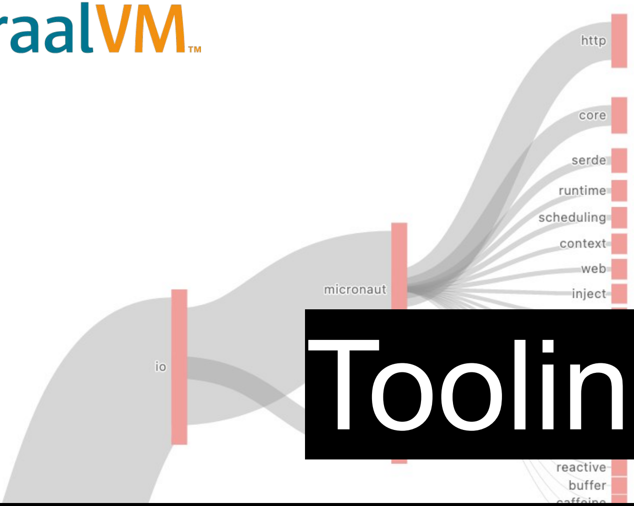
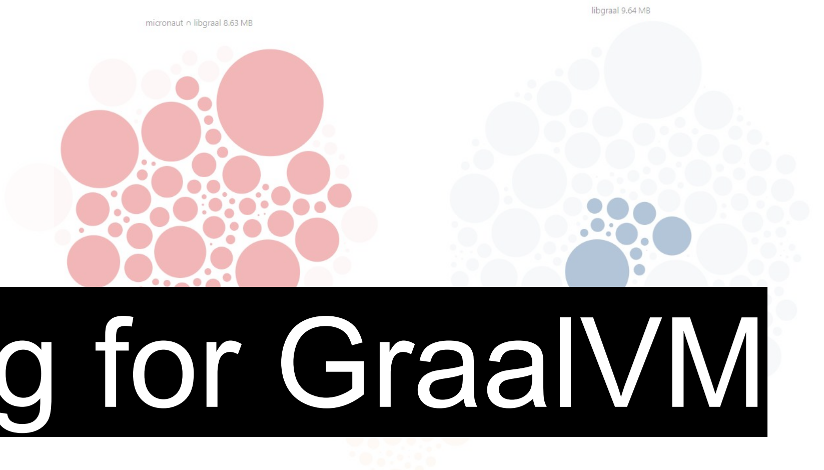
ORACLE GraalVM™

HPI Hasso Plattner Institut
Digital Engineering · Universität Potsdam

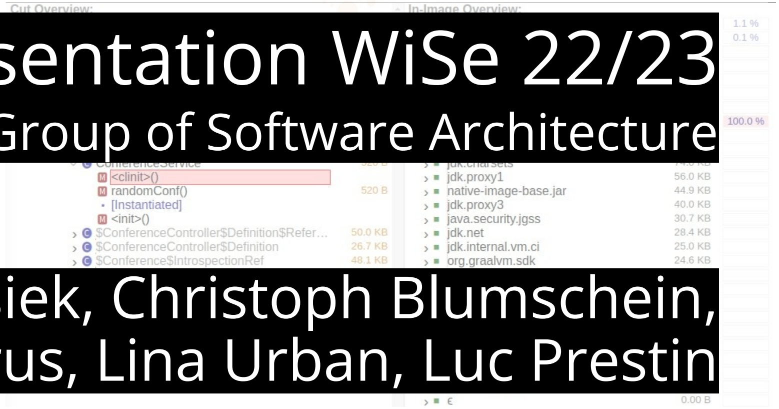




Tooling for GraalVM

Master Project Final Presentation WiSe 22/23

Research Group of Software Architecture

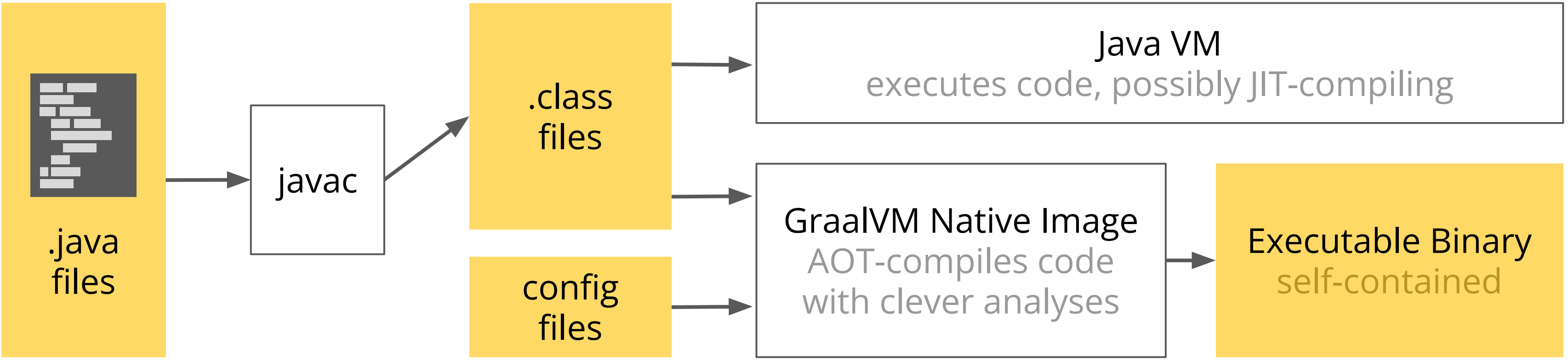


<clinit>()		jdk.proxy1	56.0 KB
randomConf()	520 B	native-image-base.jar	44.9 KB
[Instantiated]		jdk.proxy3	40.0 KB
<init>()		java.security.jgss	30.7 KB
$ConferenceController$Definition$Refer…	50.0 KB	jdk.net	28.4 KB
$ConferenceController$Definition	26.7 KB	jdk.internal.vm.ci	25.0 KB
$Conference$IntrospectionRef	48.1 KB	org.graalvm.sdk	24.6 KB

Joana Bergsiek, Christoph Blumschein,
Marcel Garus, Lina Urban, Luc Prestin

Supervised by Jens Lincke and Fabio Niephaus

GraalVM Native Image



.java files

javac

.class files

config files

Java VM
executes code, possibly JIT-compiling

GraalVM Native Image
AOT-compiles code
with clever analyses

Executable Binary
self-contained

faster startup time,
lower runtime memory overhead

Our Goal

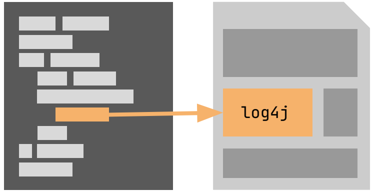
Java Jasper

Java & Spring Boot user,
new to GraalVM N.I.,
wants results ASAP,
gets frustrated easily

What’s taking up space in my image?
Why are certain classes in the image?
How can I make my image smaller?

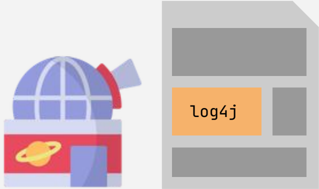
We want to create a tool that helps Java Jasper **understand the image** and gives him **actionable insights on how to improve the image**.

Our Goal in a Use Case

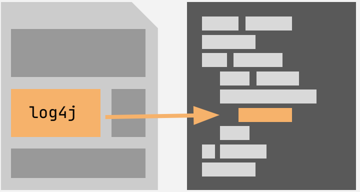


Java Jasper has a Micronaut app where **log4j** is used only in a single line.

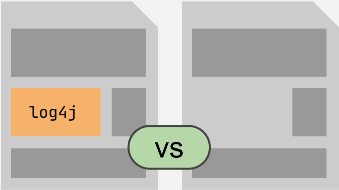
Our tool should be able to …



Show Java Jasper that **log4j is in the image** and **how much space** it takes up



Attribute the inclusion of log4j to the line of code Java Jasper can actually influence



After deleting the line, **compare the old and the new image** to confirm log4j is gone

Status Quo

Console output is de-facto standard.

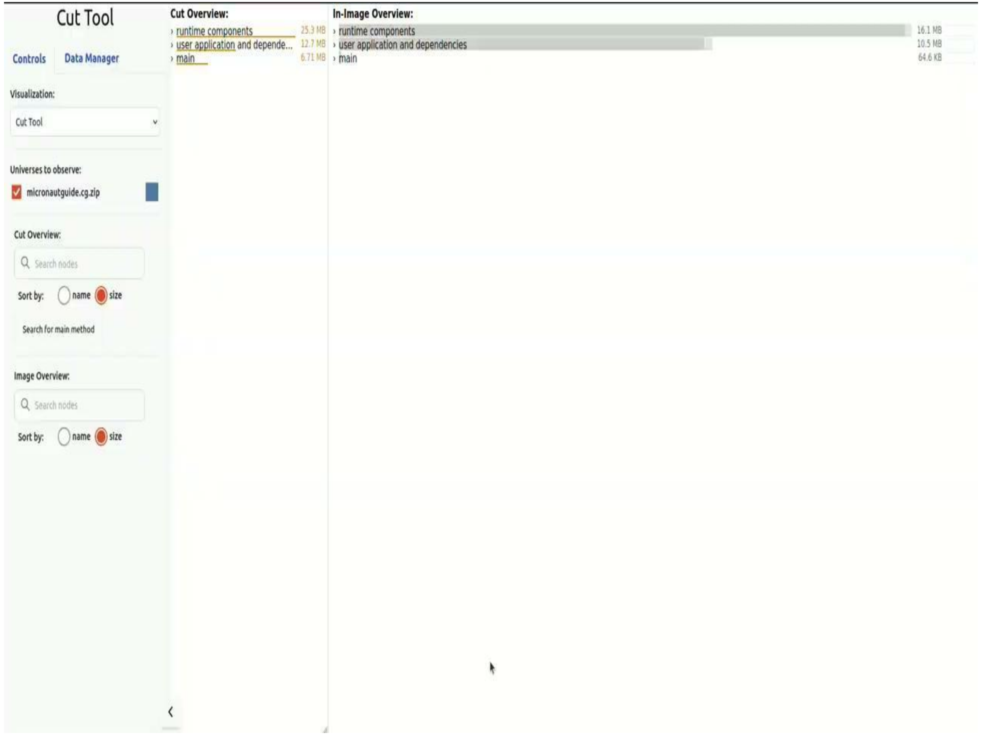
```
-H:+PrintAnalysisCallTree
-H:+PrintMethodHistogram
```

```
Size all methods                        ; 25029936
Size deopt methods                      ; 0
Size deopt methods in non-deopt mode    ; 0
Size non-deopt method                   ; 25029936
Number of methods                       ; 41781
Number of non-deopt methods             ; 41781
Number of deopt methods                 ; 0
Number of deopt entry points            ; 0
Number of deopt during calls entries    ; 0
encoded deopt entry points              ; 0
encoded during call entry points        ; 0
[7/7] Creating image...                                                                                   (6.7s @ 2.24GB)
  24.18MB (44.97%) for code area: 41,781 compilation units
  25.47MB (47.38%) for image heap:  298,830 objects and 325 resources
   4.11MB ( 7.65%) for other data
  53.76MB in total
------------------------------------------------------------------------------------------------------------------------
Top 10 packages in code area:                               Top 10 object types in image heap:
   1.66MB sun.security.ssl                                  5.20MB byte[] for code metadata
   1.01MB java.util                                         3.82MB java.lang.Class
 730.17KB com.sun.crypto.provider                           2.53MB java.lang.String
 681.87KB reactor.core.publisher                            2.32MB byte[] for java.lang.String
 574.79KB java.lang.invoke                                  2.18MB byte[] for general heap data
 565.52KB io.netty.buffer                                   1.10MB com.oracle.svm.core.hub.DynamicHubCompanion
 481.48KB io.netty.handler.codec.http2                      672.65KB byte[] for reflection metadata
```

