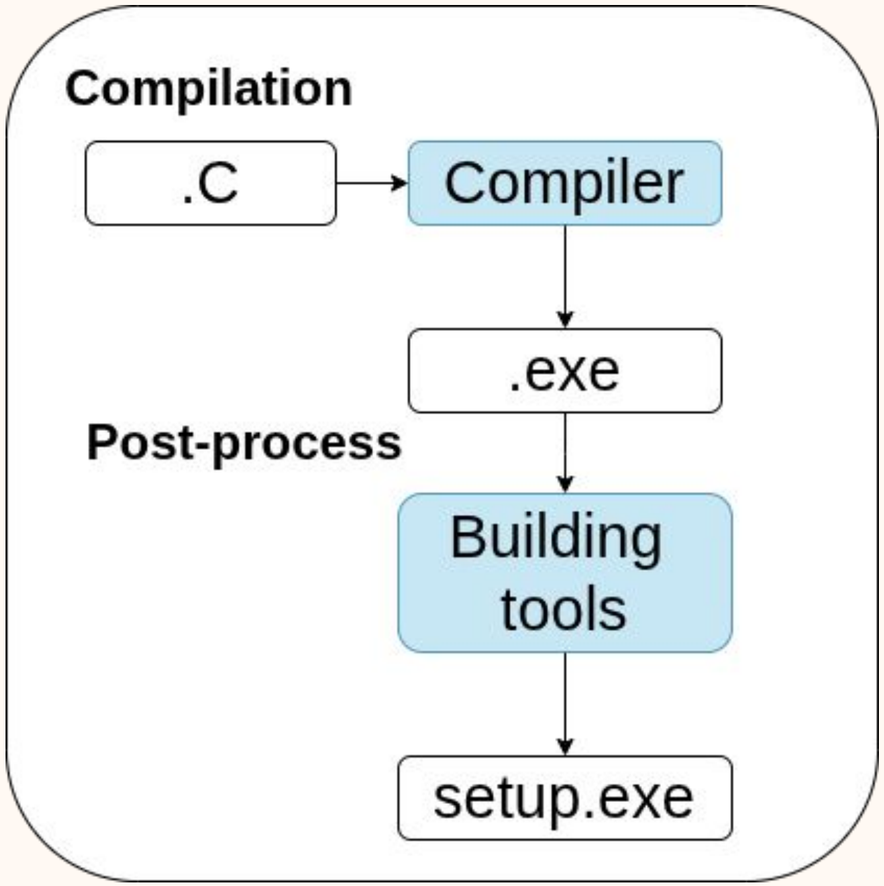

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Script-Generated Executable

Script Wrapper

- Embed interpreter
- aut2exe, bat2exe

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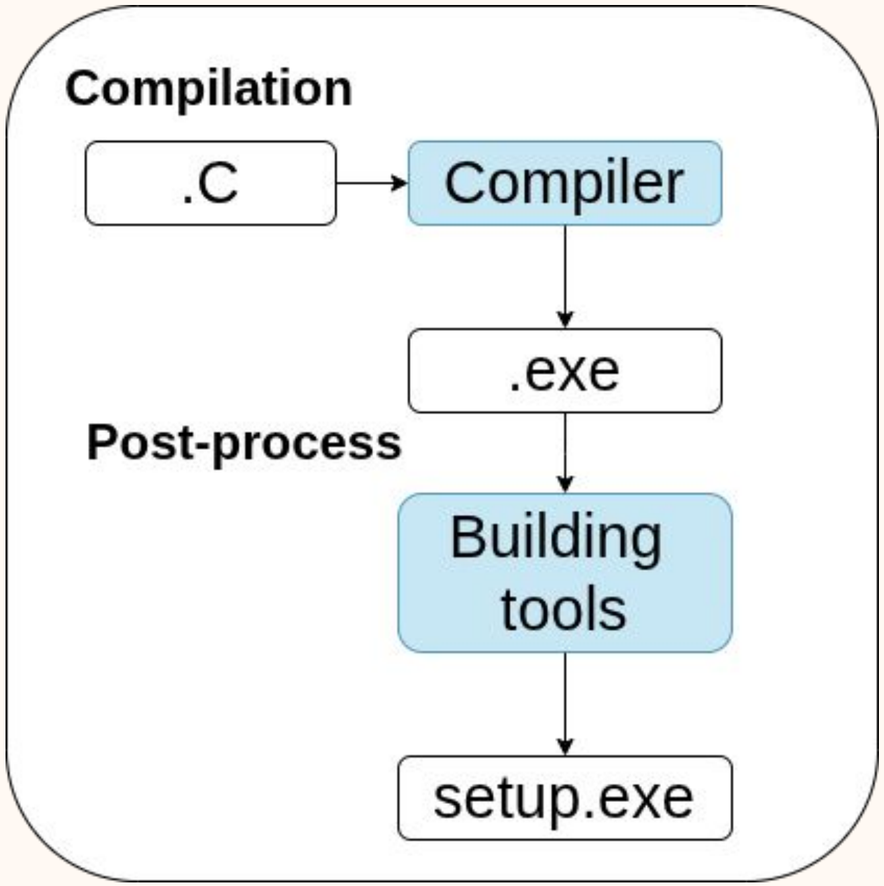

