Master Informatique 2015-2016
Spécialité STL
Développement des langages de programmation
DLP – 4I501

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Plan du cours 4

- Génération de code
- Récapitulation
- Techniques Java

Principes de compilation

- Les variables ILP sont compilées en variables C
- Les expressions ILP sont compilées en expressions/instructions C

Compilation

Le compilateur doit avoir connaissance des environnements en jeu. Il est initialement créé avec un environnement global :

Ressource: com.paracamplus.ilp1.compiler.compiler

```
public class Compiler
implements
IASTCvisitor<Void, Compiler.Context, CompilationException>

public Compiler (IOperatorEnvironment ioe,
                     IGlobalVariableEnvironment igve ) {
        this.operatorEnvironment = ioe;
        this.globalVariableEnvironment = igve;
    }
protected final
  IOperatorEnvironment operatorEnvironment;
protected final
  IGlobalVariableEnvironment globalVariableEnvironment;
```

IASTCVisitor

```
import com.paracamplus.ilp1.interfaces.IASTvisitor;

public interface
 IASTCvisitor<Result, Data, Anomaly extends Throwable>
 extends IASTvisitor<Result, Data, Anomaly> {

Result visit(IASTCglobalVariable iast, Data data)
        throws Anomaly;
Result visit(IASTClocalVariable iast, Data data)
        throws Anomaly;
Result visit(IASTCprimitiveInvocation iast, Data data)
        throws Anomaly;
Result visit(IASTCvariable iast, Data data)
        throws Anomaly;
Result visit(IASTCcomputedInvocation iast, Data data)
        throws Anomaly;

}
```

Nouvelles classes dans l'AST

```
public interface IASTCvisitable extends IASTvisitable {
    <Result, Data, Anomaly extends Throwable>
    Result accept(IASTCvisitor<Result, Data, Anomaly> visitor,
                  Data data) throws Anomaly;
}

public abstract interface IASTCvariable
extends IASTvariable, IASTCvisitable {
    boolean isMutable();
    void setMutable();
}

public interface IASTCglobalVariable extends IASTCvariable {
}

public interface IASTClocalVariable extends IASTCvariable {
...
}
```

Mais aussi de redéfinitions

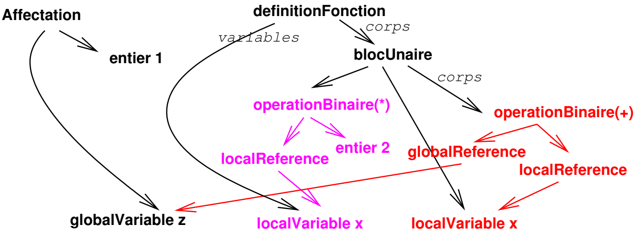
```
public class ASTCprogram extends ASTprogram
implements IASTCprogram {

public ASTCprogram (IASTexpression expression) {
        super(expression);
        this.globalVariables = new HashSet<>();
}
protected Set<IASTCglobalVariable> globalVariables;

public Set<IASTCglobalVariable> getGlobalVariables() {
        return globalVariables;
}

public void setGlobalVariables
                        (Set<IASTCglobalVariable> gvs) {
        globalVariables = gvs;
}
}
```

Qui fait l'instance du ASTCprogram ? La classe Parser ?

Normalisation

On fait une analyse statique : la Normalisation
Partage physique des objets représentant les variables.
Taxonomie des variables locales, globales, globales fonctionnelles, prédéfinies.

```
z = 1;
function f(x) {
  let x = 2*x
  in z+x
}
```



L'identification des variables :

- améliore la comparaison (et notamment la vitesse de l'interprète)
- réalise l'alpha-conversion (l'adresse est le nom).

