Comparing Software Architecture Recovery Techniques Using Accurate Dependencies

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Software Architecture Is Important

- **Software architecture** is:
  - a high-level representation of the structure of a system.
  - crucial for:
    - Program understanding
    - Software maintenance
    - Programmers communication
- Documented architectures often are outdated.

Recovering Architecture From Source Code Is Important

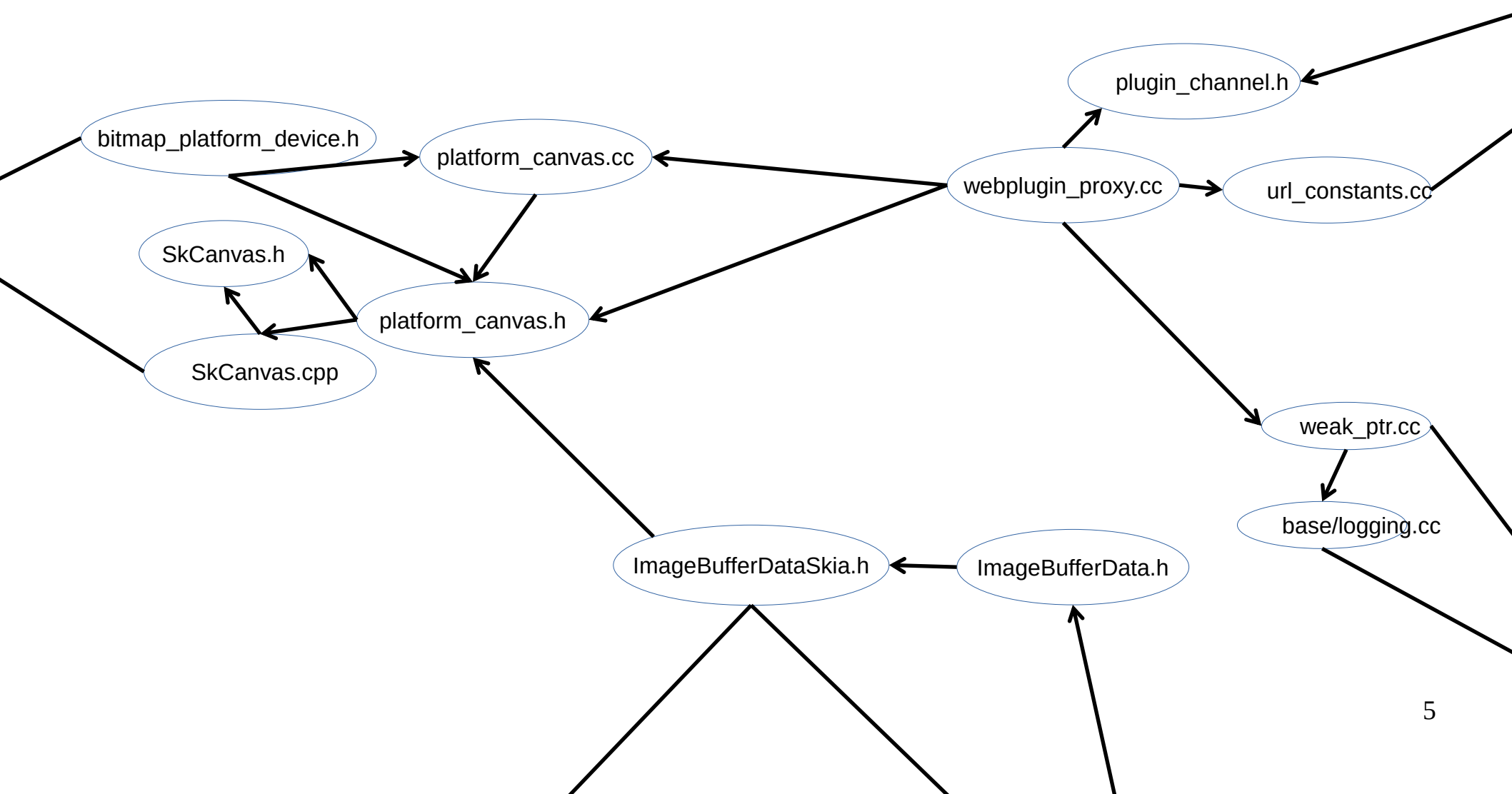
We need to recover the architecture of a program from the source code!

Automatic Architecture Recovery Is Needed

- Manual recovery is feasible but costly:
  - Recovering a medium-size project architecture takes **~100hours.** [Garcia et al., ICSE SEIP'13]
  - Deep knowledge of the project is necessary.
  - It can take **years** to manually recover the architecture of a large project!
- Many automatic recovery techniques exist.
  - They generally take a dependency graph as input.