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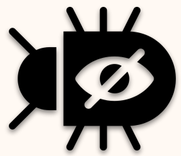
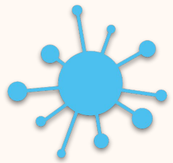
Identification with Detect-it-Easy and PackGenome

33% of samples

Analysis Approach





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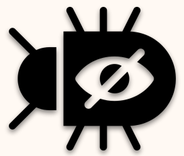
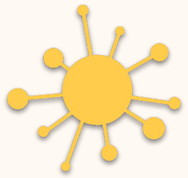
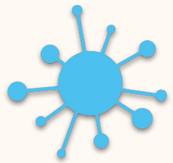
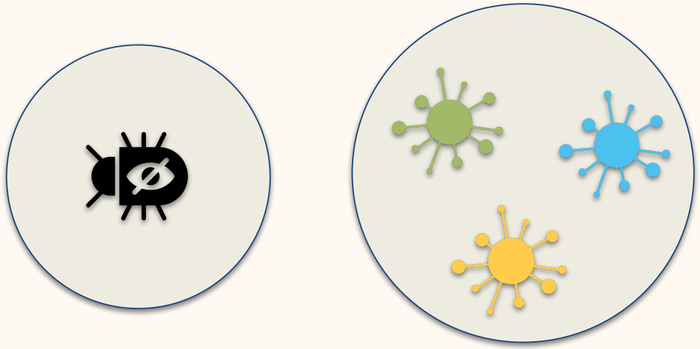




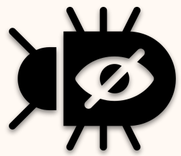


Ground Truth



Analysis Approach

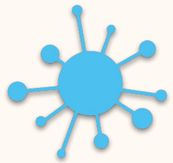
Feature Extraction



a1b2c3

a1b2c3

ffeedd



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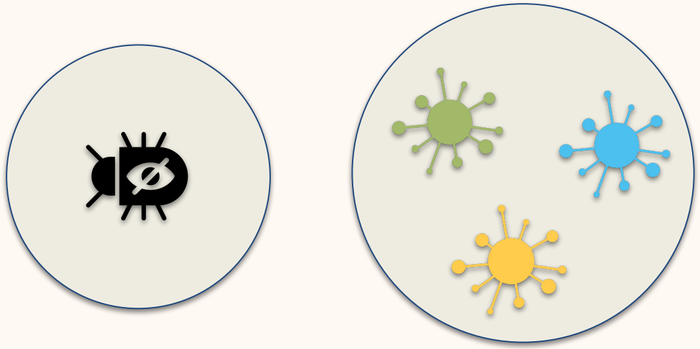