Le visiteur normalizer

```java
public class Normalizer implements
 IASTvisitor
 <IASTexpression, INormalizationEnvironment, CompilationException> {

    public Normalizer (INormalizationFactory factory) {
        this.factory = factory;
        this.globalVariables = new HashSet<>();
    }
    protected final INormalizationFactory factory;
    protected final Set<IASTvariable> globalVariables;


    public IASTCprogram transform(IASTprogram program)
            throws CompilationException {
    INormalizationEnvironment env = NormalizationEnvironment.EMPTY;

    IASTexpression body = program.getBody();
    IASTexpression newbody = body.accept(this, env);
    return factory.newProgram(newbody);
    }
```

```
public IASTexpression
  visit(IASTboolean iast, INormalizationEnvironment env)
            throws CompilationException {
        return iast;
    }

 public IASTvariable
 visit(IASTvariable iast, INormalizationEnvironment env)
      throws CompilationException {
  try {
      return env.renaming(iast); // look for a local variable
  } catch (NoSuchLocalVariableException exc) {
      for ( IASTvariable gv : globalVariables ) {
          if ( iast.getName().equals(gv.getName()) ) {
              return gv;
          }
      }
      IASTvariable gv = factory.newGlobalVariable(iast.getName())
      globalVariables.add(gv);
      return gv;
  }
 }
```

```
public IASTexpression
 visit(IASTblock iast, INormalizationEnvironment env)
      throws CompilationException {

  INormalizationEnvironment newenv = env;
  IASTbinding[] bindings = iast.getBindings();
  IASTCblock.IASTCbinding[] newbindings =
          new IASTCblock.IASTCbinding[bindings.length];
  for ( int i=0 ; i<bindings.length ; i++ ) {
      IASTbinding binding = bindings[i];
      IASTexpression expr = binding.getInitialisation();
      IASTexpression newexpr = expr.accept(this, env);
      IASTvariable variable = binding.getVariable();
      IASTvariable newvariable =
              factory.newLocalVariable(variable.getName());
      newenv = newenv.extend(variable, newvariable);
      newbindings[i] =
                        factory.newBinding(newvariable, newexpr);
   }
   IASTexpression newbody =
                        iast.getBody().accept(this, newenv);
   return factory.newBlock(newbindings, newbody);
  }
```

Environnement global

- Compiler les appels aux primitives,
- Compiler les appels aux opérateurs,
- Vérifier l'existence, l'arité.

Environnement global pour les primitives

```
public interface IGlobalVariableEnvironment {
    void addGlobalVariableValue (String variableName, String cName);
    void addGlobalFunctionValue (IPrimitive primitive);
    boolean isPrimitive(IASTvariable variable);
    IPrimitive getPrimitiveDescription(IASTvariable variable);
    String getCName (IASTvariable variable);
}

public class GlobalVariableEnvironment
implements IGlobalVariableEnvironment {

    public GlobalVariableEnvironment () {
        this.globalVariableEnvironment = new HashMap<>();
        this.globalFunctionEnvironment = new HashMap<>();
    }
    private final Map<String, String> globalVariableEnvironment;
    private final Map<String, IPrimitive> globalFunctionEnvironment;

    public void addGlobalVariableValue(String variableName, String cName) {
        globalVariableEnvironment.put(variableName, cName);
    }

    public void addGlobalFunctionValue(IPrimitive primitive) {
        globalFunctionEnvironment.put(primitive.getName(), primitive);
    }
```

Primitives

```
public class Primitive implements IPrimitive {

    public Primitive(String name, String cName, int arity) {
        this.name = name;
        this.cName = cName;
        this.arity = arity;
    }
    private final String name;
    private final String cName;
    private final int arity;

    public String getName() {
        return name;
    }

    public String getCName() {
        return cName;
    }

    public int getArity () {
        return arity;
    }
}
```

Initialisation de GlobalVariableEnvironment

Ressource: com.paracamplus.ilp1.compiler.compiler.GlobalVariableStuff

```
public class GlobalVariableStuff {

public static void fillGlobalVariables
                (IGlobalVariableEnvironment env) {
 env.addGlobalVariableValue("pi", "ILP_PI");

 env.addGlobalFunctionValue(
    new Primitive("print", "ILP_print", 1));

 env.addGlobalFunctionValue(
   new Primitive("newline", "ILP_newline", 0));

 env.addGlobalFunctionValue(
   new Primitive("throw", "ILP_throw", 1));
    }
}
```

Environnement global pour les opérateurs

```
public interface IOperatorEnvironment {
    String getUnaryOperator (IASToperator operator)
            throws CompilationException;
    String getBinaryOperator (IASToperator operator)
            throws CompilationException;
    void addUnaryOperator (String operator, String cOperator)
            throws CompilationException;
    void addBinaryOperator (String operator, String cOperator)
            throws CompilationException;
}

public class OperatorEnvironment implements IOperatorEnvironment {

    public OperatorEnvironment () {
        this.unaryOperatorEnvironment = new HashMap<>();
        this.binaryOperatorEnvironment = new HashMap<>();
    }
    private final Map<String, String> unaryOperatorEnvironment;
    private final Map<String, String> binaryOperatorEnvironment;

    ...
}
```