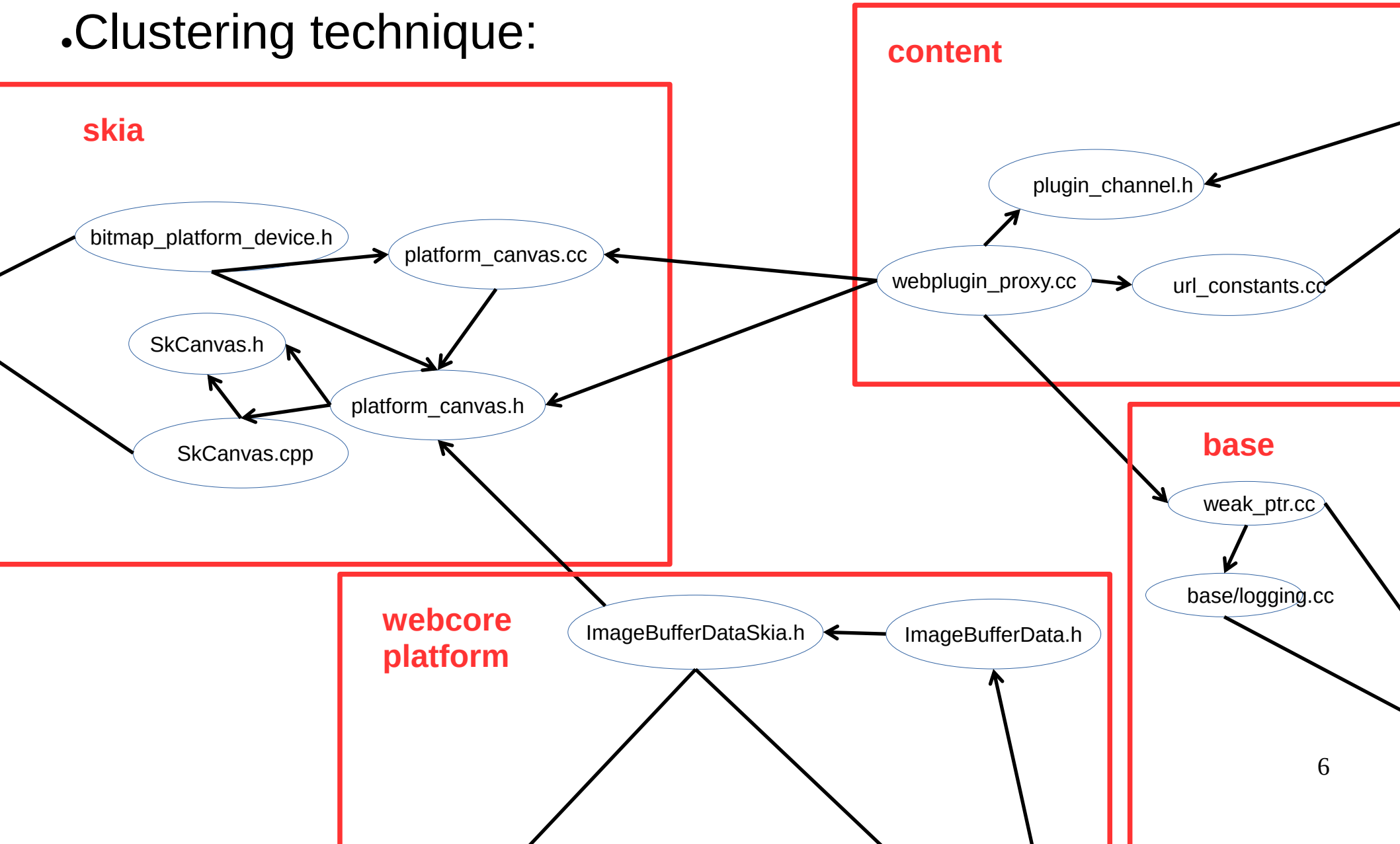
Example: Architecture Recovery

- Input: File dependency graph (Partial graph of Chromium)



Example: Architecture Recovery

- Clustering technique:



Motivation

- Previous work focuses on improving algorithms and heuristics. [Maqbool et al., CSMR'04; Andritsos et al.,EDBT'04,Garcia et al., ASE'11]
- They use **primitive and inaccurate** dependencies.
- More **accurate** dependencies based on **symbols** exist.
- It is unclear whether those techniques scale to 10MLOC.

Types of Dependencies

foo.c:

```
#include “foo.h”
#include “bar.h”
#include “unused.h”

void foo(){
        bar();
}
```

bar.h:

```
void bar();
```

bar.c:

```
#include “bar.h”
void bar(){
        do_something()};
```

unused.h:

```
void executeCommand(*Command);
```

Include Dependencies

foo.c:

```
#include “foo.h”
#include “bar.h”
#include “unused.h”

void foo(){
        bar();
}
```