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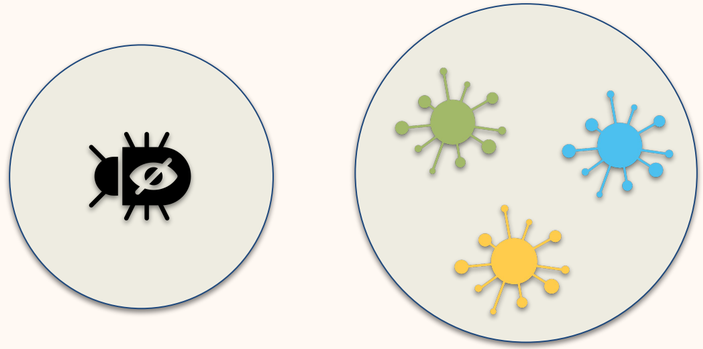

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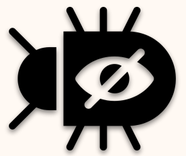

a1b2c3

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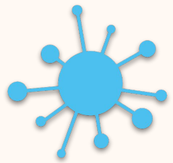
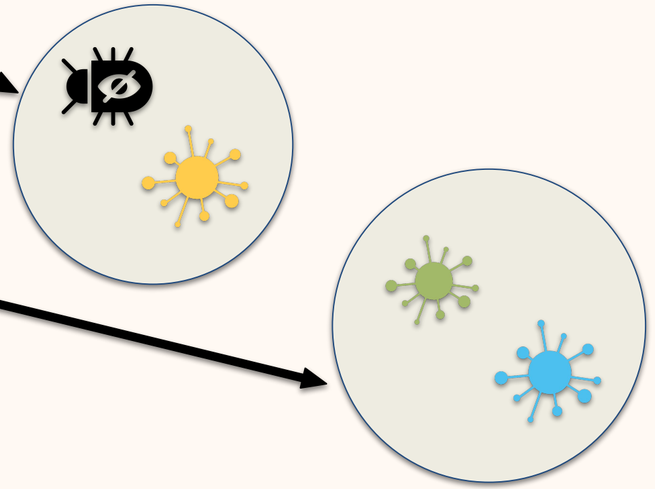
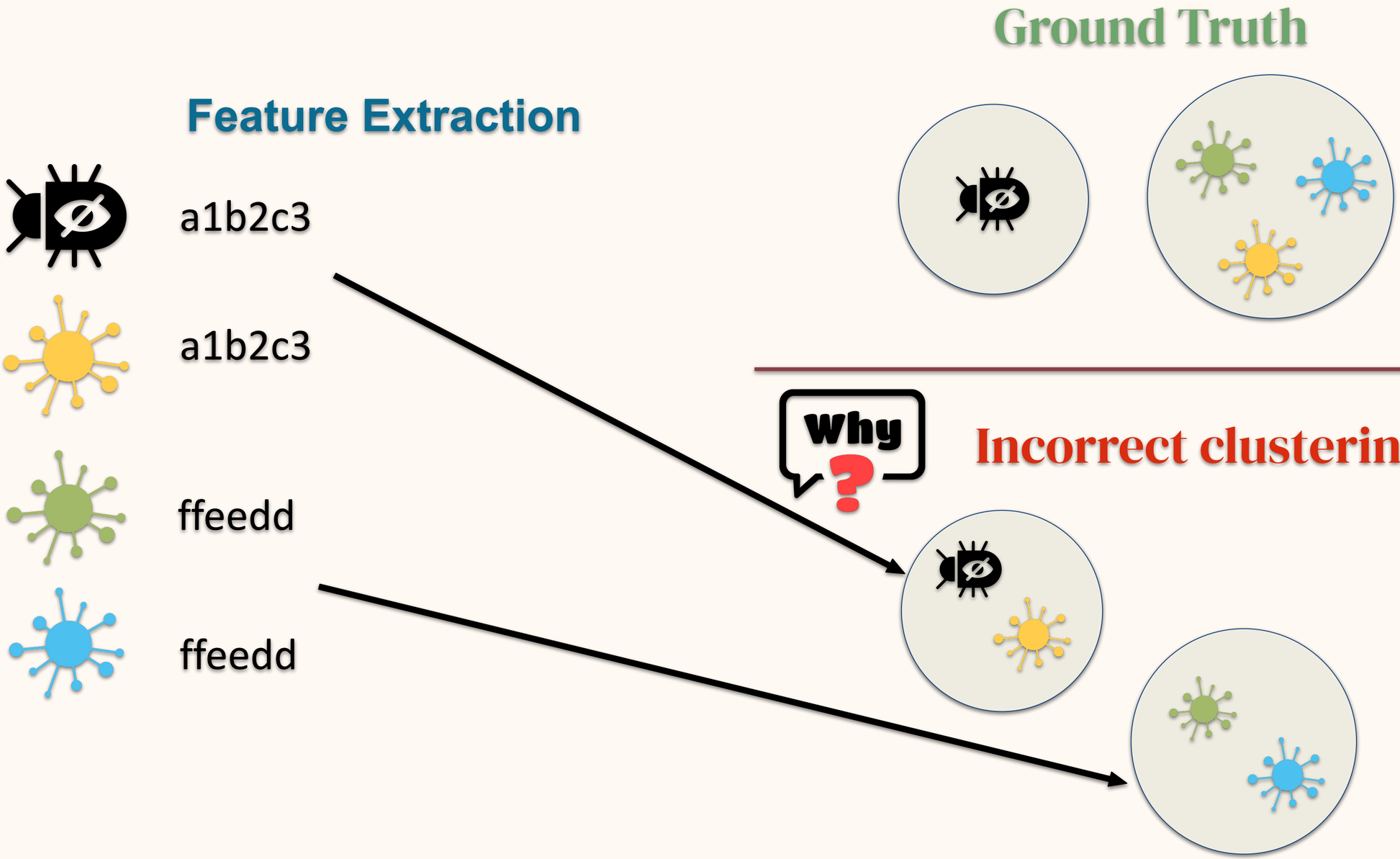