< Demo Time! >

Recognizing and Removing Outliers

Backup video



Cut Tool

Visualization: Cut Tool

Universes to observe:

☑ micronautguide.cg.zip

Cut Overview:

Sort by: ○ name ● size

Image Overview:

Sort by: ○ name ● size

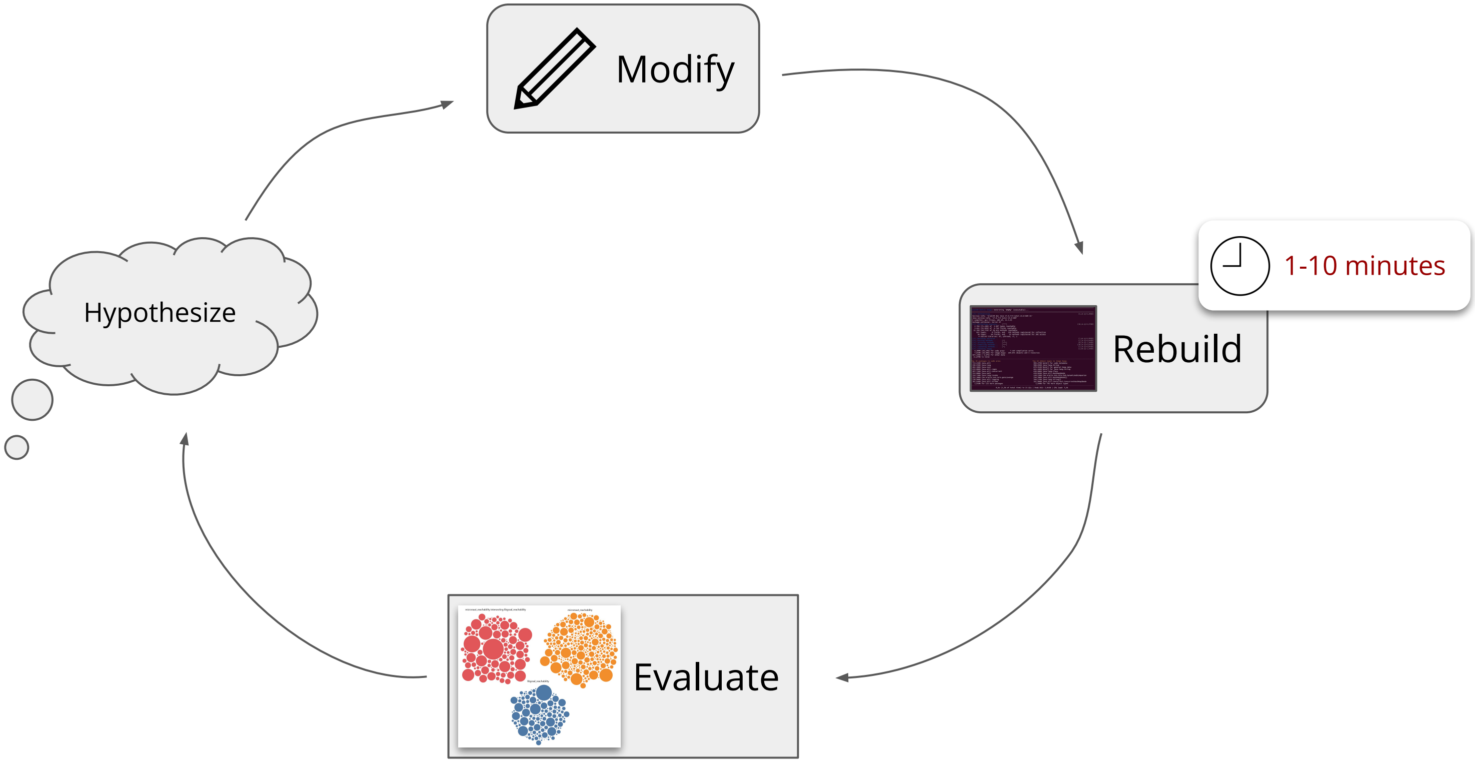
Cut Overview:

```
› runtime components              25.3 MB
› user application and depende... 12.7 MB
› main                            6.71 MB
```

In-Image Overview:

```
› runtime components                 16.1 MB
› user application and dependencies  10.5 MB
› main                               64.6 KB
```

Previous Workflow



Modify

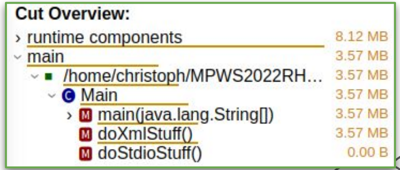
Rebuild

1-10 minutes

Evaluate

Hypothesize

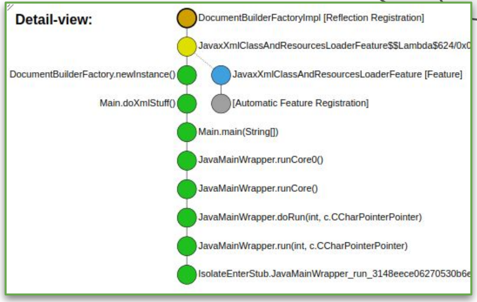
CutTool Workflow



Cut Overview:

```
› runtime components                8.12 MB
⌄ main                              3.57 MB
  ⌄ ■ /home/christoph/MPWS2022RH…   3.57 MB
    ⌄ C Main                        3.57 MB
      › M main(java.lang.String[])  3.57 MB
        M doXmlStuff()              3.57 MB
        M doStdioStuff()            0.00 B
```

Hypothesize



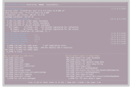
Detail-view:

```
                                DocumentBuilderFactoryImpl [Reflection Registration]
                                JavaxXmlClassAndResourcesLoaderFeature$$Lambda$624/0x0
DocumentBuilderFactory.newInstance()    JavaxXmlClassAndResourcesLoaderFeature [Feature]
                 Main.doXmlStuff()      [Automatic Feature Registration]
                                Main.main(String[])
                                JavaMainWrapper.runCore0()
                                JavaMainWrapper.runCore()
                                JavaMainWrapper.doRun(int, c.CCharPointerPointer)
                                JavaMainWrapper.run(int, c.CCharPointerPointer)
                                IsolateEnterStub.JavaMainWrapper_run_3148eece06270530b6e
```

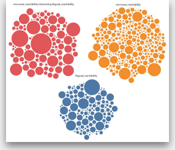
Modify

Simulate

0.1-1 seconds

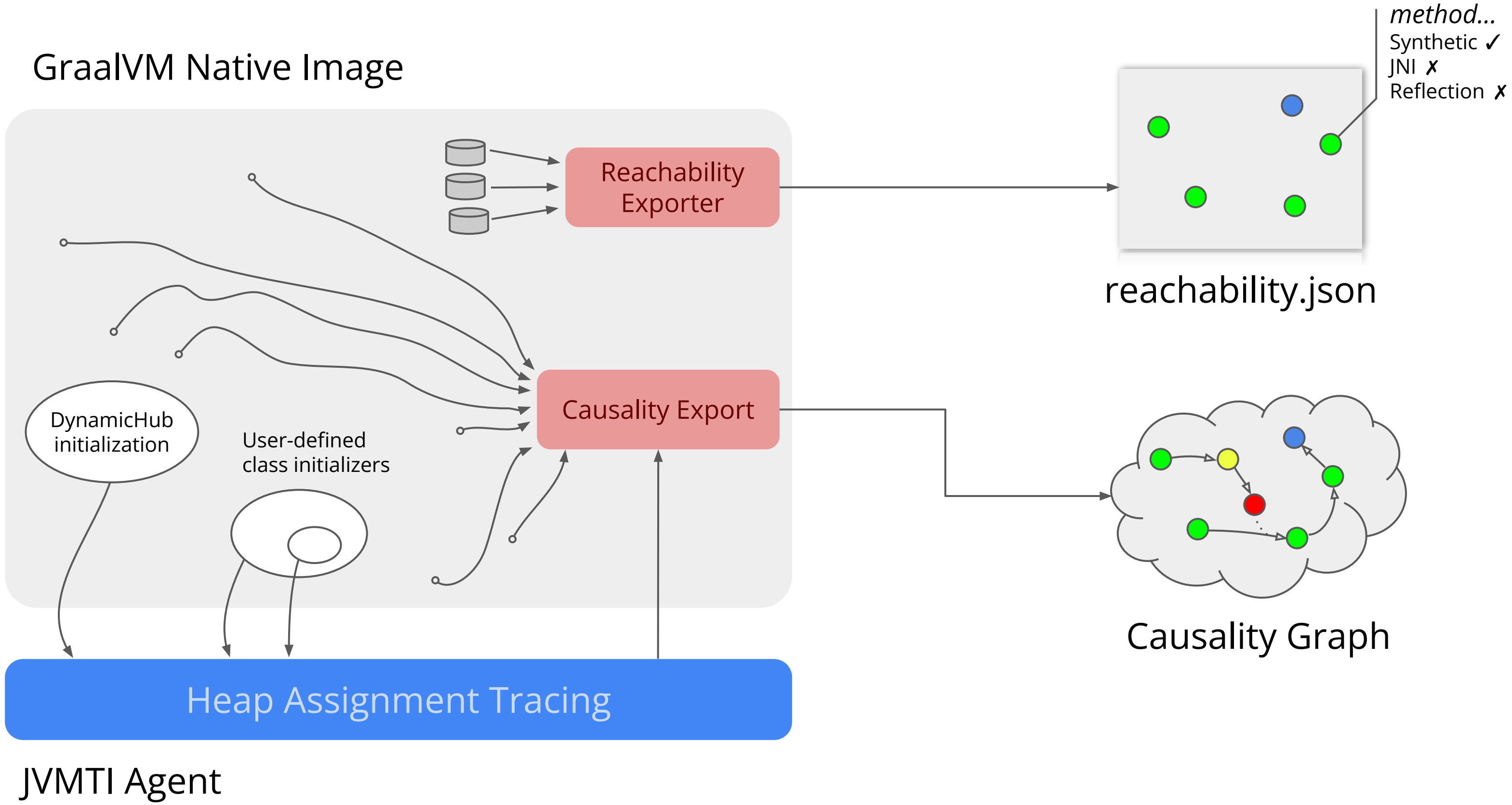


Rebuild



Evaluate

Data Export



GraalVM Native Image

Reachability Exporter

Causality Export

DynamicHub initialization

User-defined class initializers

Heap Assignment Tracing

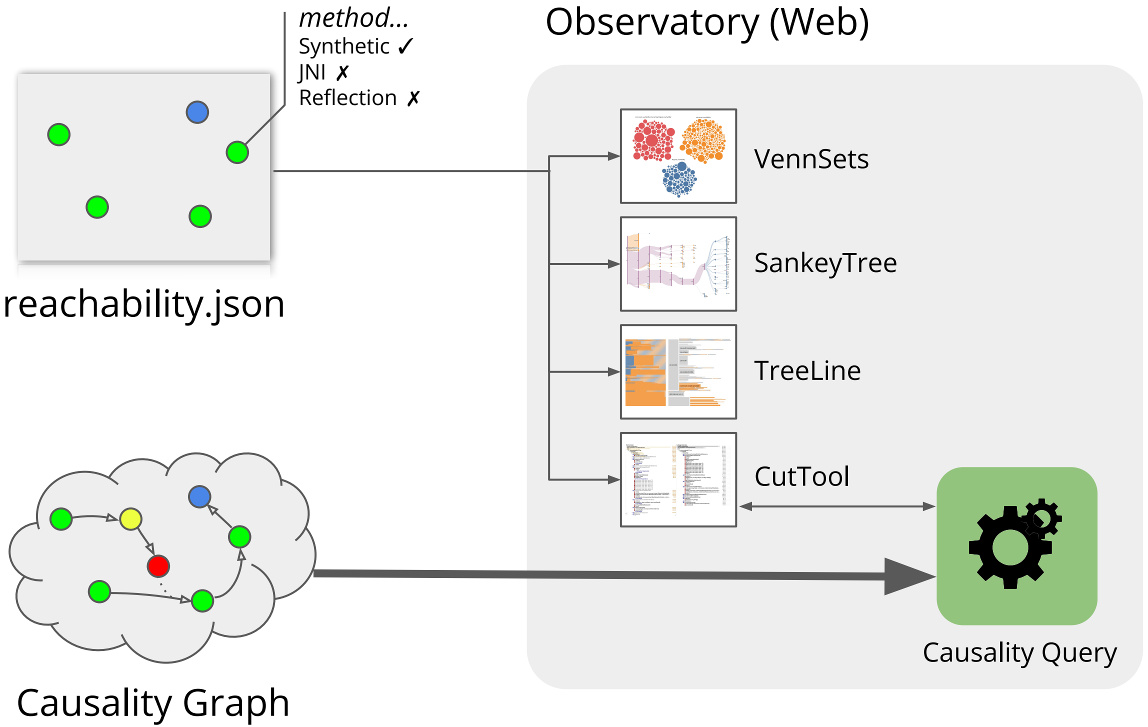
JVMTI Agent

method...
Synthetic ✓
JNI ✗
Reflection ✗

reachability.json

Causality Graph

Data use



method...
Synthetic ✓
JNI ✗
Reflection ✗

reachability.json

Observatory (Web)