Initialisation de OperatorEnvironment

Ressource: com.paracamplus.ilp1.compiler.compiler.OperatorStuff

```
public class OperatorStuff {

    public static void fillUnaryOperators (IOperatorEnvironmen
            throws CompilationException {
        env.addUnaryOperator("-", "ILP_Opposite");
        env.addUnaryOperator("!", "ILP_Not");
    }

    public static void fillBinaryOperators (IOperatorEnvironme
            throws CompilationException {
        env.addBinaryOperator("+", "ILP_Plus");
        env.addBinaryOperator("*", "ILP_Times");
        env.addBinaryOperator("/", "ILP_Divide");
        env.addBinaryOperator("-", "ILP_Minus");
        ...
    }
}
```

Compilation

```
public class Compiler
implements
IASTCvisitor<Void, Compiler.Context, CompilationException> {

public Compiler (IOperatorEnvironment ioe,
                     IGlobalVariableEnvironment igve ) {
        this.operatorEnvironment = ioe;
        this.globalVariableEnvironment = igve;
    }

protected Writer out;

public String compile(IASTprogram program)
            throws CompilationException {

        IASTCprogram newprogram = normalize(program);
        ...
        Context context = new Context(NoDestination.NO_DESTINATION);
        visit(newprogram, context);
        out.flush();
       ...
        return sw.toString();
    }
```

Context

```java
public static class Context {
    public Context (IDestination destination) {
        this.destination = destination;
    }
    public IDestination destination;
    public static AtomicInteger counter = new AtomicInteger(0);

    public IASTvariable newTemporaryVariable () {
        int i = counter.incrementAndGet();
        return new ASTvariable("ilptmp" + i);
    }

    public Context redirect (IDestination d) {
        if ( d == destination ) {
            return this;
        } else {
            return new Context(d);
        }
    }
}
```

Destination

Toute expression doit rendre un résultat.
Toute fonction doit rendre la main avec `return`.
La **destination** indique que faire de la valeur d'une expression ou d'une instruction.
Notations pour ILP1 :

$\overset{\longrightarrow}{\textit{expression}}$	laisser la valeur en place
$\overset{\longrightarrow\texttt{return}}{\textit{expression}}$	sortir de la fonction avec la valeur
$\overset{\longrightarrow\texttt{(x =)}}{\textit{expression}}$	assigner la valeur à la variable x

Destination

```
public class NoDestination implements IDestination {
        public static final NoDestination NO_DESTINATION =
            new NoDestination();
        private NoDestination () {}
        public String compile() {
                        return "";

public class AssignDestination implements IDestination {
        public AssignDestination (IASTvariable variable) {
                        this.variable = variable;
        private final IASTvariable variable;
        public String compile() {
            return variable.getMangledName() + " = ";

public class ReturnDestination implements IDestination {
        private ReturnDestination () {}
        public static final ReturnDestination RETURN_DESTINATION =
                 new  ReturnDestination();
        public String compile() {
            return "return ";
```

Génération de code

On est prêt pour la génération de code, mais ... pas besoin d'un environnement lexicale ?

```
 public Void visit(IASTCprogram iast, Context context) throws CompilationException {
      emit(cProgramPrefix);
      emit(cBodyPrefix);
      Context cr = context.redirect(ReturnDestination.RETURN_DESTINATION);
      iast.getBody().accept(this, cr);
      emit(cBodySuffix);
      emit(cProgramSuffix);
      return null;
}

  protected String cProgramPrefix = ""
          + "#include <stdio.h> \n"
          + "#include <stdlib.h> \n"
          + "#include \"ilp.h\" \n\n";
  protected String cBodyPrefix = "\n"
          + "ILP_Object ilp_program () \n"
          + "{ \n";
  protected String cBodySuffix = "\n"
          + "} \n";
  protected String cProgramSuffix = "\n"
         "int main (int argc, char *argv[]) \n"
          + "{ \n"
          + "  ILP_print(ilp_program()); \n"
          + "  ILP_newline(); \n"
          + "  return EXIT_SUCCESS; \n"
          + "} \n";
```