bar.h:

```
void bar();
```

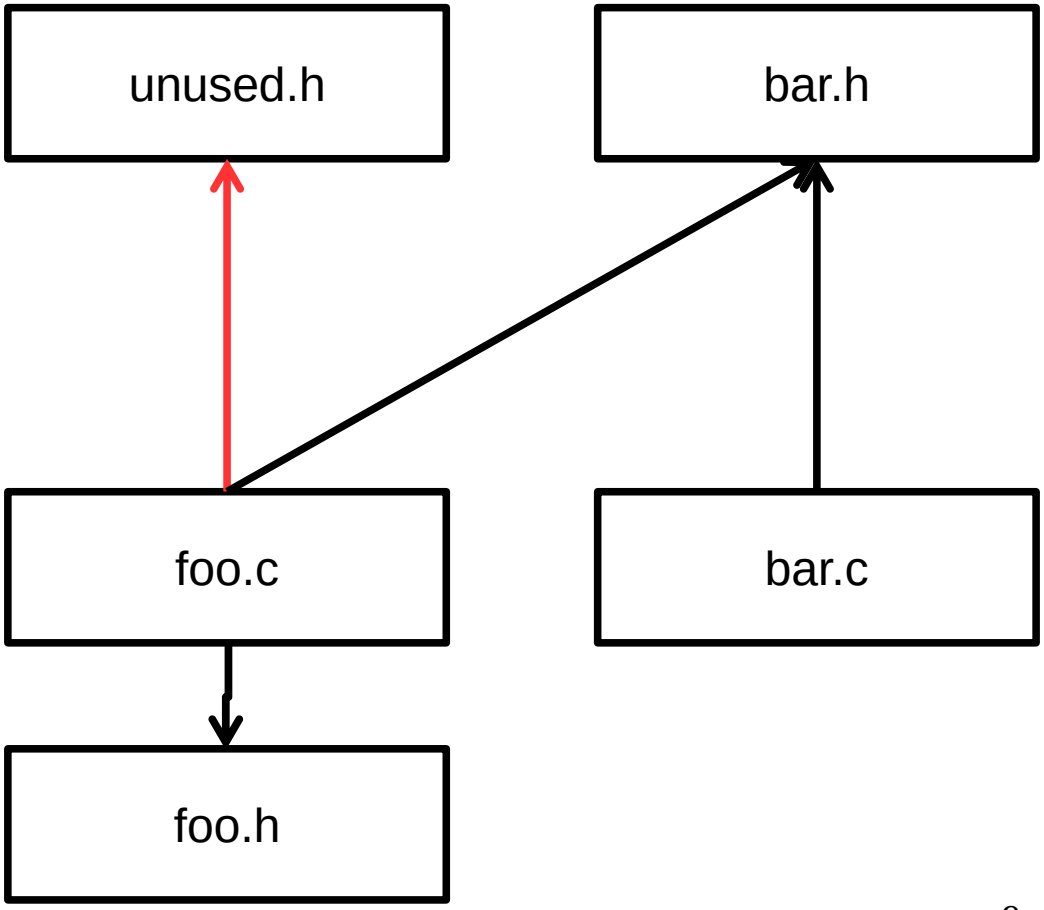
bar.c:

```
#include “bar.h”
void bar(){
        do_something()};
```