VennSets

SankeyTree

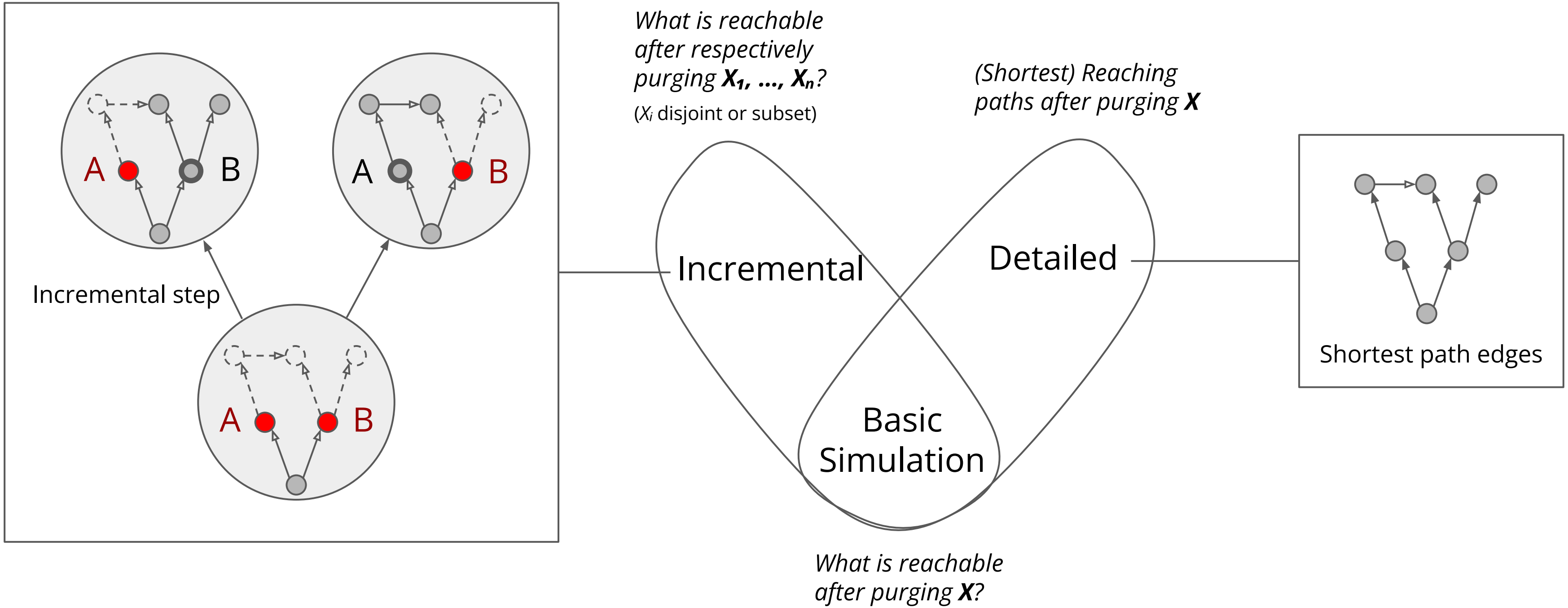
TreeLine

CutTool

Causality Query

Causality Graph

Causality Query: Algorithm



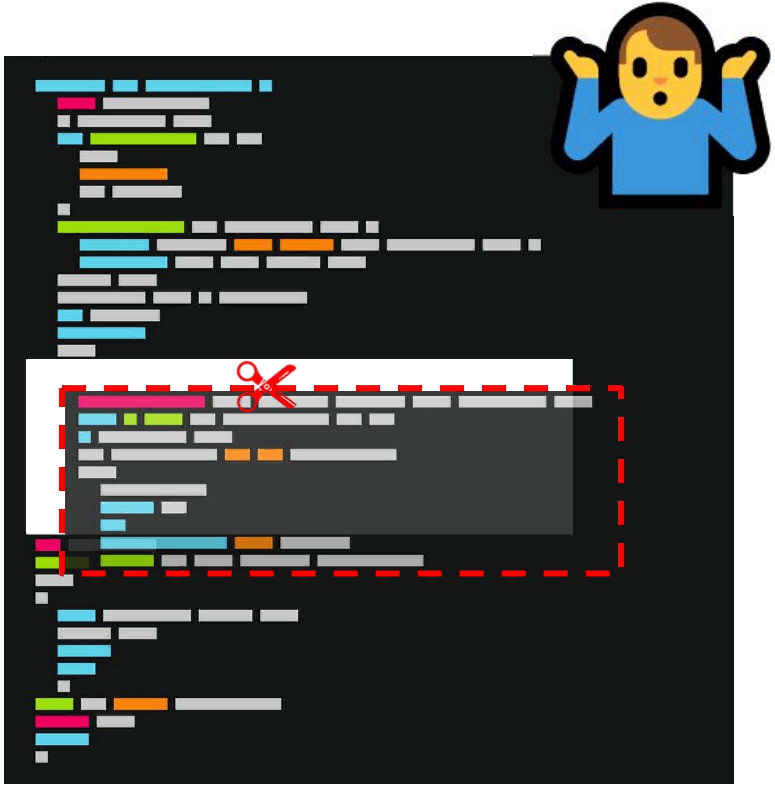
What is reachable after respectively purging $\boldsymbol{X_1, \dots, X_n}$?

(X_i disjoint or subset)

(Shortest) Reaching paths after purging $\boldsymbol{X}$

What is reachable after purging $\boldsymbol{X}$*?*

Java Jasper Back in His Code

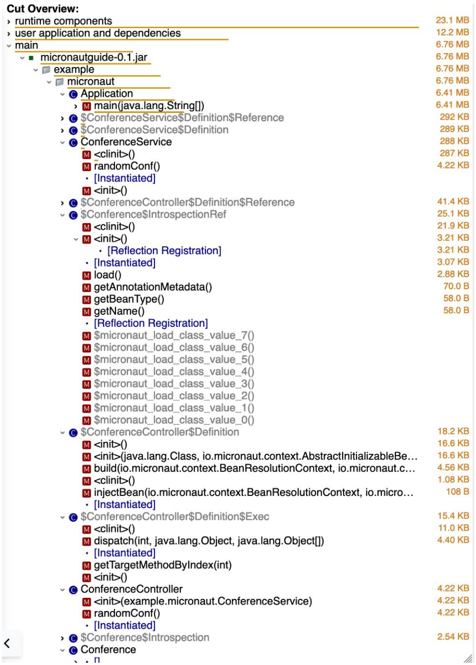


Now Jasper wonders:

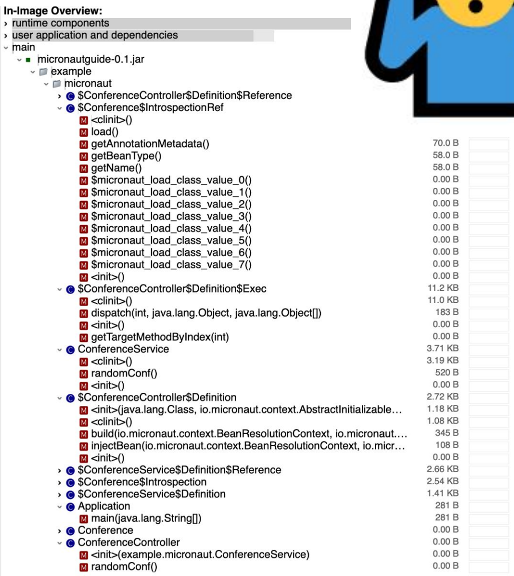
- … is my image now smaller?
- … did log4j really get removed from the image?
- … what’s different to my previous version?
- … if I use another logging library, will it use less space?

…is my image now smaller?