Habillage du code

```
#include <stdio.h>
#include <stdlib.h>
#include "ilp.h"

ILP_Object
ilp_program()
{
...
}

int
main(int argc, char *argv[])
{
        ILP_START_GC;
        ILP_print(ilp_program());
        ILP_newline();
        return EXIT_SUCCESS;
}
```

Grandes règles

- les variables ILP sont compilées en variables C
- les expressions ILP sont compilées en expressions C ou en instructions C dépendant du context

Compilation de l'alternative

alternative = (condition, consequence, alternant)

$$\overrightarrow{alternative}^{\mathrm{d}}$$

```
if ( ILP_isEquivalentToTrue( $\overrightarrow{condition}$ ) ) {
   $\overrightarrow{consequence}^{\mathrm{d}}$ ;
} else {
   $\overrightarrow{alternant}^{\mathrm{d}}$ ;
}
```

Compilation de l'alternative

```
public Void visit(IASTalternative iast, Context context)
            throws CompilationException {

IASTvariable tmp1 = context.newTemporaryVariable();
emit("{ \n");
emit("  ILP_Object " + tmp1.getMangledName() + "; \n");
Context c = context.redirect(new AssignDestination(tmp1));
iast.getCondition().accept(this, c);
emit("  if ( ILP_isEquivalentToTrue(");
emit(tmp1.getMangledName());
emit(" ) ) {\n");
iast.getConsequence().accept(this, context);
if ( iast.isTernary() ) {
    emit("\n  } else {\n");
    iast.getAlternant().accept(this, context);
 }
emit("\n  }\n}\n");
return null;
}
```

Compilation de la séquence

sequence = (instruction1, ... dernièreInstruction)

$$\overset{\longrightarrow \mathtt{d}}{\textit{séquence}}$$

```
{ ILP_Object temp;
   ⟶(temp =)
  instruction1 ;
   ⟶(temp =)
  instruction2 ;
  ...
              ⟶d
  dernièreInstruction ;
}
```

Compilation de la séquence

```
public Void visit(IASTsequence iast, Context context)
throws CompilationException {

IASTvariable tmp = context.newTemporaryVariable();
IASTexpression[] expressions = iast.getExpressions();
Context c = context.redirect(new AssignDestination(tmp)
emit("{ \n");
emit("  ILP_Object " + tmp.getMangledName() + "; \n");
for ( IASTexpression expr : expressions ) {
        expr.accept(this, c);
}
emit(context.destination.compile());
emit(tmp.getMangledName());
emit("; \n} \n");
return null;
}
```

Compilation de la séquence

```
<sequence>
<string>Un, </string>
<string>Deux, </string>
<string>Trois, </string>
</sequence>
</program>
```

```
{
ILP_Object      ilptmp117;
ilptmp117 = ILP_String2ILP("Un, ");
ilptmp117 = ILP_String2ILP("Deux, ");
ilptmp117 = ILP_String2ILP("Trois, ");
return ilptmp117;
}
```

Compilation du bloc unaire I

Comme au judo, utiliser la force du langage cible !
bloc = (variable, initialisation, corps)
corps = (instruction1, ... dernièreInstruction)

$$\overrightarrow{bloc}^{\,\mathtt{d}}$$

```
{
   ILP_Object variable = $\overrightarrow{initialisation}$ ;

   ILP_Object temp;
   $\overrightarrow{instruction1}^{\mathtt{(temp\ =)}}$ ;
   $\overrightarrow{instruction2}^{\mathtt{(temp\ =)}}$ ;
   ...
   $\overrightarrow{dernièreInstruction}^{\,\mathtt{d}}$ ;
}
```

Compilation du bloc unaire II

$$\overrightarrow{bloc}^{\mathtt{d}}$$

```
{
  ILP_Object temporaire = $\overrightarrow{initialisation}$ ;
  ILP_Object variable = temporaire;

  ILP_Object temp;
  $\overrightarrow{instruction1}^{\mathtt{(temp\ =)}}$ ;
  $\overrightarrow{instruction2}^{\mathtt{(temp\ =)}}$ ;
  ...
  $\overrightarrow{dernièreInstruction}^{\mathtt{d}}$ ;
}
```