unused.h: ← Not used in foo.c!

```
void executeCommand(*Command);
```

Dependency graph based on include dep



Symbol Dependencies

foo.c:

```
#include “foo.h”
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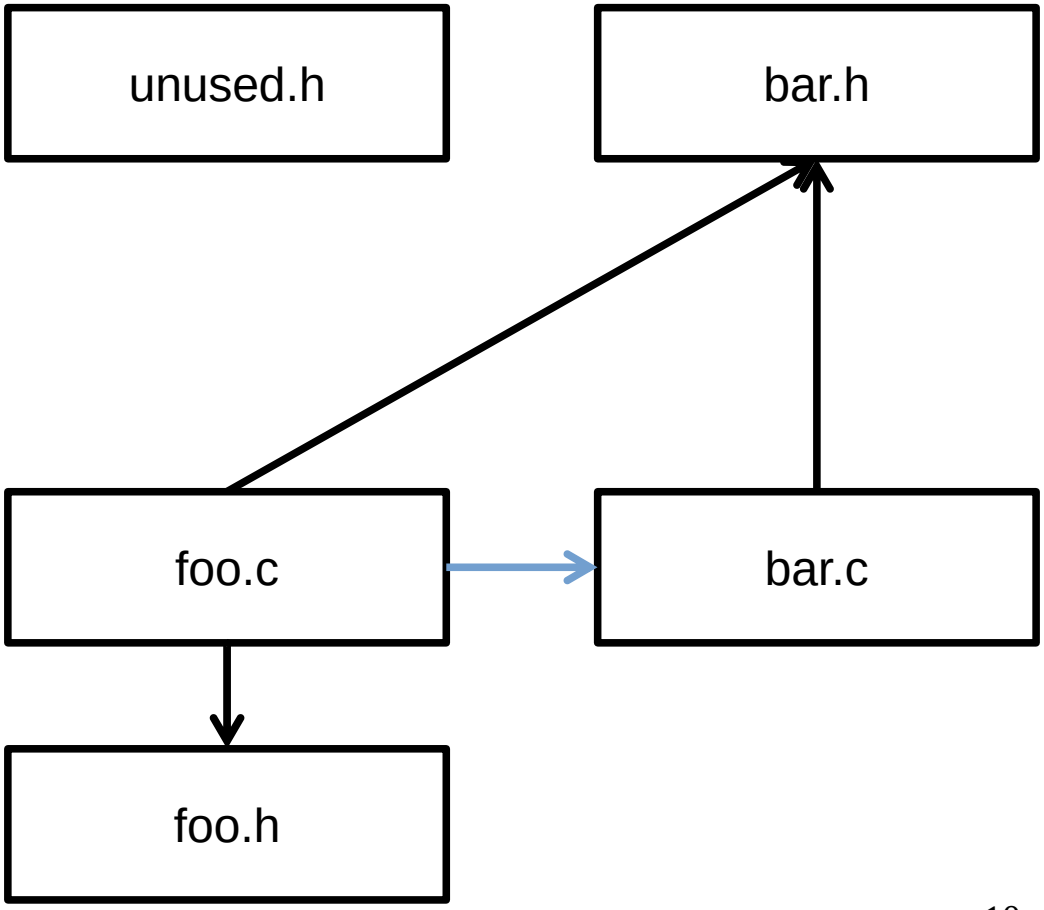
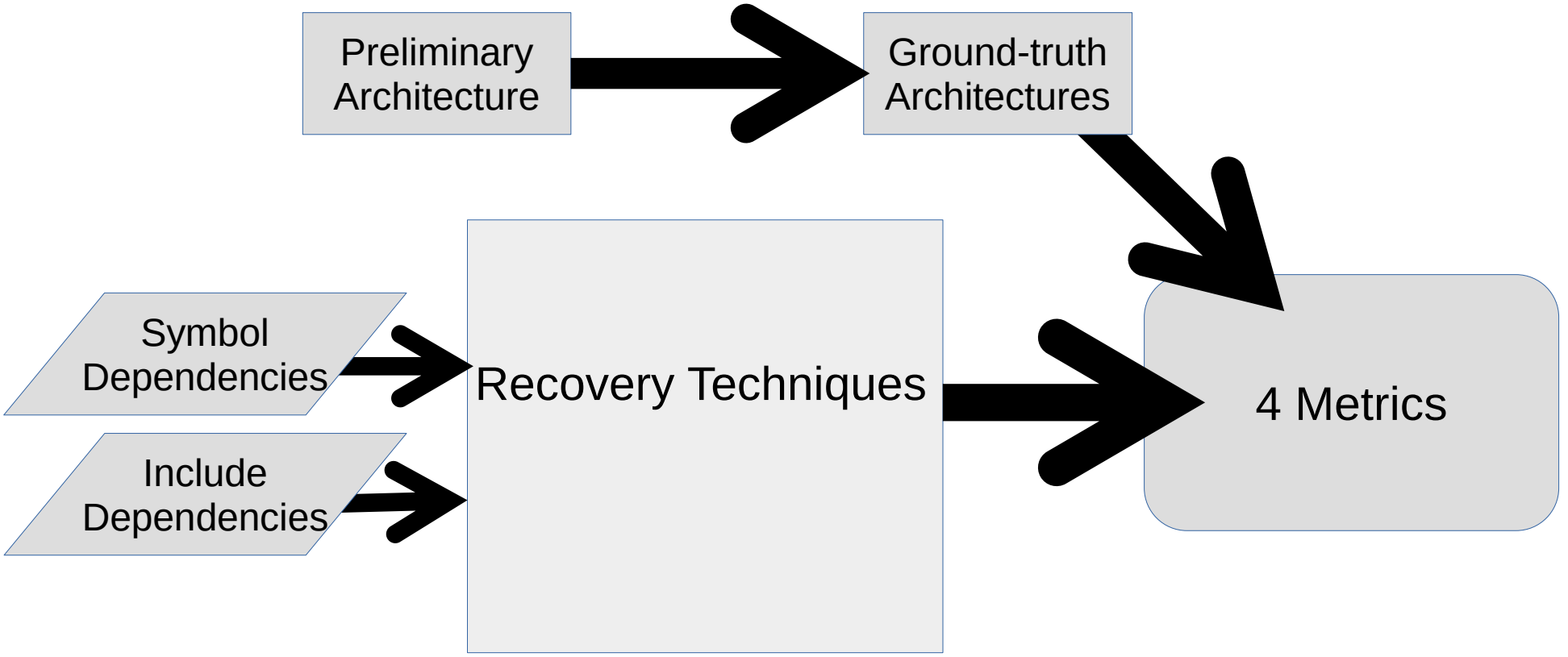
Dependency graph based on symbol dep



Contributions

- We compared 9 architecture recovery techniques:
  - **The accuracy of dependencies is a factor to consider** for high recovery accuracy.
  - Some techniques scale to large projects and some do not (ZBR, LIMBO, Bunch-SAHC).
- We recovered the ground truth of **Chromium**:
  - This is **the largest ground truth** recovered to date.
- We proposed a new groud-truth recovery technique.

Our Approach



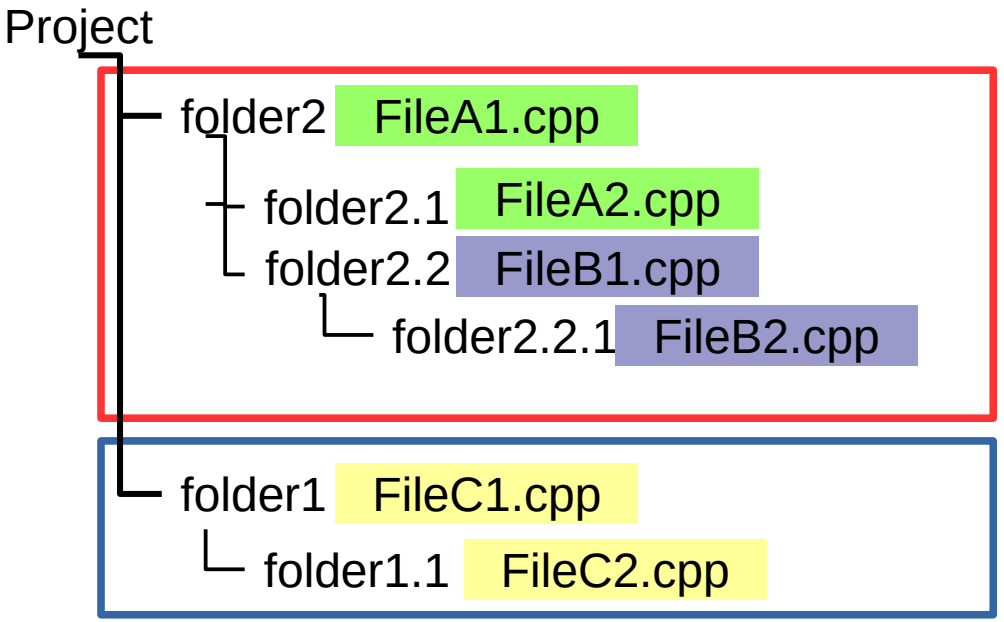
Recovering a Ground Truth

- Manually extracting a ground truth is a **tedious** task.
- People typically start with an automatic approach.
- We presented automatically recovered architectures to Chromium developers.
  - They found them difficult to interpret.
  - They prefered to use modules instead of files.

Submodule-Based Approach

- Large software generally have **modules** defined.
- We cluster the files based on modules described in configuration files.
- We merge modules based on the directory tree.
- Developers found it more relevant to use as a preliminary architecture.

Submodule Approach: Example



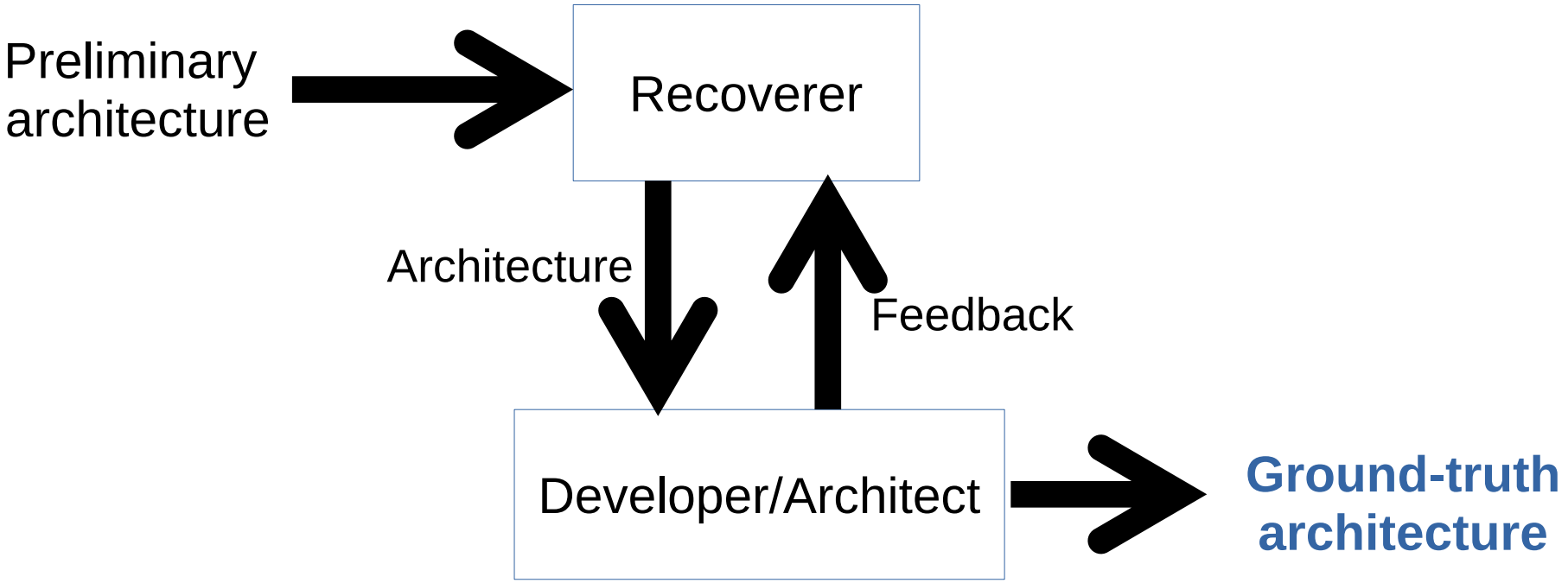
Module A

Module B

Module C

Cluster 1:	All files of Module B in a subdirectory of Module A files
