Comparing Rapid Type Analysis with Points-To Analysis in GraalVM Native Image

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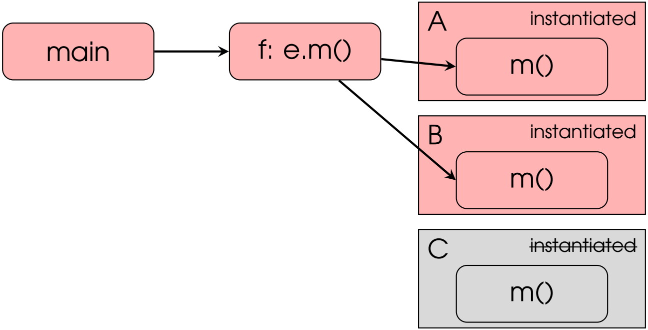

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- Closed-world assumption:
  - All code that can be executed at runtime has to be available at compile time.
  - All dynamic features, e.g. reflection, proxy, dynamic class loading, have to be explicitly configured.
- Produces standalone binaries containing the application along with all dependencies and runtime components.

GraalVM Native Image

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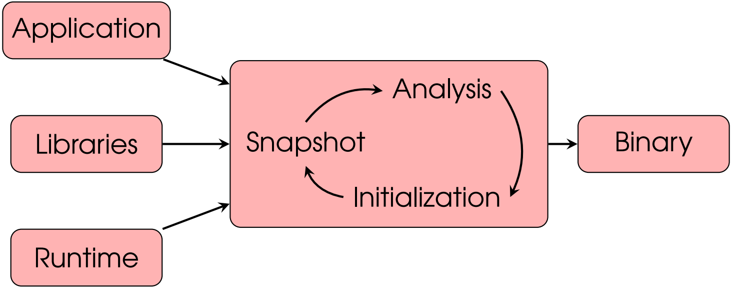

- Fixed-point computation starting from a set of entrypoints.

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- Scalability - debug mode for Native Image.
- Reasonable precision - do not increase the workload for the compilation phase too much.
- Fit into the environment of Native Image - interact with features such as heap snapshotting.
- Incrementality - reuse results from previous compilations.

Call Graph Construction

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After careful examination, we chose Rapid Type Analysis, which offers a good tradeoff between precision and scalability.

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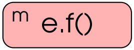
   $\forall t \in \mathit{Subtypes}(\mathit{StaticType}(e))$.
   $t \in I \wedge \mathit{StaticLookup}(t, f) = m'$
   $\implies m' \in R$.
3. $\forall m \in R\ \forall \mathit{new}\ C() \in \mathit{InstExpr}(m)$. $C \in I$.



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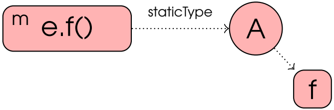

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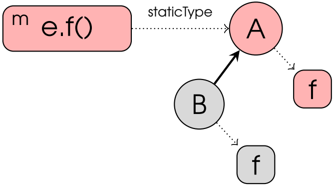

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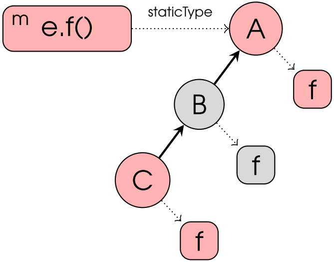

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- We designed an extension of rapid type analysis suited for the context of GraalVM Native Image.
- We extended the proposed algorithm to be parallel and incremental.
- The incrementality was achieved using method summaries that sum up the effect of each analyzed method.
- We provided a detailed comparison of the new variant of RTA with a points-to analysis for ahead-of-time compilation of Java.

RTA - Core Algorithm

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  - The update is done by calling specialized `register*` methods.
- Once a given method is made reachable, the decision is never reverted.
- The analysis stops once a fixed-point is reached.

Algorithm 1 RTA Core Algorithm.

```
for m ∈ rootMethods do
    registerAsInvoked(m)
procedure REGISTERASINVOKED(m)
    if mark(m.isInvoked) then                        ▻ atomic check
        schedule(() → onInvoked(m))                  ▻ schedule new task
procedure ONINVOKED(m)
    irGraph ← parseMethod(m)
    s ← extractSummary(irGraph)
    applySummary(s)
```

- All `register*` methods guarded by atomic checks.
  - Each class/method/field is processed only once.
- Non-trivial operations scheduled as separate tasks.

Method Summaries for RTA

- The effect of each method can be described using a method summary consisting of sets containing the following information:
  - directly invoked methods,
  - virtually invoked methods,
  - accessed types,
  - instantiated types,
  - read fields,
  - written fields, and
  - embedded constants.

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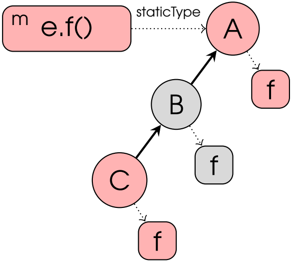
- These summaries can be extracted by a linear pass over the intermediate representation.

Handling of Virtual Methods

Algorithm 2 RTA handling of virtual methods.

```
procedure REGISTERASVIRTUALINVOKED(m)
    if mark(m.isVirtInvoked) then
        t ← m.declType
        t.virtInvoked.add(m)

        for subt ∈ t.instSubtypes do
            res ← subt.resolveMethod(m)
            registerAsInvoked(res)
```



- First, method *m* is marked as virtual invoked.
- Then, all instantiated subtypes of the declaring type are considered when computing the call targets.