ffeedd

Incorrect clustering



Analysis Approach



RQ1: Similarity Feature Precision

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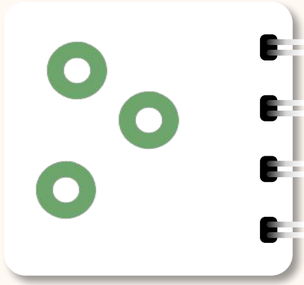
99%

Authentihash
Certificate Thumbprint
Certificate Subject



- 99% singletons
- 93% precision no singletons

RQ1: Similarity Feature Precision

- 71-85% singletons
- 94% precision no singletons

Pehash
Ssdeep
Tlsh
Vhash

94-97%

99%

Authentihash
Certificate Thumbprint
Certificate Subject

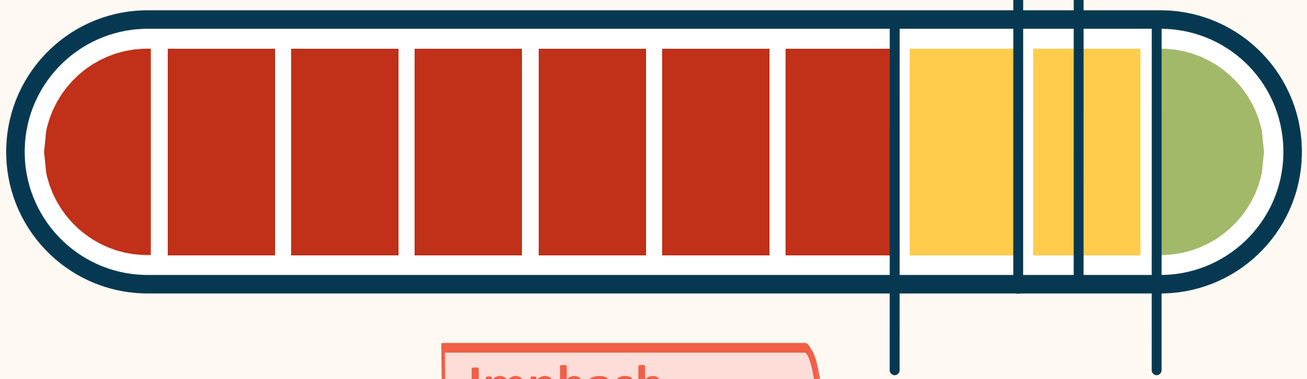
- 99% singletons
- 93% precision no singletons