Cluster 2:	All files of Module C in a different directory

Obtaining the Ground Truth



It took **2 years of discussion** with Chromium developers to obtain a ground truth.

Research Questions

Can more accurate dependencies improve the accuracy of existing architecture recovery techniques?

Can existing architecture recovery techniques scale to large projects comprising 10MSLOC or more?

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Projects Evaluated

Project	Version	Description	SLOC	File
Chromium	svn-171054	Web Browser	9.7M	18,698
ITK	4.5.2	Image Segmentation Toolkit	1M	7,310
Bash	4.2	Unix Shell	115K	373
Hadoop	0.19.0	Data Processing	87K	591
ArchStudio	4	Architecture Development	55K	604

C/C++ Java

- We recovered the ground truth of Chromium.
- We updated the ground truths of Bash and ArchStudio.
- All ground truths have been validated by developers.

Techniques Evaluated

- ACDC
- Bunch-NACH
- Bunch-SAHC
- WCA-UENM
- WCA-UEM
- LIMBO

Dependency-based techniques

- ARC
- ZBR-tok
- ZBR-uni

Information retrieval techniques

Metrics Selection

- It is hard to compare graphs using a single number.
- We use **4** different metrics:
  - **MoJoFM** was commonly used in previous work.
  - **a2a** measures the evolution of the architecture. It address some of MoJoFM issues.
  - **c2c** assesses component-level accuracy.
  - **TurboMQ** measures the quality of an architecture independently of a ground truth.
- All metrics show that **using symbol dependencies improve architecture recovery.**

Metrics: MoJoFM

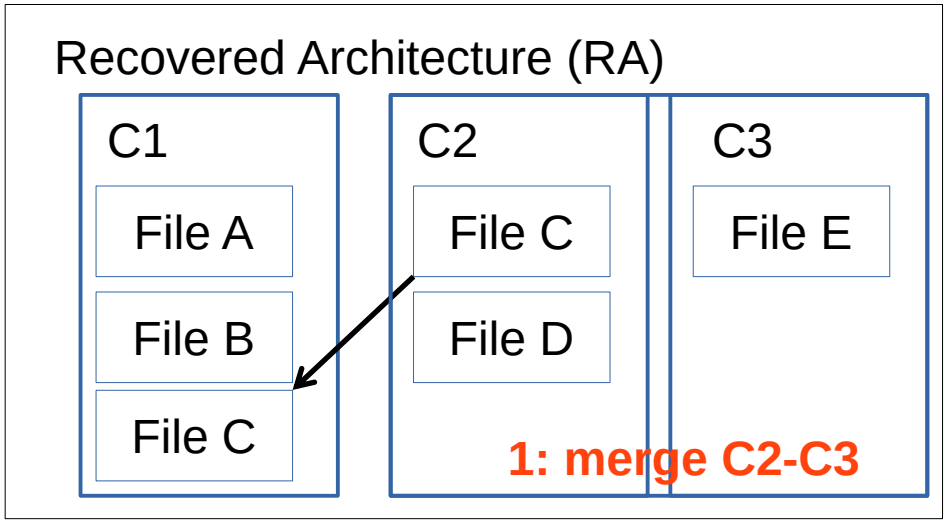