Handling of Virtual Methods

Algorithm 3 RTA handling of virtual methods.

```
procedure REGISTERASINSTANTIATED(t)
    if mark(t.isInst) then
        for st ∈ t.superTypes do
            st.instSubtypes.add(t)
        for st ∈ t.superTypes do
            for m ∈ st.virtInvoked do
                res ← t.resolveMethod(m)
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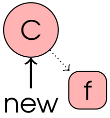

- First, the type t is marked as instantiated in all its supertypes.
- Then, all supertypes of the declaring type are traversed and each of their virtual invoked methods is processed.
- Note that type t is always used for the resolution.

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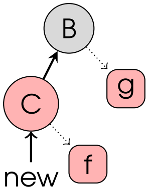

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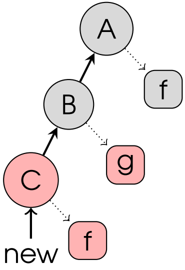

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```java
public class Hello {
    public static void main() {
        new Hello().foo(new A());
        log();
    }
    static void log(){
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    void foo(I i){
        i.bar();
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Method Summaries:

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  - Virtual invoke - bar

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Table: Results of the analyses on the running example.

Analysis	Results	
	Instantiated types	Invoked methods
PTA	Hello, A, B	log, foo, A.bar
RTA	Hello, A, B	log, foo, {A, B}.bar

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- Issues:
  - Parsing a method in Native Image has side effects.
  - Many summaries contain non-trivial constants.

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Table: Detailed statistics of the evaluated benchmarks.

Suite	Benchmark	Reachable Methods PTA	Reachable Methods RTA	Analysis Time (s) PTA	Analysis Time (s) RTA	Total time (s) PTA	Total time (s) RTA	Binary size (MB) PTA	Binary size (MB) RTA
Console	helloworld	18	**+17%**	14	**+21%**	36	**+17%**	13	**+23%**
Dacapo	avrora	24	**+25%**	12	-8%	51	+6%	23	**+30%**
	fop	94	+4%	46	-30%	128	-10%	105	+11%
	jython	71	+8%	55	**-35%**	140	**-26%**	134	+9%
	luindex	26	+23%	13	-8%	54	**+7%**	32	+25%
Microservices	micronaut-helloworld-wrk	74	+4%	34	-32%	88	-9%	45	+18%
	mushop:order	168	+2%	102	-59%	209	-30%	104	+13%
	mushop:payment	82	+4%	36	-33%	91	-10%	50	+14%
	mushop:user	115	+3%	57	-44%	135	-18%	76	+13%
	petclinic-wrk	207	+4%	159	**-64%**	297	**-35%**	144	+15%
	quarkus-helloworld-wrk	52	+6%	18	-22%	69	-3%	50	+4%
	quarkus:registry	111	+5%	49	-39%	126	-16%	69	**+19%**
	spring-helloworld-wrk	67	+4%	30	-33%	87	-10%	47	+13%
	tika-wrk	82	**+6%**	29	-28%	117	-6%	88	+6%
Renaissance	chi-square	173	+8%	129	-60%	260	-30%	100	+17%
	dec-tree	324	+6%	2009	-95%	X	X	X	X
	future-genetic	27	**+22%**	15	0%	44	+5%	19	**+21%**
	gauss-mix	189	+8%	146	-61%	286	**-32%**	107	+17%
	log-regression	334	+7%	2215	**-95%**	X	X	X	X
	page-rank	171	+8%	129	-60%	258	-31%	119	+13%
	reactors	30	+13%	19	+16%	47	+11%	19	+21%
	scala-stm-bench7	30	+20%	19	**+26%**	49	**+14%**	19	+21%

Scalability In Number of Cores

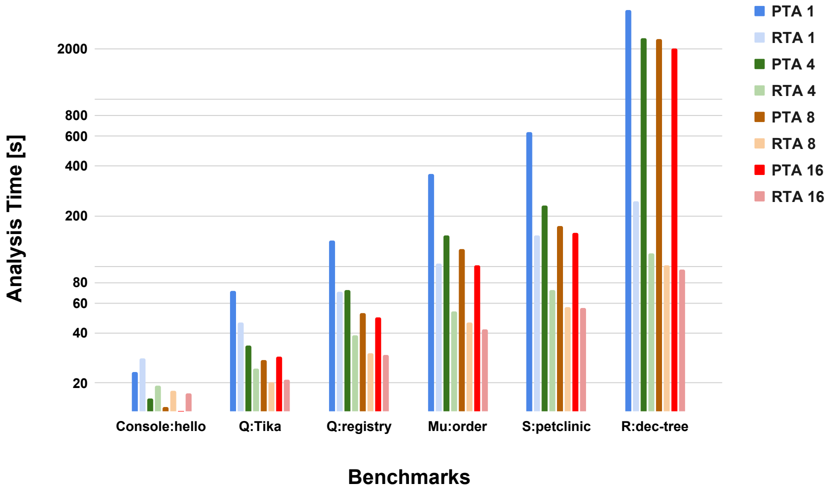

Figure: Scalability in number of cores.

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- For Spring Petclinic, we reduced the analysis time by **64%**, the overall build time by **35%** at the cost of increasing the image size by **15%**.
- Next steps:
  - Extend the support for incremental analysis.
  - Combine points-to analysis with rapid type analysis.

Thank You For Your Attention.