…if I use another logging library, will it use less space?



```
Cut Overview:
› runtime components                                                    23.1 MB
› user application and dependencies                                    12.2 MB
⌄ main                                                                  6.76 MB
  ⌄ ■ micronautguide-0.1.jar                                            6.76 MB
    ⌄ example                                                           6.76 MB
      ⌄ micronaut                                                       6.76 MB
        ⌄ Application                                                   6.41 MB
          › main(java.lang.String[])                                    6.41 MB
        › $ConferenceService$Definition$Reference                        292 KB
        › $ConferenceService$Definition                                  289 KB
        ⌄ ConferenceService                                              288 KB
            <clinit>()                                                   287 KB
            randomConf()                                                4.22 KB
            • [Instantiated]
            <init>()
        › $ConferenceController$Definition$Reference                    41.4 KB
        ⌄ $Conference$IntrospectionRef                                  25.1 KB
            <clinit>()                                                  21.9 KB
          ⌄ <init>()                                                    3.21 KB
              • [Reflection Registration]                               3.21 KB
            • [Instantiated]                                            3.07 KB
            load()                                                      2.88 KB
            getAnnotationMetadata()                                     70.0 B
            getBeanType()                                               58.0 B
            getName()                                                   58.0 B
            • [Reflection Registration]
            $micronaut_load_class_value_7()
            $micronaut_load_class_value_6()
            $micronaut_load_class_value_5()
            $micronaut_load_class_value_4()
            $micronaut_load_class_value_3()
            $micronaut_load_class_value_2()
            $micronaut_load_class_value_1()
            $micronaut_load_class_value_0()
        ⌄ $ConferenceController$Definition                              18.2 KB
            <init>()                                                    16.6 KB
            <init>(java.lang.Class, io.micronaut.context.AbstractInitializableBe…  16.6 KB
            build(io.micronaut.context.BeanResolutionContext, io.micronaut.c…      4.56 KB
            <clinit>()                                                  1.08 KB
            injectBean(io.micronaut.context.BeanResolutionContext, io.micro…        108 B
            • [Instantiated]
        ⌄ $ConferenceController$Definition$Exec                         15.4 KB
            <clinit>()                                                  11.0 KB
            dispatch(int, java.lang.Object, java.lang.Object[])         4.40 KB
            • [Instantiated]
            getTargetMethodByIndex(int)
            <init>()
        ⌄ ConferenceController                                          4.22 KB
            <init>(example.micronaut.ConferenceService)                 4.22 KB
            randomConf()                                                4.22 KB
            • [Instantiated]
        › $Conference$Introspection                                     2.54 KB
        ⌄ Conference
          › • []
```



```
In-Image Overview:
› runtime components
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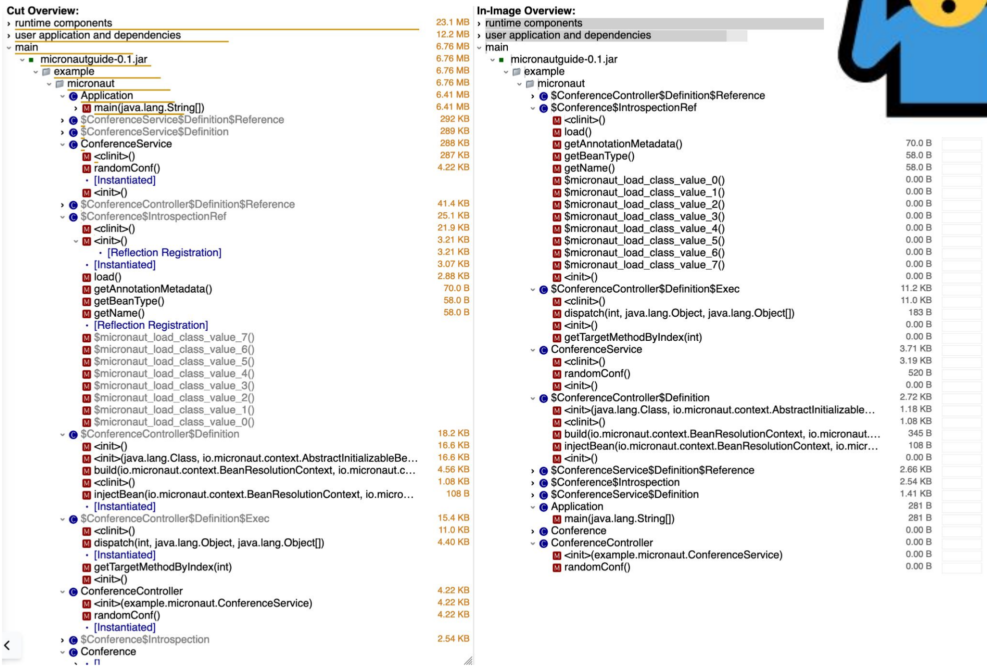
⌄ main
  ⌄ ■ micronautguide-0.1.jar
    ⌄ example
      ⌄ micronaut
        › $ConferenceController$Definition$Reference
        ⌄ $Conference$IntrospectionRef
            <clinit>()
            load()
            getAnnotationMetadata()                                     70.0 B
            getBeanType()                                               58.0 B
            getName()                                                   58.0 B
            $micronaut_load_class_value_0()                             0.00 B
            $micronaut_load_class_value_1()                             0.00 B
            $micronaut_load_class_value_2()                             0.00 B
            $micronaut_load_class_value_3()                             0.00 B
            $micronaut_load_class_value_4()                             0.00 B
            $micronaut_load_class_value_5()                             0.00 B
            $micronaut_load_class_value_6()                             0.00 B
            $micronaut_load_class_value_7()                             0.00 B
            <init>()                                                    0.00 B
        ⌄ $ConferenceController$Definition$Exec                         11.2 KB
            <clinit>()                                                  11.0 KB
            dispatch(int, java.lang.Object, java.lang.Object[])          183 B
            <init>()                                                    0.00 B
            getTargetMethodByIndex(int)                                 0.00 B
        ⌄ ConferenceService                                             3.71 KB
            <clinit>()                                                  3.19 KB
            randomConf()                                                 520 B
            <init>()                                                    0.00 B
        ⌄ $ConferenceController$Definition                              2.72 KB
            <init>(java.lang.Class, io.micronaut.context.AbstractInitializable…    1.18 KB
            <clinit>()                                                  1.08 KB
            build(io.micronaut.context.BeanResolutionContext, io.micronaut.…        345 B
            injectBean(io.micronaut.context.BeanResolutionContext, io.micr…         108 B
            <init>()                                                    0.00 B
        › $ConferenceService$Definition$Reference                       2.66 KB
        › $Conference$Introspection                                     2.54 KB
        › $ConferenceService$Definition                                 1.41 KB
        ⌄ Application                                                    281 B
            main(java.lang.String[])                                     281 B
        › Conference                                                    0.00 B
        ⌄ ConferenceController                                          0.00 B
            <init>(example.micronaut.ConferenceService)                 0.00 B
            randomConf()                                                0.00 B
```

✓

…did log4j really get removed from the image?



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    ⌄ example                                                               6.76 MB
      ⌄ micronaut                                                           6.76 MB
        ⌄ C Application                                                     6.41 MB
          › M main(java.lang.String[])                                      6.41 MB
        › C $ConferenceService$Definition$Reference                         292 KB
        › C $ConferenceService$Definition                                   289 KB
        ⌄ C ConferenceService                                               288 KB
            M <clinit>()                                                    287 KB
            M randomConf()                                                  4.22 KB
            • [Instantiated]
            M <init>()
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            M <clinit>()                                                    21.9 KB
          ⌄ M <init>()                                                      3.21 KB
              • [Reflection Registration]                                   3.21 KB
            • [Instantiated]                                                3.07 KB
            M load()                                                        2.88 KB
            M getAnnotationMetadata()                                       70.0 B
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            M getName()                                                     58.0 B
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        ⌄ C ConferenceController                                            4.22 KB
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            M randomConf()                                                  4.22 KB
            • [Instantiated]
        › C $Conference$Introspection                                       2.54 KB
        ⌄ C Conference
```

```
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            M $micronaut_load_class_value_5()                               0.00 B
            M $micronaut_load_class_value_6()                               0.00 B
            M $micronaut_load_class_value_7()                               0.00 B
            M <init>()                                                      0.00 B
        ⌄ C $ConferenceController$Definition$Exec                           11.2 KB
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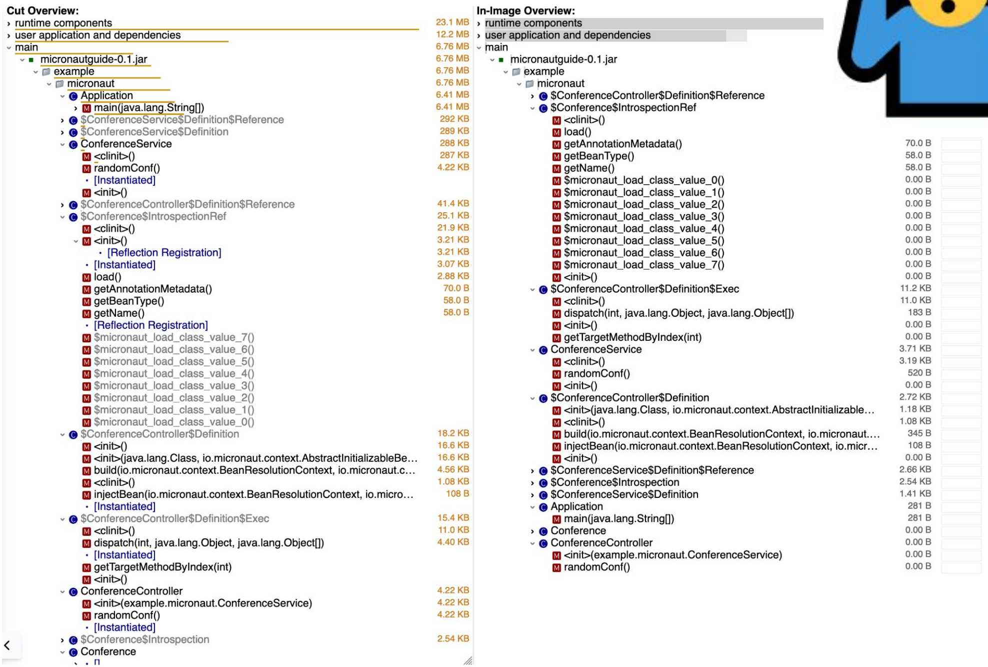
        ⌄ C ConferenceController                                            0.00 B
            M <init>(example.micronaut.ConferenceService)                   0.00 B
            M randomConf()                                                  0.00 B
```

…what’s different to my previous version?



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                    M load()                                        2.88 KB
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                    M getBeanType()                                 58.0 B
                    M getName()                                     58.0 B
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                    M randomConf()                                  4.22 KB
                    • [Instantiated]
              › C $Conference$Introspection                         2.54 KB
              ⌄ C Conference
                  › • []
```

In-Image Overview:

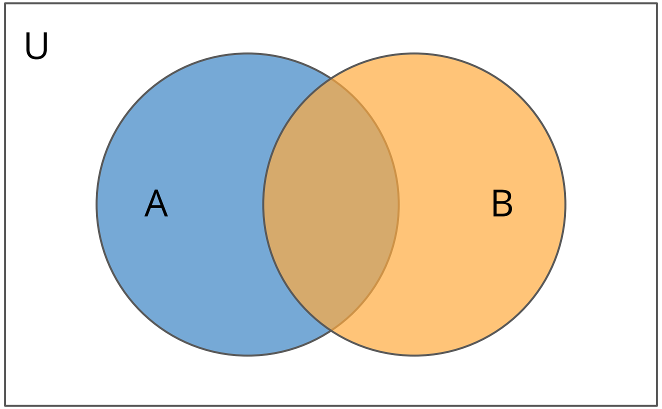
```
› runtime components
› user application and dependencies
⌄ main
  ⌄ ■ micronautguide-0.1.jar
      ⌄ example
          ⌄ micronaut
              › C $ConferenceController$Definition$Reference
              ⌄ C $Conference$IntrospectionRef
                    M <clinit>()
                    M load()
                    M getAnnotationMetadata()                       70.0 B
                    M getBeanType()                                 58.0 B
                    M getName()                                     58.0 B
                    M $micronaut_load_class_value_0()               0.00 B
                    M $micronaut_load_class_value_1()               0.00 B
                    M $micronaut_load_class_value_2()               0.00 B
                    M $micronaut_load_class_value_3()               0.00 B
                    M $micronaut_load_class_value_4()               0.00 B
                    M $micronaut_load_class_value_5()               0.00 B
                    M $micronaut_load_class_value_6()               0.00 B
                    M $micronaut_load_class_value_7()               0.00 B
                    M <init>()                                      0.00 B
              ⌄ C $ConferenceController$Definition$Exec             11.2 KB
                    M <clinit>()                                    11.0 KB
                    M dispatch(int, java.lang.Object, java.lang.Object[])    183 B
                    M <init>()                                      0.00 B
                    M getTargetMethodByIndex(int)                   0.00 B
              ⌄ C ConferenceService                                 3.71 KB
                    M <clinit>()                                    3.19 KB
                    M randomConf()                                   520 B
                    M <init>()                                      0.00 B
              ⌄ C $ConferenceController$Definition                  2.72 KB
                    M <init>(java.lang.Class, io.micronaut.context.AbstractInitializable…   1.18 KB
                    M <clinit>()                                    1.08 KB
                    M build(io.micronaut.context.BeanResolutionContext, io.micronaut.…       345 B
                    M injectBean(io.micronaut.context.BeanResolutionContext, io.micr…        108 B
                    M <init>()                                      0.00 B
              › C $ConferenceService$Definition$Reference           2.66 KB
              › C $Conference$Introspection                         2.54 KB
              › C $ConferenceService$Definition                     1.41 KB
              ⌄ C Application                                        281 B
                    M main(java.lang.String[])                       281 B
              › C Conference                                        0.00 B
              ⌄ C ConferenceController                              0.00 B
                    M <init>(example.micronaut.ConferenceService)   0.00 B
                    M randomConf()                                  0.00 B
```

…did log4j really get removed from the image?