Compilation du bloc unaire II

```
public Void visit(IASTblock iast, Context context) throws CompilationException {
    emit("{ \n");
    IASTbinding[] bindings = iast.getBindings();
    IASTvariable[] tmps = new IASTvariable[bindings.length];
    for ( int i=0 ; i<bindings.length ; i++ ) {
        IASTvariable tmp = context.newTemporaryVariable();
        emit("  ILP_Object " + tmp.getMangledName() + "; \n");
        tmps[i] = tmp;
    }
    for ( int i=0 ; i<bindings.length ; i++ ) {
        IASTbinding binding = bindings[i];
        IASTvariable tmp = tmps[i];
        Context c = context.redirect(new AssignDestination(tmp));
        binding.getInitialisation().accept(this, c);
    }
    emit("\n  {\n");
    for ( int i=0 ; i<bindings.length ; i++ ) {
        IASTbinding binding = bindings[i];
        IASTvariable tmp = tmps[i];
        IASTvariable variable = binding.getVariable();
        emit("    ILP_Object ");
        emit(variable.getMangledName());
        emit(" = ");
        emit(tmp.getMangledName());
        semit(";\n");
    }
    iast.getBody().accept(this, context);
    emit("\n  }\n}\n");
    return null;
}
```

Compilation d'une constante

$$\overset{\longrightarrow\mathtt{d}}{\mathit{constante}}$$

```
d   ILP_Integer2ILP(constanteEntière)
                    /* ou CgenerationException */
d   ILP_Float2ILP(constanteFlottante)
d   ILP_TRUE
d   ILP_FALSE
d   ILP_String2ILP("constanteChaînePlusProtection")
```

Compilation d'un Integer

```
public Void visit(IASTinteger iast, Context context)
            throws CompilationException {

        emit(context.destination.compile());
        emit("ILP_Integer2ILP(");
        emit(iast.getValue().toString());
        emit("); \n");
        return null;
    }
```

Compilation d'une variable

$$\overset{\longrightarrow \mathtt{d}}{\mathit{variable}}$$

```
d variable      /* ou CgenerationException */
```

Attention aussi une conversion (*mangling*) est parfois nécessaire !

Compilation d'une invocation

On utilise la force du langage C. La bibliothèque d'exécution comprend également les implantations des fonctions prédéfinies `print` et `newline` (respectivement `ILP_print` et `ILP_newline`).
invocation = (fonction, argument1, ...)

$$\overrightarrow{invocation}^{\mathrm{d}}$$

$$\begin{array}{l}
\texttt{d fonctionCorrespondante(} \\
\qquad\qquad \overrightarrow{argument1}\ \texttt{,} \\
\qquad\qquad \overrightarrow{argument2}\ \texttt{,} \\
\qquad\qquad \texttt{...)}
\end{array}$$

Compilation d'une opération

À chaque opérateur d'ILP1 correspond une fonction dans la bibliothèque d'exécution.
operation = (opérateur, opérandeGauche, opérandeDroit)

$$\overrightarrow{\mathit{opération}}^{\mathtt{d}}$$

$$\begin{array}{l} \mathtt{d\ fonctionCorrespondante(} \\ \qquad\qquad \overrightarrow{\mathit{opérandeGauche}}\ \mathtt{,} \\ \qquad\qquad \overrightarrow{\mathit{opérandeDroit}}\ \ \mathtt{)} \end{array}$$

Ainsi, `+` correspond à `ILP_Plus`, `-` correspond à `ILP_Minus`, etc.

Compilation d'une opération

```
public Void visit(IASTbinaryOperation iast, Context context)
        throws CompilationException {
    IASTvariable tmp1 = context.newTemporaryVariable();
    IASTvariable tmp2 = context.newTemporaryVariable();
    emit("{ \n");
    emit("  ILP_Object " + tmp1.getMangledName() + "; \n");
    emit("  ILP_Object " + tmp2.getMangledName() + "; \n");
    Context c1 = context.redirect(new AssignDestination(tmp1));
    iast.getLeftOperand().accept(this, c1);
    Context c2 = context.redirect(new AssignDestination(tmp2));
    iast.getRightOperand().accept(this, c2);
    String cName = operatorEnvironment.getBinaryOperator(iast.getOpera
    emit(context.destination.compile());
    emit(cName);
    emit("(");
    emit(tmp1.getMangledName());
    emit(", ");
    emit(tmp2.getMangledName());
    emit(");\n");
    emit("} \n");
    return null;
}
```