$$MoJoFM(M) = (1 - \frac{mno(A,B)}{max(mno(\forall A,B))}) \times 100\%$$

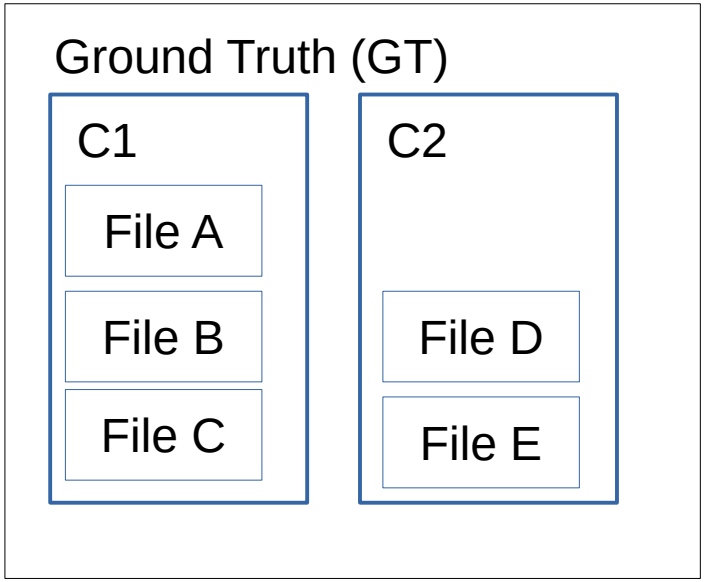
$mno(A,B)$ Minimum number of operations to transform A into B.

Possible operations are:

- To move an element from cluster 1 to cluster 2,
- To merge 2 clusters.

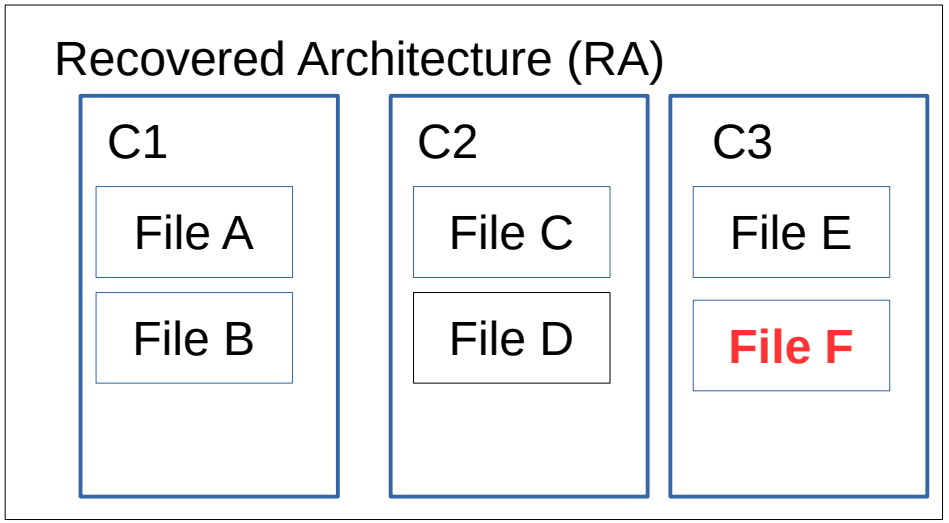
Metrics: MoJoFM

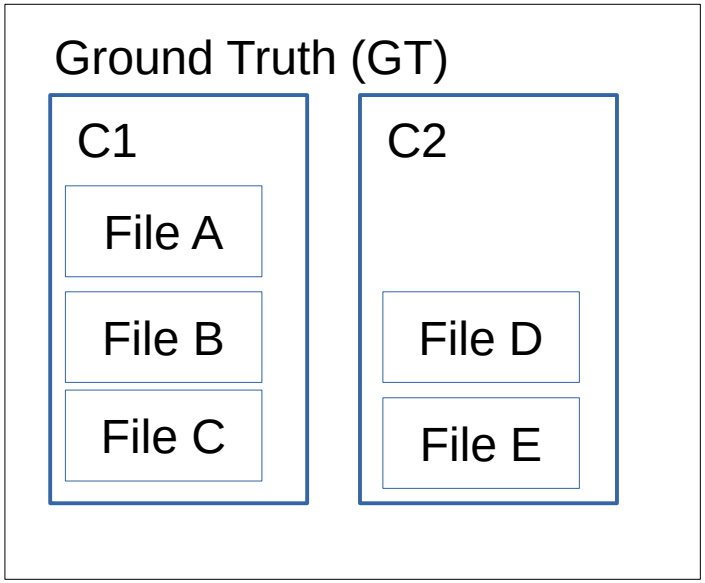




- **2** operations from RA to GT.
- **MoJoFM=33%**

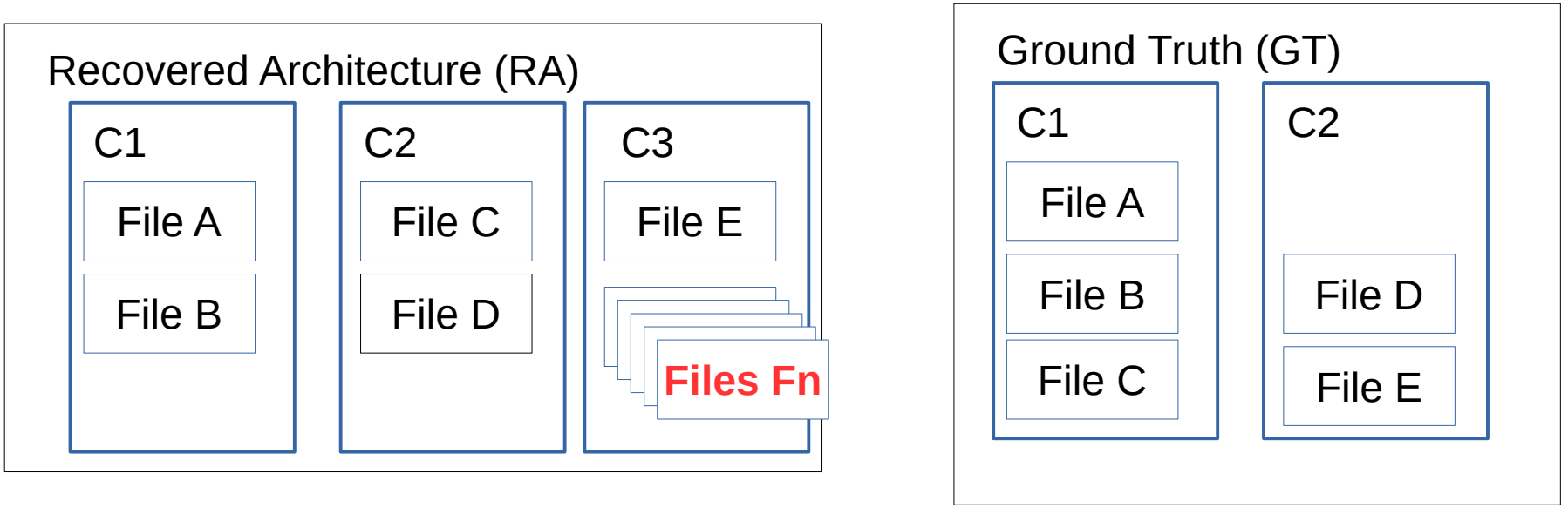
Metrics: MoJoFM





- What happens if some elements of RA are not in GT?
- *mno* cannot be correctly calculated.
- MoJoFM results will be **inaccurate**.
- With the existing implementation:
- *File F* will be ignored.
- **MoJoFM=33%**
- It's the same value than for the previous architecture!

Metrics: MoJoFM



- What happens if some elements of RA are not in GT?
- *mno* cannot be correctly calculated.
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- With the existing implementation:
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Metrics: a2a

$$a2a(A_i, A_j) = (1 - \frac{mto(A_i, A_j)}{aco(A_i) + aco(A_j)}) \times 100\%$$

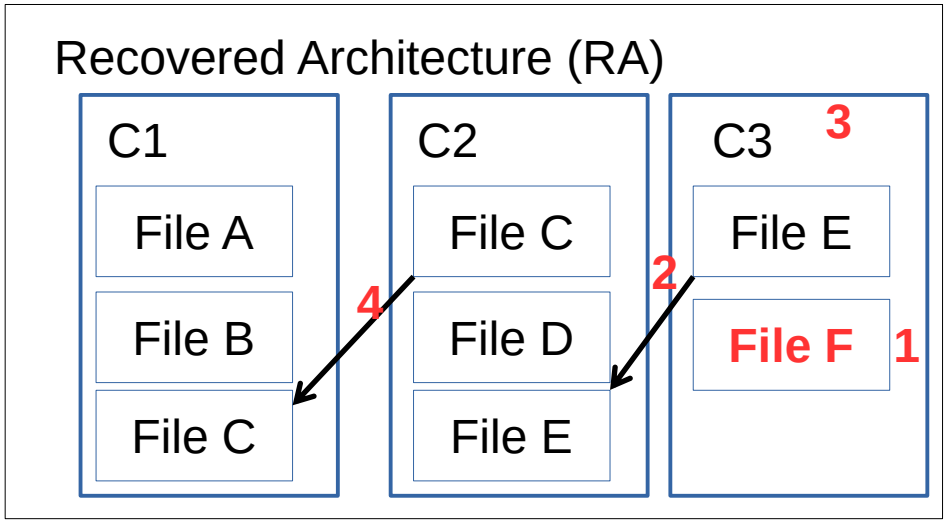
$mto(A_i, A_j)$ Minimum number of operations to transform A_i to A_j.

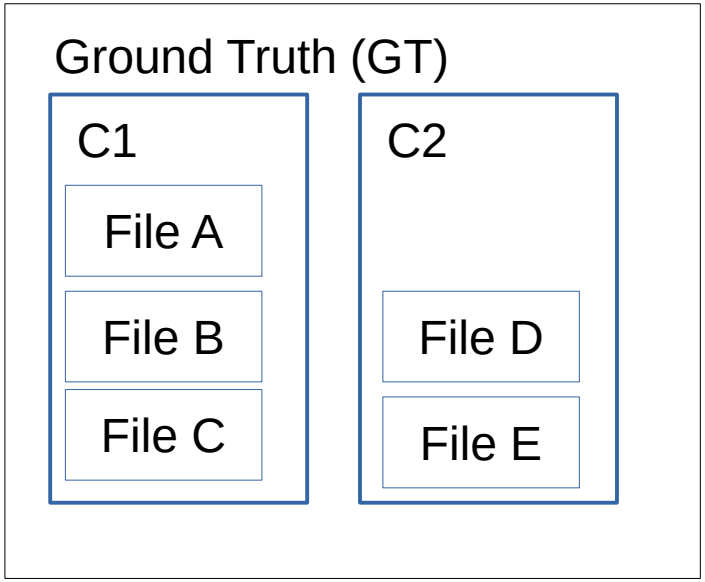
$aco(A_i)$ Minimum number of operations to obtain A_i from a “null” architecture.

Possible operations are:

- Remove a cluster, add a cluster,
- **Remove an element, add an element,**
- Move an element from cluster 1 to cluster 2.

Metrics: a2a





- Remove File F