…what's different to my previous version?

→ Visualizations for Diffing

+ Helpful Interactions

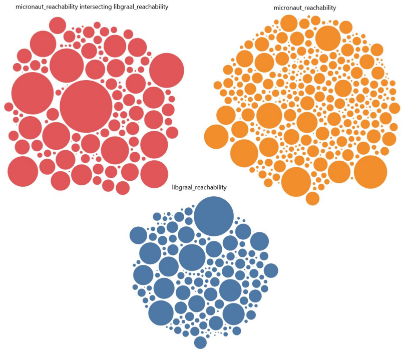


< Demo Time! >

Diffing, Selecting, Filtering

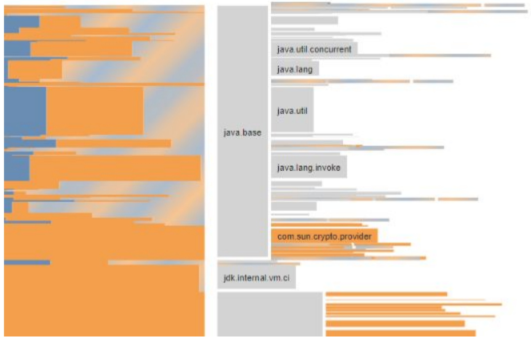
Backup video

Diffing Visualizations



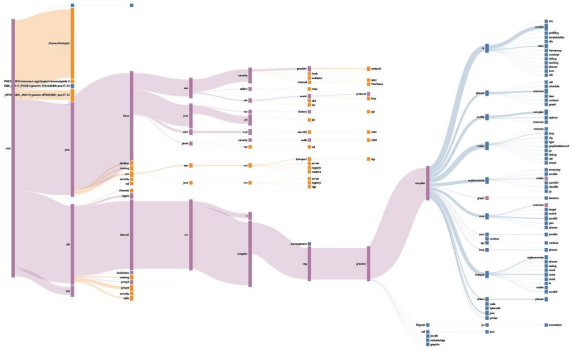
Venn Sets

- + present intersections and unique subsets
- + can display >= 2 universes
- ● separate display of abstraction levels
- – incomprehensible on low abstraction levels



Tree Line

- + most accurate display of code sizes
- + can display >= 2 universes
- ● display of hierarchy
- ● smooth transition between abstraction levels
- – needs some getting used to



Sankey Tree

- + display of hierarchy
- + focus on certain nodes/ branches
- ● smooth transition between abstraction levels
- – incomprehensible on low abstraction levels when fully extended

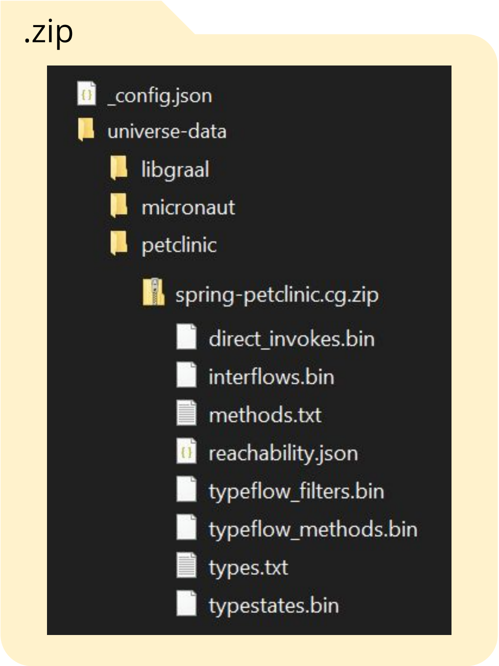
Data Sharing

Idea:
Export all the explorations that were made to share insights with colleagues

Implementation:

- raw data is stored on upload and added to the archive when requesting it
- the _config.json is essentially the serialization of our pinia stores

Export Structure:



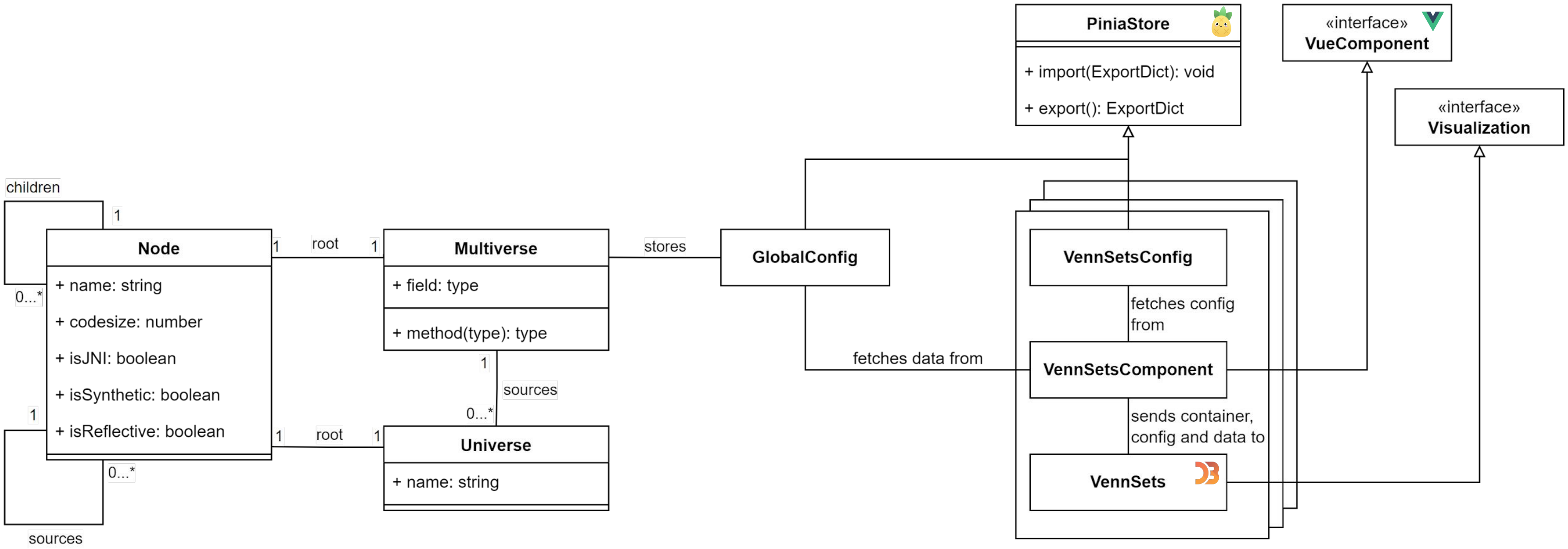
```
_config.json
universe-data
    libgraal
    micronaut
    petclinic
        spring-petclinic.cg.zip
            direct_invokes.bin
            interflows.bin
            methods.txt
            reachability.json
            typeflow_filters.bin
            typeflow_methods.bin
            types.txt
            typestates.bin
```

< Demo Time! >

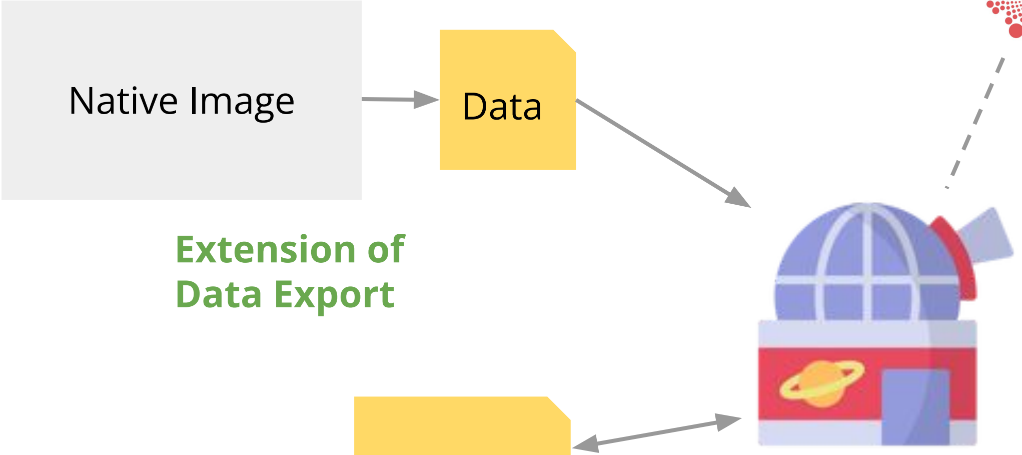
Sharing your View with Colleagues

Backup video

Code Structure of the Observatory



The Big Picture



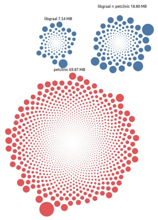
Native Image

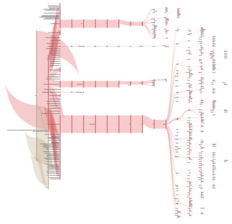
Data

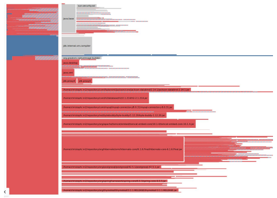
Config

Extension of Data Export

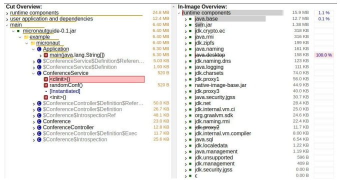
Config export/import for sharing







Multiple visualizations for image diffing and exploration



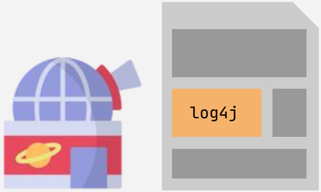
```
Cut Overview:
› runtime components                               24.8 MB
› user application and dependencies                12.4 MB
⌄ main                                             6.40 MB
  ⌄ ■ micronautguide-0.1.jar                       6.40 MB
    ⌄ example                                      6.40 MB
      ⌄ micronaut                                  6.40 MB
        ⌄ C Application                            6.30 MB
          › M main(java.lang.String[])             6.30 MB
        › C $ConferenceService$Definition$Referen… 5.03 KB
        › C $ConferenceService$Definition          1.93 KB
        ⌄ C ConferenceService                      520 B
            M <clinit>()
            M randomConf()                         520 B
            • [Instantiated]
            M <init>()
        › C $ConferenceController$Definition$Refer… 50.0 KB
        › C $ConferenceController$Definition       26.7 KB
        › C $Conference$IntrospectionRef           48.1 KB
        › C Conference                             23.0 KB
        › C ConferenceController                   12.8 KB
        › C $ConferenceController$Definition$Exec  11.7 KB
        › C $Conference$Introspection              25.6 KB
```

```
In-Image Overview:
⌄ runtime components             15.9 MB   1.1 %
  › ■ java.base                  12.7 MB   0.1 %
  › ■ svm.jar                    1.38 MB
  › ■ jdk.crypto.ec              318 KB
  › ■ java.rmi                   316 KB
  › ■ jdk.zipfs                  199 KB
  › ■ java.naming                161 KB
  › ■ ~~java.desktop~~           158 KB    100.0 %
  › ■ jdk.naming.dns             123 KB
  › ■ java.logging               111 KB
  › ■ jdk.charsets               74.0 KB
  › ■ jdk.proxy1                 56.0 KB
  › ■ native-image-base.jar      44.9 KB
  › ■ jdk.proxy3                 40.0 KB
  › ■ java.security.jgss         30.7 KB
  › ■ jdk.net                    28.4 KB
  › ■ jdk.internal.vm.ci         25.0 KB
  › ■ org.graalvm.sdk            24.6 KB
  › ■ jdk.naming.rmi             22.4 KB
  › ■ ~~jdk.proxy2~~             11.7 KB
  › ■ jdk.internal.vm.compiler   8.00 KB
  › ■ java.sql                   6.54 KB
  › ■ jdk.localedata             1.22 KB
  › ■ java.management            1.19 KB
  › ■ jdk.unsupported            596 B
  › ■ jdk.management             409 B
  › ■ jdk.security.jgss          0.00 B
  › ■ ϵ                          0.00 B
```

CutTool to help reduce image size

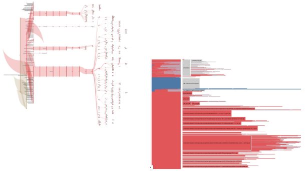
Evaluation

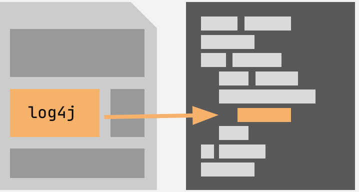
Our tool should be able to ...



