

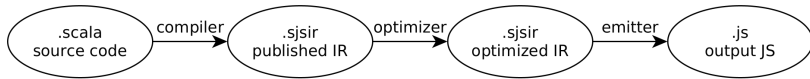
Foundations of Software Fall 2022

Week 14

Sébastien Doeraene

Elements of the Scala.js IR type system

Scala.js compilation pipeline



Why formally study an IR

Why formally study an IR

- ▶ Optimizations may only be applicable if the type system is sound
- ▶ Prove that certain optimizations are correct
- ▶ Prove that the translation from source and to the target language are correct
- ▶ etc.

Mixing primitives and objects

Motivation

Featherweight Java only has objects. How do we model primitives, for example, `int` and `bool`?

Motivation

Featherweight Java only has objects. How do we model primitives, for example, `int` and `bool`?

Moreover, in Scala, primitive types are “object-like”. We can use them in arbitrary type parameters, and they should behave like objects.

On the JVM, this is implemented with *boxing*. In Scala.js, however, boxing would be detrimental to *interoperability* with JavaScript. How do we make primitives object-like without boxing?

Motivation

Featherweight Java only has objects. How do we model primitives, for example, `int` and `bool`?

Moreover, in Scala, primitive types are “object-like”. We can use them in arbitrary type parameters, and they should behave like objects.

On the JVM, this is implemented with *boxing*. In Scala.js, however, boxing would be detrimental to *interoperability* with JavaScript. How do we make primitives object-like without boxing?

Idea: make primitive types *subtypes* of their “representative classes”.

Types and subtyping

$T ::=$

C

int

bool

types

class

primitive int

primitive bool

$$\frac{CT(C) = \text{class } C \text{ extends } D \{ \dots \}}{C <: D}$$

$T <: T$

$$\frac{S <: W \quad W <: T}{S <: T}$$

$\text{int} <: \text{Integer}$

$\text{bool} <: \text{Boolean}$

Representative classes

$$tpcls(C) = C$$

$$tpcls(int) = Integer$$

$$tpcls(bool) = Boolean$$

$$T <: tpcls(T)$$

Syntax (terms)

`t ::=`

`x`

`t.f`

`t.m(\bar{t})`

`new C(\bar{t})`

`(T) t`

`false`

`true`

`if t then t else t`

`0`

`succ t`

`pred t`

`iszero t`

terms

variable

field access

method invocation

object creation

cast

Syntax (values)

`v ::=`

`new C(\bar{v})`

`nv`

`bv`

values

object creation

numeric value

boolean value

`nv ::=`

`0`

`succ nv`

numeric values

zero

non-zero

`bv ::=`

`false`

`true`

boolean values

false

true

Typing rules: method calls

Adapting from Featherweight Java:

$$\frac{\begin{array}{l} \Gamma \vdash t_0 : C_0 \\ mtype(m, C_0) = \bar{S} \rightarrow T \\ \Gamma \vdash \bar{t} : \bar{S}_1 \quad \bar{S}_1 <: \bar{S} \end{array}}{\Gamma \vdash t_0.m(\bar{t}) : T} \quad (T\text{-INVK})$$

What if t_0 is a primitive?

Typing rules: method calls

Adapting from Featherweight Java:

$$\frac{\begin{array}{l} \Gamma \vdash t_0 : C_0 \\ \text{mtype}(\mathbf{m}, C_0) = \bar{S} \rightarrow T \\ \Gamma \vdash \bar{t} : \bar{S}_1 \quad \bar{S}_1 <: \bar{S} \end{array}}{\Gamma \vdash t_0.\mathbf{m}(\bar{t}) : T} \quad (\text{T-INVK})$$

What if t_0 is a primitive?

$$\frac{\begin{array}{l} \Gamma \vdash t_0 : T_0 \\ \text{mtype}(\mathbf{m}, \text{tpcls}(T_0)) = \bar{S} \rightarrow T \\ \Gamma \vdash \bar{t} : \bar{S}_1 \quad \bar{S}_1 <: \bar{S} \end{array}}{\Gamma \vdash t_0.\mathbf{m}(\bar{t}) : T} \quad (\text{T-INVK})$$

If $\Gamma \vdash x : \text{int}$, the call $x.\mathbf{m}(\dots)$ is typed by looking up \mathbf{m} in `Integer`.