- Move File E from C3 to C2
- Remove C3
- Move File C from C2 to C1

With *File F*:
4 moves from RA to GT
a2a=75%

Without *File F*: **3** moves
from RA to GT
a2a=80%

Experimental Results

- A2a (%) results:

Algo.	Bash	
	Inc	Sym
ACDC	64	81
B-NAHC	66	86
B-SAHC	68	87
WCA-UE	63	81
WCA-UENM	63	81
LIMBO	63	80
ARC	67	
ZBR-tok	31	
ZBR-uni	32	

Include Dependencies

Symbol Dependencies

Source-Code based techniques

Experimental Results

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Include Dependencies

Symbol Dependencies

Source-Code based techniques

- Using **symbol dependencies improves the results.**
- We obtained similar results with other metrics.

Symbol vs. Include deps.

- a2a (%) results:

Algo.	Bash		ITK		Chromium		ArchStudio		Hadoop	
	Inc	Sym	Inc	Sym	Inc	Sym	Inc	Sym	Inc	Sym
ACDC	64	**81**	67	**74**	71	**73**	71	**88**	68	**84**
B-NAHC	66	**86**	71	**80**	69	**73**	71	**83**	68	**81**
B-SAHC	68	**87**	69	**80**	60*	**71***	72	**85**	69	**83**
WCA-UE	63	**81**	74	**82**	70	**75**	71	**84**	68	**81**
WCA-UENM	63	**81**	74	**82**	70	**75**	71	**84**	68	**81**
LIMBO	63	**80**	71	**80**	TO	**71**	67	**79**	68	**80**
ARC	67		60		56		87		84	
ZBR-tok	31		MEM		MEM		85		81	
ZBR-uni	32		MEM		MEM		86		83	

- Using **symbol dependencies improves the results.**
- We obtained similar results with other metrics.

Symbol vs. Include deps.

- TurboMQ results:

Algo.	Bash		ITK		Chromium		ArchStudio		Hadoop	
	Inc	Sym	Inc	Sym	Inc	Sym	Inc	Sym	Inc	Sym
ACDC	5	17	503	422	183	443	19	52	13	22
B-NAHC	3	5	6	27	3	7	8	22	12	10
B-SAHC	3	7	5	193	141*	291*	16	22	11	14