Exemple

(begin (if true (print "invisible")) 48)

```
#include <stdio.h>
#include <stdlib.h>
#include "ilp.h"

ILP_Object ilp_program()
{{ILP_Object    ilptmp121;
   {ILP_Object  ilptmp122;
     ilptmp122 = ILP_TRUE;
     if (ILP_isEquivalentToTrue(ilptmp122)) {
      { ILP_Object      ilptmp123;
        ilptmp123 = ILP_String2ILP("invisible");
        ilptmp121 = ILP_print(ilptmp123); } }
     else {ilptmp121 = ILP_FALSE;}}
     ilptmp121 = ILP_Integer2ILP(48);
     return ilptmp121;}}

int  main(int argc, char *argv[])
{
        ILP_START_GC;
        ILP_print(ilp_program());
        ILP_newline();
        return EXIT_SUCCESS;
}
```

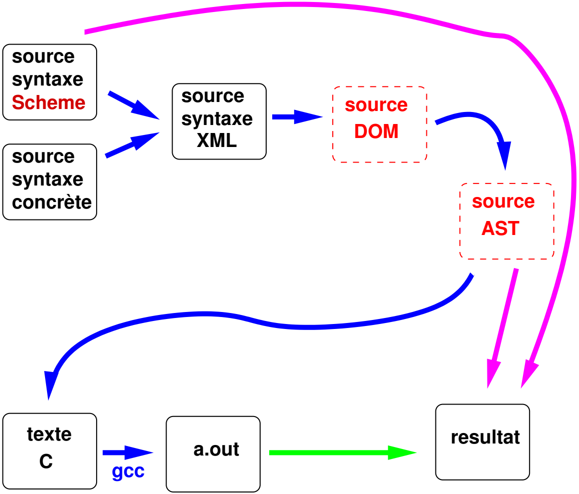
Test : processFile

Ressource: com.paracamplus.ilp1.compiler.test.CompilerTest

```
public void processFile () throws Throwable {

System.err.println("Testing " + file.getAbsolutePath() + " ...");
assertTrue(file.exists());
Input input = new InputFromFile(file);
parser.setInput(input);
File rngFile = new File(rngFileName);
parser.setGrammar(rngFile);
IASTprogram program = parser.getProgram();
IOperatorEnvironment ioe = new OperatorEnvironment();
OperatorStuff.fillUnaryOperators(ioe);
OperatorStuff.fillBinaryOperators(ioe);
IGlobalVariableEnvironment gve =
                                new GlobalVariableEnvironment();
GlobalVariableStuff.fillGlobalVariables(gve);
Compiler compiler = new Compiler(ioe, gve);
String compiled = compiler.compile(program);
File cFile = changeSuffix(file, "c");
```

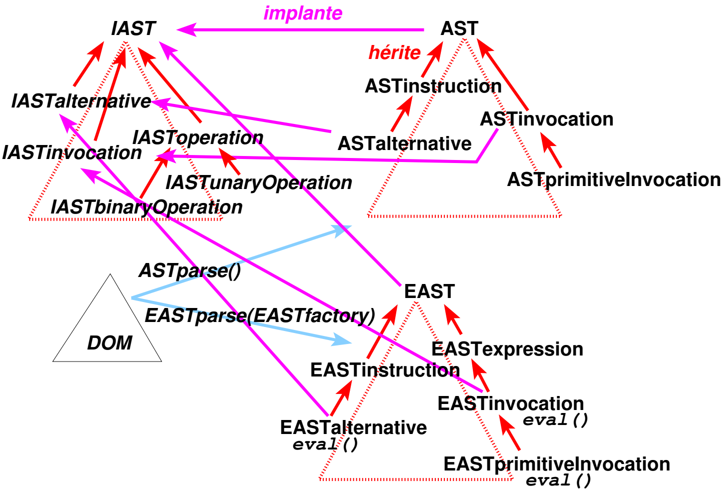
```
String compileProgram = "bash C/compileThenRun.sh +gc "
            + cFile.getAbsolutePath();
ProgramCaller pc = new ProgramCaller(compileProgram);
pc.setVerbose();
pc.run();
assertEquals("Comparing return code", 0, pc.getExitValue()
String executionPrinting = pc.getStdout().trim();
checkPrintingAndResult(executionPrinting);
}
```