RQ1: Similarity Feature Precision

- 71-85% singletons
- 94% precision no singletons

Pehash
Ssdeep
Tlsh
Vhash

94-97%



90%

99%

Authentihash
Certificate Thumbprint
Certificate Subject

Imphash
Richpe
Icon hash
Icon dhash

- Precision 85-88%

- 99% singletons
- 93% precision no singletons

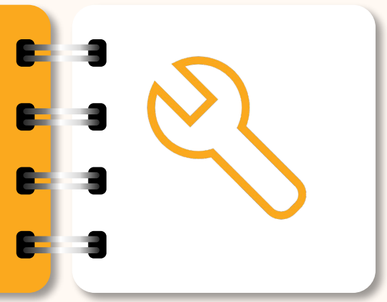
RQ2: Limits of Static Features

Whole-file fuzzy hashes

- Affected by same EXE building tools
- Similarity not from malicious code

Remove building tools

- 2.5% improvement



SSDEEP Top 10 Largest Clusters

# - Reason	Samples	Mixed Clusters	Families
1 - installer:inno	310	✓	5
2 - GT errors	185	✓	4
3 - script:aut2exe	173	✓	19
4 - archive:sfx	167	✓	2
5 -	162	✓	1
6 - No overlay sha256 file	157	✓	2
7 - packer:dxpack	157	✓	2
8 - packer:upx	149	✓	8
9 - GT errors	132	✓	3
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Large clusters

- All clusters > 100 samples
- Largest cluster > 300 samples

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Large clusters

- All clusters > 100 samples
- Largest cluster > 300 samples

9/10 mixed clusters

- 6/9 due to EXE building tools
  - 2 SFXs and 2 packers
  - 1 installer and 1 script
- 2/9 due to dataset errors

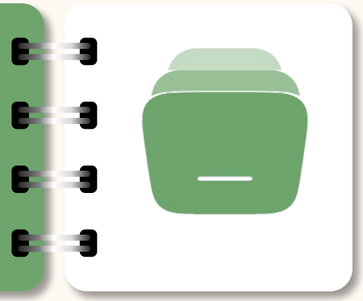
RQ2: Limits of Static Features

Imphash

- Strongly affected by same EXE building tools
- Different packers can produce same import table

Import DLLs filtering

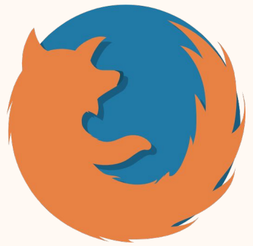
- 10% improvement
- +3% after excluding samples with <10 imports



RQ2: Limits of Static Features

Certificate

- Often due to dataset errors (aliases)
- Few cases of “stolen” benign certificates



Remove invalid certificates

- 2-4% improvement

RQ2: Similarity Feature Limits

Icons

- Collisions due to common icons
- Not specific to family

Ignore generic icons

- Challenge by itself

Conclusions

Feature effectiveness

Similarity features grouped into 3 groups

Impact of EXE-Building Tools

Packers, installers, SFX archives, script-building tools

Feature pre-processing

Improvements to the similarity features

RQ1: Similarity Feature Precision

- 71-85% singletons
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RQ2: Similarity Feature Limits

Fuzzy hashes

- Affected by same EXE building tools

Certificate

- Often due to dataset errors
- Few cases of “stolen” benign certificates

Imphash

- Affected by same EXE building tools
- Different packers can produce same import table

Richpe

- Affected by different/same EXE building tools
- Collisions without EXE building tools