WCA-UE	0.1	2	0.5	2	0.1	1	0.5	18	1	7
WCA-UENM	0.1	2	0.5	1.5	0.1	1	0.5	18	1	7
LIMBO	1	5	1.8	2.5	TO	1	1	25	1	15
ARC	3	9	0.1	0.3	8	10	14	37	5	25
ZBR-tok	0.3	1	MEM		MEM		4	15	3	13
ZBR-uni	0.6	0.6	MEM		MEM		3	15	4	17

- Using **symbol dependencies improves the results.**
- We obtained similar results with other metrics.

Scalability

Algo.	Bash		ITK		Chromium		ArchStudio		Hadoop	
	Inc	Sym	Inc	Sym	Inc	Sym	Inc	Sym	Inc	Sym
ACDC	Few seconds		< 1 h		< 2 hrs		Few seconds		Few seconds	
B-NAHC			2 h	1 h	~24h	~20h				
B-SAHC			2-3h		24h*	24h*				
WCA-UE					~14h	~8 h				
WCA-UENM										
LIMBO					TO	~14 h				
ARC			2-3 h		~8 h.					
ZBR-tok	Few minutes		MEM		MEM		Few minutes		Few minutes	
ZBR-uni			MEM		MEM					

MEM: The algorithm ran out of memory (Java heap 48GB).

***:** The algorithm was stopped after 24 hours. Intermediate results are available.

TO (Time Out): The algorithm did not terminate after 3 days.
No intermediate results are provided.

Lessons Learned

- The **granularity of the dependencies** affects the scalability and accuracy of the recovery techniques.
- Extreme architectures expose limits of the metrics.
- Different techniques can be used for different purposes:
  - Large software: ACDC, ARC, WCA
  - Low-level architectures: ACDC
  - Different level of abstractions: WCA, LIMBO, ARC

Conclusion

- We evaluated 9 recovery techniques on 5 projects.
- Using **symbol dependencies** improves the accuracy of recovery techniques.
- Our study include Chromium, the largest project used in an evaluation of architecture recovery techniques.