Show Java Jasper that **log4j is in the image** and **how much space** it takes up

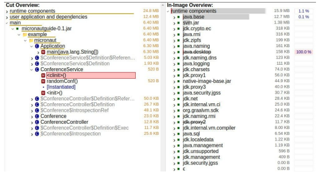
✓





Attribute the inclusion of log4j to the line of code Java Jasper can actually influence

✓



```
Cut Overview:
› runtime components                                      24.8 MB
› user application and dependencies                       12.4 MB
⌄ main                                                    6.40 MB
  ⌄ ■ micronautguide-0.1.jar                              6.40 MB
    ⌄ example                                             6.40 MB
      ⌄ micronaut                                         6.40 MB
        ⌄ C Application                                   6.30 MB
          › M main(java.lang.String[])                    6.30 MB
        › C $ConferenceService$Definition$Referen...      5.03 KB
        › C $ConferenceService$Definition                 1.93 KB
        ⌄ C ConferenceService                              520 B
            M <clinit>()
            M randomConf()                                 520 B
            • [Instantiated]
            M <init>()
        › C $ConferenceController$Definition$Refer...     50.0 KB
        › C $ConferenceController$Definition              26.7 KB
        › C $Conference$IntrospectionRef                  48.1 KB
        › C Conference                                    23.0 KB
        › C ConferenceController                          12.8 KB
        › C $ConferenceController$Definition$Exec         11.7 KB
        › C $Conference$Introspection                     25.6 KB
```

```
In-Image Overview:
⌄ runtime components                 15.9 MB    1.1 %
  › ■ java.base                      12.7 MB    0.1 %
  › ■ svm.jar                        1.38 MB
  › ■ jdk.crypto.ec                   318 KB
  › ■ java.rmi                        316 KB
  › ■ jdk.zipfs                       199 KB
  › ■ java.naming                     161 KB
  › ■ ~~java.desktop~~                158 KB  100.0 %
  › ■ jdk.naming.dns                  123 KB
  › ■ java.logging                    111 KB
  › ■ jdk.charsets                   74.0 KB
  › ■ jdk.proxy1                     56.0 KB
  › ■ native-image-base.jar          44.9 KB
  › ■ jdk.proxy3                     40.0 KB
  › ■ java.security.jgss             30.7 KB
  › ■ jdk.net                        28.4 KB
  › ■ jdk.internal.vm.ci             25.0 KB
  › ■ org.graalvm.sdk                24.6 KB
  › ■ jdk.naming.rmi                 22.4 KB
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  › ■ java.sql                       6.54 KB
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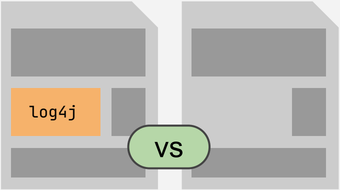
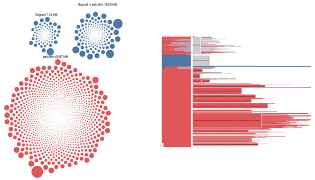
  › ■ jdk.management                  409 B
  › ■ jdk.security.jgss              0.00 B
  › ■ ϵ                              0.00 B
```



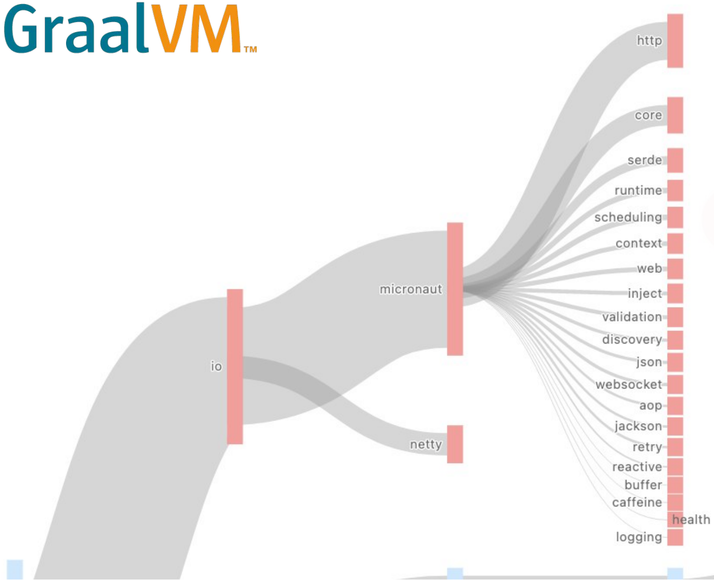
After deleting the line, **compare the old and the new image** to confirm log4j is gone

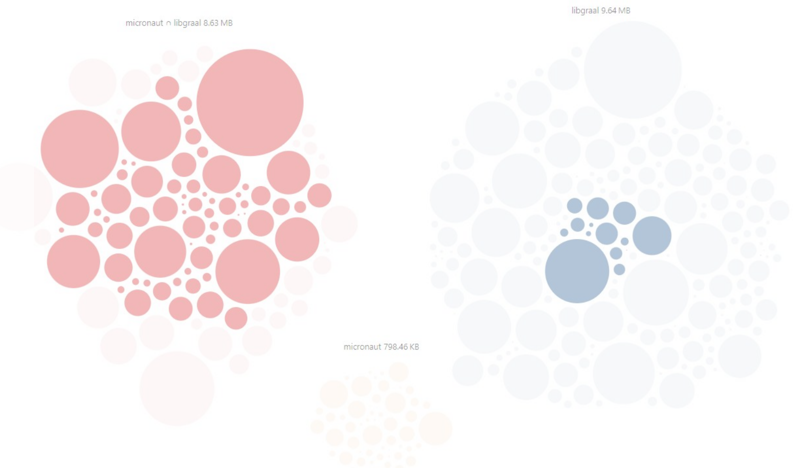
✓



ORACLE GraalVM™

HPI Hasso Plattner Institut
Digital Engineering • Universität Potsdam





```
Cut Overview:
› runtime components                                      24.8 MB
› user application and dependencies                       12.4 MB
⌄ main                                                    6.40 MB
   ⌄ ■ micronautguide-0.1.jar                             6.40 MB
      ⌄ example                                           6.40 MB
         ⌄ micronaut                                      6.40 MB
            ⌄ C Application                               6.30 MB
               › M main(java.lang.String[])               6.30 MB
            › C $ConferenceService$Definition$Referen…    5.03 KB
            › C $ConferenceService$Definition             1.93 KB
            ⌄ C ConferenceService                          520 B
                 M <clinit>()
                 M randomConf()                            520 B
```

```
In-Image Overview:
⌄ runtime components              15.9 MB     1.1 %
   › ■ java.base                  12.7 MB     0.1 %
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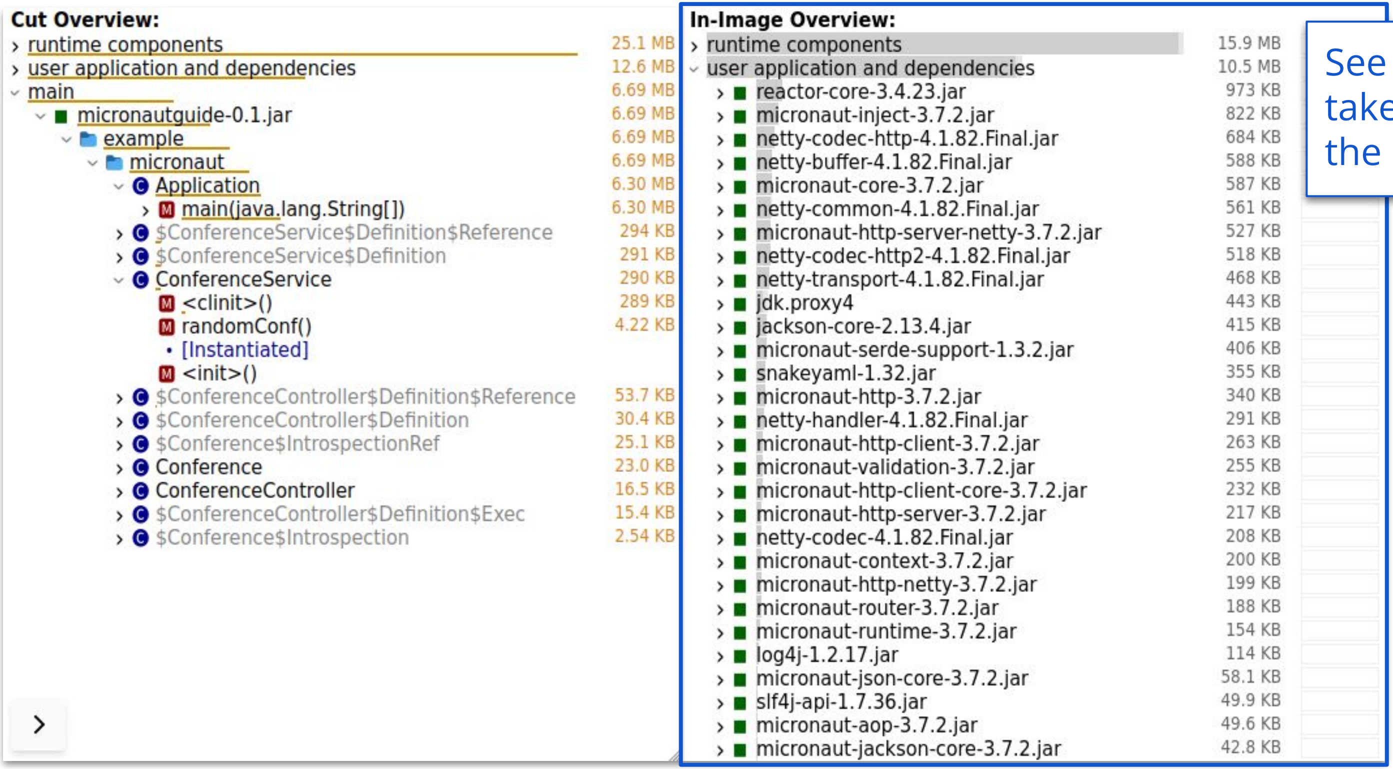
   › ■ jdk.unsupported              596 B
   › ■ jdk.management               409 B
   › ■ jdk.security.jgss          0.00 B
```

Thanks for listening!

Feedback? Questions?