Example

```
class Boolean extends Object { Boolean() { super(); } }
class Integer extends Object {
  Integer() { super(); }
  int plus(int that) {
    return if (iszero that) then ((int) this)
           else (succ this.plus(pred that)); }
}
class Pair extends Object {
  Object fst;
  Object snd;
  Pair(Object fst, Object snd) {
    super(); this.fst=fst; this.snd=snd; }
  int sum() {
    return ((int) this.fst).plus((int) this.snd); }
}

new Pair(5, 11).sum()
```


Typing rules: fields

Adapting from Featherweight Java:

$$\frac{\Gamma \vdash t_0 : C_0 \quad \text{fields}(C_0) = \bar{T} \ \bar{f}}{\Gamma \vdash t_0.f_i : T_i} \quad (\text{T-FIELD})$$

What if t_0 is a primitive?

Typing rules: fields

Adapting from Featherweight Java:

$$\frac{\Gamma \vdash t_0 : C_0 \quad \text{fields}(C_0) = \bar{T} \ \bar{f}}{\Gamma \vdash t_0.f_i : T_i} \quad (\text{T-FIELD})$$

What if t_0 is a primitive?

We can't have that!

Typing rules: fields

Adapting from Featherweight Java:

$$\frac{\Gamma \vdash t_0 : C_0 \quad \text{fields}(C_0) = \bar{T} \ \bar{f}}{\Gamma \vdash t_0.f_i : T_i} \quad (\text{T-FIELD})$$

What if t_0 is a primitive?

We can't have that!

Add additional well-formedness conditions for representative classes:

$$\frac{\text{fields}(\text{Integer}) = \emptyset \quad \text{fields}(\text{Boolean}) = \emptyset}{\text{repr classes OK}}$$

Typing rules: casts

Straightforward generalization to all types.

$$\frac{\Gamma \vdash t_0 : S \quad S <: T}{\Gamma \vdash (T)t_0 : T} \quad (\text{T-UCAST})$$

$$\frac{\Gamma \vdash t_0 : S \quad T <: S \quad T \neq S}{\Gamma \vdash (T)t_0 : T} \quad (\text{T-DCAST})$$

$$\frac{\Gamma \vdash t_0 : S \quad T \not<: S \quad S \not<: T \quad \textit{stupid warning}}{\Gamma \vdash (T)t_0 : T} \quad (\text{T-SCAST})$$

Typing rules: casts

Since it is an Intermediate Representation, warnings are not relevant anymore. Therefore, we keep only one typing rule for casts.

$$\frac{\Gamma \vdash t_0 : S}{\Gamma \vdash (T)t_0 : T} \quad (\text{T-CAST})$$

Typing rules: casts

Since it is an Intermediate Representation, warnings are not relevant anymore. Therefore, we keep only one typing rule for casts.

$$\frac{\Gamma \vdash t_0 : S}{\Gamma \vdash (T)t_0 : T} \quad (\text{T-CAST})$$

Question: can we remove the premise of that rule?

Evaluation rules

$$\frac{fields(C) = \bar{T} \ \bar{f}}{(new \ C(\bar{v})) . f_i \longrightarrow v_i} \quad (E-PROJNEW)$$

$$\frac{mbody(m, tpcls(vtpe(v))) = (\bar{x}, t_0)}{v.m(\bar{u}) \longrightarrow [\bar{x} \mapsto \bar{u}, this \mapsto v]t_0} \quad (E-INVKVAL)$$

$$\frac{vtpe(v) <: T}{(T)v \longrightarrow v} \quad (E-CASTVAL)$$

$$vtpe(new \ C(\bar{v})) = C \quad vtpen(v) = int \quad vtpen(bv) = bool$$

plus congruence rules and rules for `if`, `pred`, `succ` and `iszero` (omitted)