Icons

- Collisions due to common icons

Conclusions

Feature effectiveness

Similarity features grouped into 3 groups

Impact of EXE-Building Tools

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Feature pre-processing

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Contact

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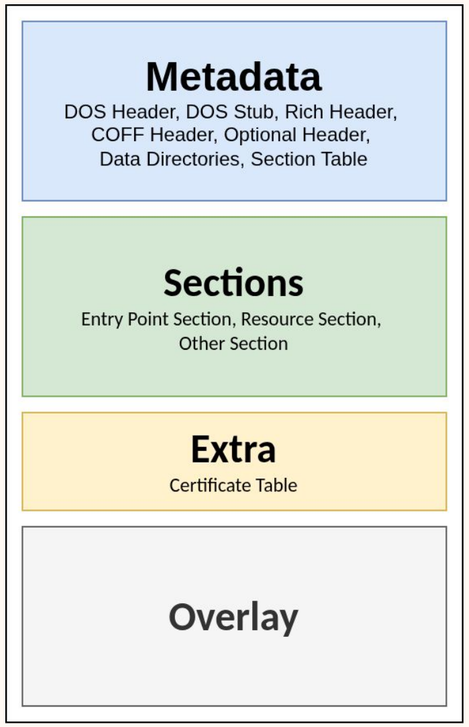
Analysis Features - Others

Overlay

Data appended to end

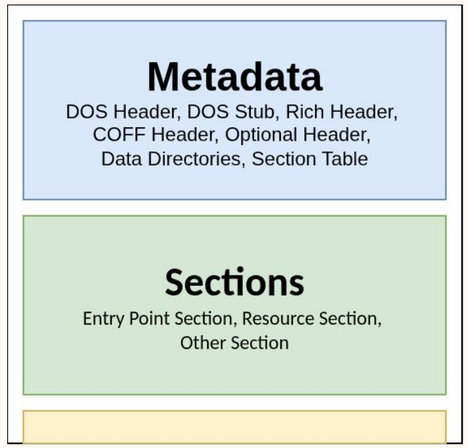
- Data not loaded, but can be accessed
- 36% of samples



Truncation

Corrupted file

- Expected size larger than real file
- Does not run
- 3% of samples



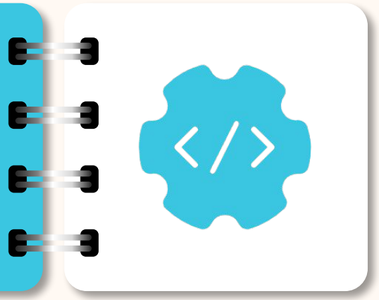
RQ2: Limits of Static Features

Richpe

- Affected by different/same building tools
- Collisions also without building tools

Collisions due to same compiler

- Small number of entries



Backup Slide 1 - Certificates and Precision

What is an invalid certificate?

Certificate with an invalid trust chain (e.g., misconfigured or benign entities)

Q1

Why Authentihash and Thumbprint reach 99% precision?

Authentihash: almost identical binaries (ignores signing fields & checksum).
Certificate Thumbprint: binaries signed by the same certificate.
High precision comes from strict, byte-level or signer equality.

Q2

Are the results computed over singletons?

Yes. Precision includes singletons but also recalculated without them.

Q3

Backup Slide 2 - Overlap ad Feature Differnces

Dataset overlap

Only 10 samples overlap between datasets.

Q4

Authentihash vs. Certificate Thumbprint

Authentihash: Measure Content similarity, only group identical code.
Certificate Thumbprint: Measure signer identity, may group unrelated binaries.

Q5

Why do Imphash and RichPE perform worse?

Imphash: affected by packers/installers creating identical import tables.
RichPE: collisions from same compilers or build environments.

Q6

Backup Slide 3 -EXE Building Tools Detection

What % of samples use EXE-building tools?

≈ 33% (20.6% packed, 6.2% SFX, 4.2% installers, 2.7% scripts).

Q7

Are script wrappers or SFX archives detected automatically?

Yes, via DiE/PackGenome signatures (no manual labeling).

Q8

How were these detected?

Detect-It-Easy (DiE): signature-based.
PackGenome: YARA rules for 20 packers.
PEiD excluded (outdated).

Q9

Backup Slide 4 - Applications

How can results apply to threat intelligence?

Q12

Helps distinguish true family links vs. artificial similarities.
Avoids misinterpreting packer-based clusters.