CutTool



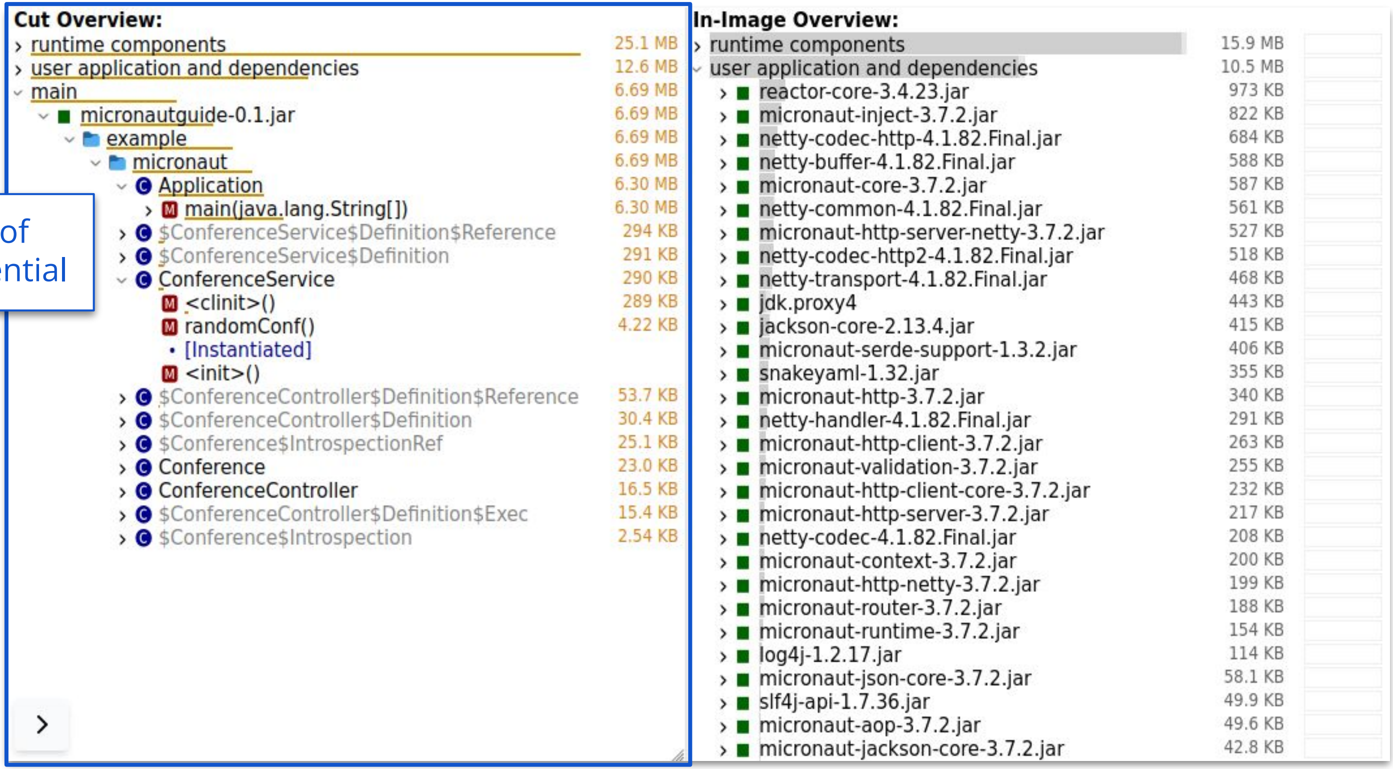
```
Cut Overview:
› runtime components                                         25.1 MB
› user application and dependencies                          12.6 MB
⌄ main                                                       6.69 MB
  ⌄ ■ micronautguide-0.1.jar                                 6.69 MB
    ⌄ example                                                6.69 MB
      ⌄ micronaut                                            6.69 MB
        ⌄ C Application                                      6.30 MB
          › M main(java.lang.String[])                       6.30 MB
        › C $ConferenceService$Definition$Reference          294 KB
        › C $ConferenceService$Definition                    291 KB
        ⌄ C ConferenceService                                290 KB
            M <clinit>()                                     289 KB
            M randomConf()                                   4.22 KB
            • [Instantiated]
            M <init>()
        › C $ConferenceController$Definition$Reference       53.7 KB
        › C $ConferenceController$Definition                 30.4 KB
        › C $Conference$IntrospectionRef                     25.1 KB
        › C Conference                                       23.0 KB
        › C ConferenceController                             16.5 KB
        › C $ConferenceController$Definition$Exec            15.4 KB
        › C $Conference$Introspection                        2.54 KB
```

```
In-Image Overview:
› runtime components                                  15.9 MB
⌄ user application and dependencies                   10.5 MB
  › ■ reactor-core-3.4.23.jar                         973 KB
  › ■ micronaut-inject-3.7.2.jar                      822 KB
  › ■ netty-codec-http-4.1.82.Final.jar               684 KB
  › ■ netty-buffer-4.1.82.Final.jar                   588 KB
  › ■ micronaut-core-3.7.2.jar                        587 KB
  › ■ netty-common-4.1.82.Final.jar                   561 KB
  › ■ micronaut-http-server-netty-3.7.2.jar           527 KB
  › ■ netty-codec-http2-4.1.82.Final.jar              518 KB
  › ■ netty-transport-4.1.82.Final.jar                468 KB
  › ■ jdk.proxy4                                      443 KB
  › ■ jackson-core-2.13.4.jar                         415 KB
  › ■ micronaut-serde-support-1.3.2.jar               406 KB
  › ■ snakeyaml-1.32.jar                              355 KB
  › ■ micronaut-http-3.7.2.jar                        340 KB
  › ■ netty-handler-4.1.82.Final.jar                  291 KB
  › ■ micronaut-http-client-3.7.2.jar                 263 KB
  › ■ micronaut-validation-3.7.2.jar                  255 KB
  › ■ micronaut-http-client-core-3.7.2.jar            232 KB
  › ■ micronaut-http-server-3.7.2.jar                 217 KB
  › ■ netty-codec-4.1.82.Final.jar                    208 KB
  › ■ micronaut-context-3.7.2.jar                     200 KB
  › ■ micronaut-http-netty-3.7.2.jar                  199 KB
  › ■ micronaut-router-3.7.2.jar                      188 KB
  › ■ micronaut-runtime-3.7.2.jar                     154 KB
  › ■ log4j-1.2.17.jar                                114 KB
  › ■ micronaut-json-core-3.7.2.jar                   58.1 KB
  › ■ slf4j-api-1.7.36.jar                            49.9 KB
  › ■ micronaut-aop-3.7.2.jar                         49.6 KB
  › ■ micronaut-jackson-core-3.7.2.jar                42.8 KB
```

See what takes space in the image

CutTool

Prediction of cutoff potential



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Cut Overview:
› runtime components                                        25.1 MB
› user application and dependencies                         12.6 MB
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   › ■ micronaut-http-server-3.7.2.jar               217 KB
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   › ■ micronaut-jackson-core-3.7.2.jar              42.8 KB
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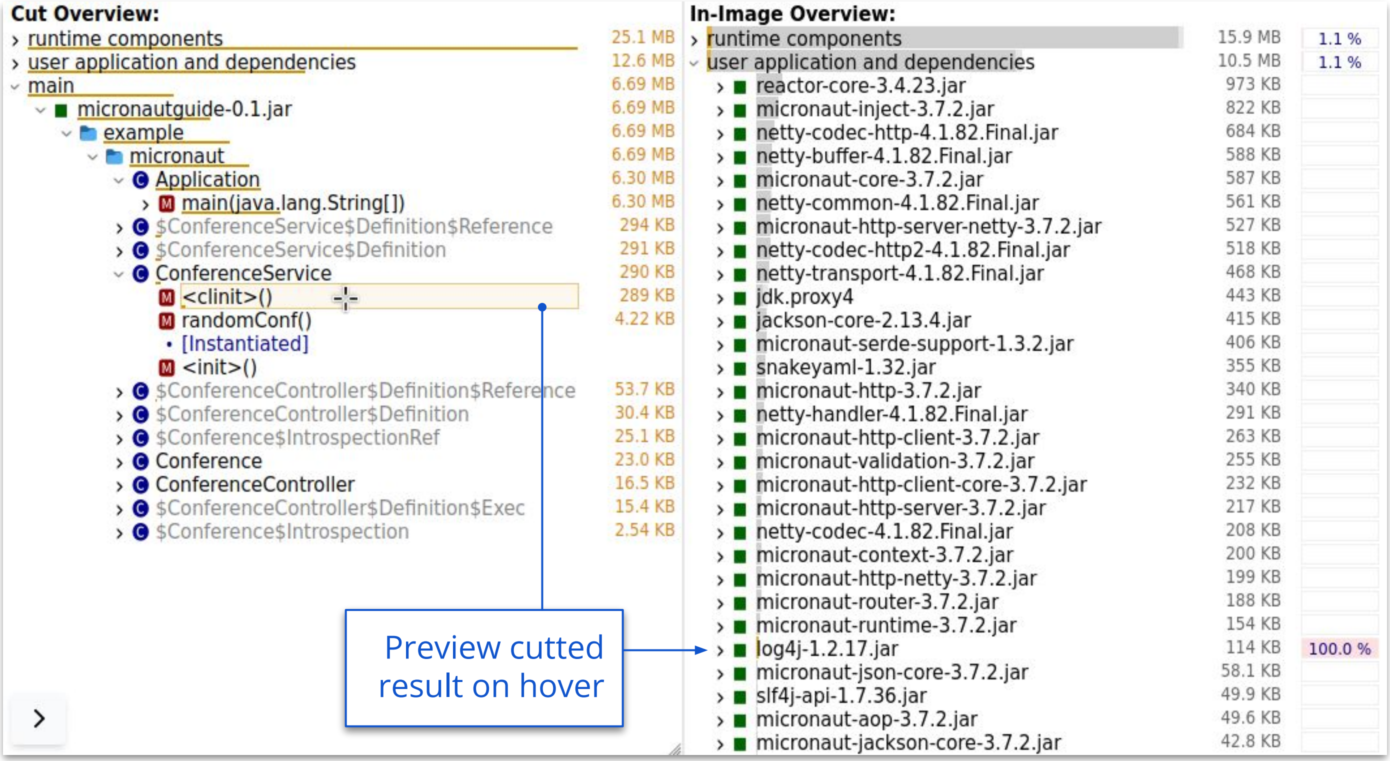
CutTool



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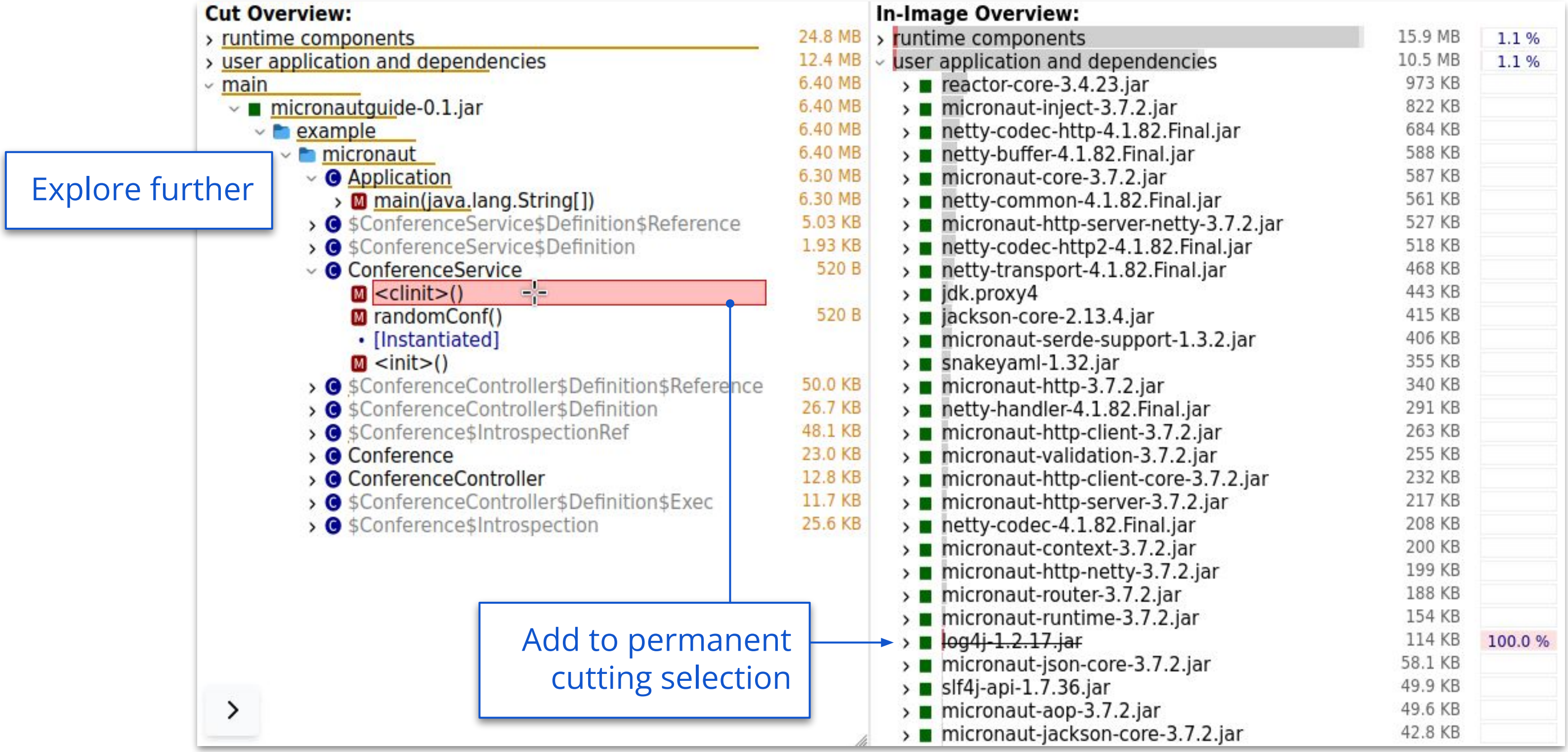
› C Conference	23.0 KB
› C ConferenceController	16.5 KB
› C $ConferenceController$Definition$Exec	15.4 KB
› C $Conference$Introspection	2.54 KB

In-Image Overview:

› runtime components	15.9 MB	1.1 %
⌄ user application and dependencies	10.5 MB	1.1 %
› ■ reactor-core-3.4.23.jar	973 KB	
› ■ micronaut-inject-3.7.2.jar	822 KB	
› ■ netty-codec-http-4.1.82.Final.jar	684 KB	
› ■ netty-buffer-4.1.82.Final.jar	588 KB	
› ■ micronaut-core-3.7.2.jar	587 KB	
› ■ netty-common-4.1.82.Final.jar	561 KB	
› ■ micronaut-http-server-netty-3.7.2.jar	527 KB	
› ■ netty-codec-http2-4.1.82.Final.jar	518 KB	
› ■ netty-transport-4.1.82.Final.jar	468 KB	
› ■ jdk.proxy4	443 KB	
› ■ jackson-core-2.13.4.jar	415 KB	
› ■ micronaut-serde-support-1.3.2.jar	406 KB	
› ■ snakeyaml-1.32.jar	355 KB	
› ■ micronaut-http-3.7.2.jar	340 KB	
› ■ netty-handler-4.1.82.Final.jar	291 KB	
› ■ micronaut-http-client-3.7.2.jar	263 KB	
› ■ micronaut-validation-3.7.2.jar	255 KB	
› ■ micronaut-http-client-core-3.7.2.jar	232 KB	
› ■ micronaut-http-server-3.7.2.jar	217 KB	
› ■ netty-codec-4.1.82.Final.jar	208 KB	
› ■ micronaut-context-3.7.2.jar	200 KB	
› ■ micronaut-http-netty-3.7.2.jar	199 KB	
› ■ micronaut-router-3.7.2.jar	188 KB	
› ■ micronaut-runtime-3.7.2.jar	154 KB	
› ■ log4j-1.2.17.jar	114 KB	100.0 %
› ■ micronaut-json-core-3.7.2.jar	58.1 KB	
› ■ slf4j-api-1.7.36.jar	49.9 KB	
› ■ micronaut-aop-3.7.2.jar	49.6 KB	
› ■ micronaut-jackson-core-3.7.2.jar	42.8 KB	

Preview cutted result on hover

CutTool



```
Cut Overview:
> runtime components                                        24.8 MB
> user application and dependencies                         12.4 MB
v main                                                      6.40 MB
  v ■ micronautguide-0.1.jar                                6.40 MB
    v 📁 example                                            6.40 MB
      v 📁 micronaut                                        6.40 MB
        v C Application                                     6.30 MB
          > M main(java.lang.String[])                      6.30 MB
        > C $ConferenceService$Definition$Reference         5.03 KB
        > C $ConferenceService$Definition                   1.93 KB
        v C ConferenceService                               520 B
            M <clinit>()
            M randomConf()                                  520 B
            • [Instantiated]
            M <init>()
        > C $ConferenceController$Definition$Reference      50.0 KB
        > C $ConferenceController$Definition                26.7 KB
        > C $Conference$IntrospectionRef                    48.1 KB
        > C Conference                                      23.0 KB
        > C ConferenceController                            12.8 KB
        > C $ConferenceController$Definition$Exec           11.7 KB
        > C $Conference$Introspection                       25.6 KB
```

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In-Image Overview:
> runtime components                            15.9 MB    1.1 %
v user application and dependencies            10.5 MB    1.1 %
  > ■ reactor-core-3.4.23.jar                   973 KB
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  > ■ ~~log4j-1.2.17.jar~~                      114 KB    100.0 %
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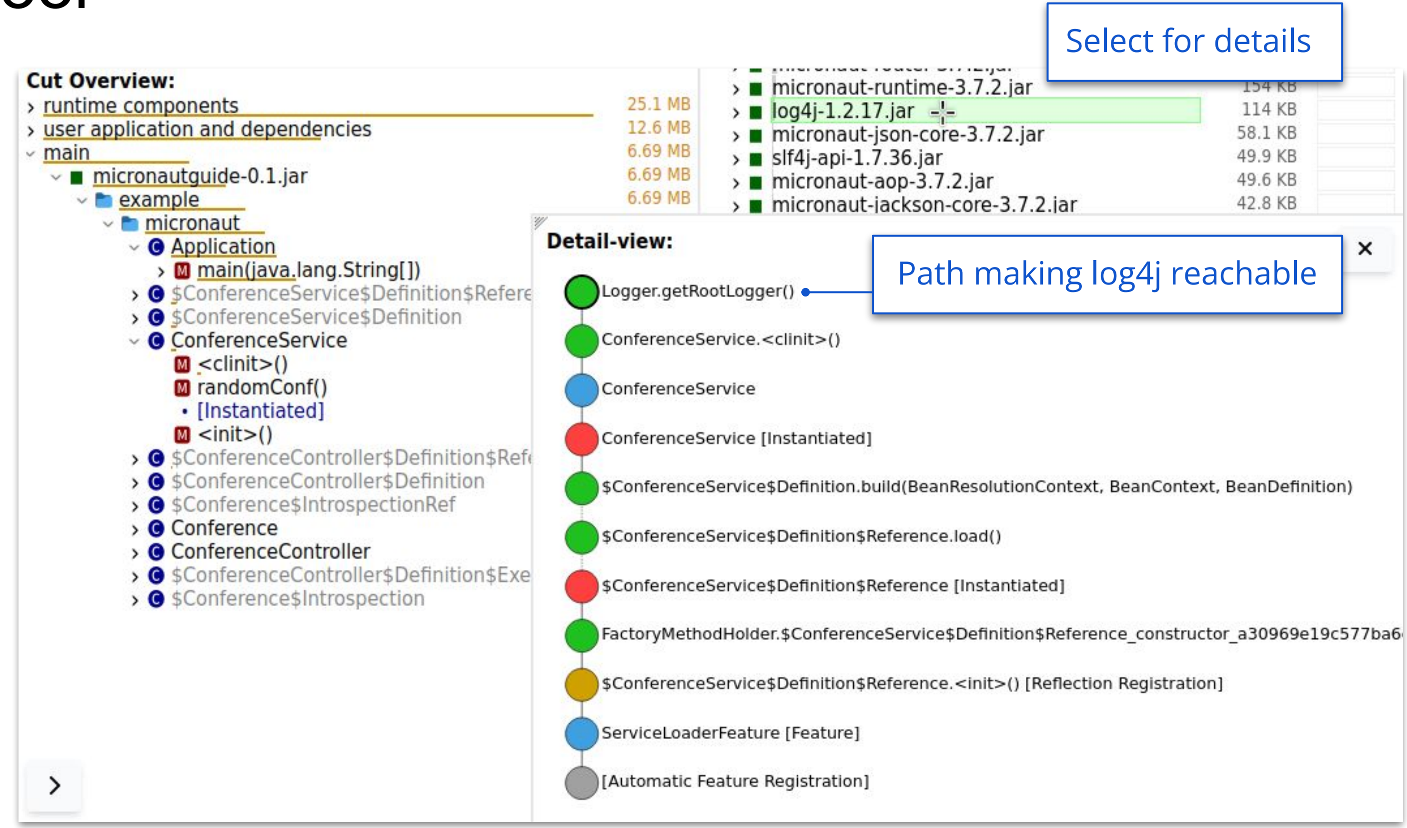
  > ■ slf4j-api-1.7.36.jar                      49.9 KB
  > ■ micronaut-aop-3.7.2.jar                   49.6 KB
  > ■ micronaut-jackson-core-3.7.2.jar          42.8 KB
```

Explore further

Add to permanent cutting selection

CutTool



Select for details

Cut Overview:

› runtime components 25.1 MB

› user application and dependencies 12.6 MB

⌄ main 6.69 MB

⌄ micronautguide-0.1.jar 6.69 MB

⌄ example 6.69 MB

⌄ micronaut 6.69 MB

⌄ C Application

› M main(java.lang.String[])

› C $ConferenceService$Definition$Refere

› C $ConferenceService$Definition

⌄ C ConferenceService

M <clinit>()

M randomConf()

• [Instantiated]

M <init>()

› C $ConferenceController$Definition$Refe

› C $ConferenceController$Definition

› C $Conference$IntrospectionRef

› C Conference

› C ConferenceController

› C $ConferenceController$Definition$Exe

› C $Conference$Introspection

› micronaut-runtime-3.7.2.jar	154 KB
› log4j-1.2.17.jar	114 KB
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› micronaut-aop-3.7.2.jar	49.6 KB
› micronaut-jackson-core-3.7.2.jar	42.8 KB

Detail-view:

Path making log4j reachable

- Logger.getRootLogger()
- ConferenceService.<clinit>()
- ConferenceService
- ConferenceService [Instantiated]
- $ConferenceService$Definition.build(BeanResolutionContext, BeanContext, BeanDefinition)
- $ConferenceService$Definition$Reference.load()
- $ConferenceService$Definition$Reference [Instantiated]
- FactoryMethodHolder.$ConferenceService$Definition$Reference_constructor_a30969e19c577ba6
- $ConferenceService$Definition$Reference.<init>() [Reflection Registration]
- ServiceLoaderFeature [Feature]
- [Automatic Feature Registration]

Recap: Personas

Exploration Emma
Curious, wants to learn, lots of time

Optimization Otto
GraalVM expert, wants to minimize resources, patient

Library Lena
GraalVM expert, develops efficient Java libraries

Java Jasper
Wants results ASAP, gets frustrated easily, Spring Boot user

Desperate Denise
GraalVM newbie, JIT compiles but native image doesn’t, clueless what to do