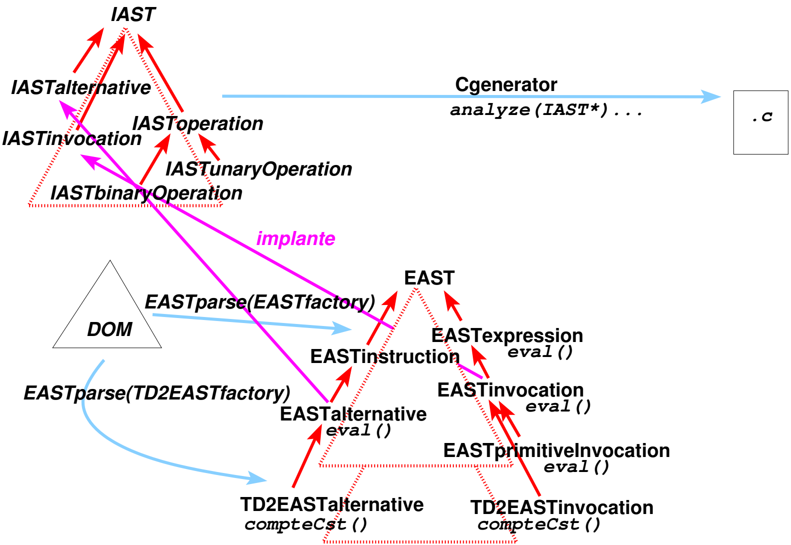
Grandes masses



Récapitulation

- statique/dynamique
- choix de représentation (à l'exécution) des valeurs
- bibliothèque d'exécution
- schema de compilation
- destination


implante
IAST
AST
hérite
ASTinstruction
IASTalternative
ASTinvocation
IASToperation
ASTalternative
IASTinvocation
IASTunaryOperation
ASTprimitiveInvocation
IASTbinaryOperation
ASTparse()
EAST
EASTparse(EASTfactory)
DOM
EASTexpression
EASTinstruction
EASTinvocation
eval()
EASTalternative
eval()
EASTprimitiveInvocation
eval()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eval()
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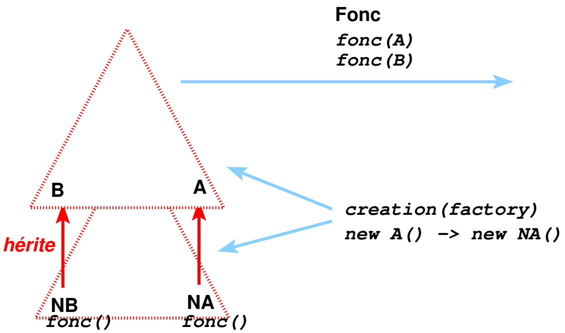
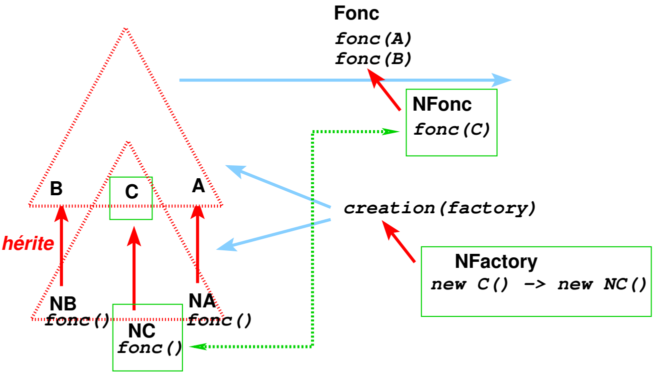
EASTinvocation
eval()
EASTalternative
eval()
EASTprimitiveInvocation
eval()
TD2EASTalternative
compteCst()
TD2EASTinvocation
compteCst()

Extensions

Deux sortes d'évolution :

- introduction de nouveaux noeuds d'AST (NA, NB)
- introduction de nouvelles fonctionnalités (*fonc*)




Fonc
fonc(A)
fonc(B)
NFonc
fonc(C)
B
C
A
hérite
creation(factory)
NFactory
new C() -> new NC()
NB
fonc()
NA
fonc()
NC
fonc()

Un compromis : le visiteurs

```
public interface IASTvisitor
<Result, Data, Anomaly extends Throwable> {
    Result visit(IASTalternative iast, Data data)
        throws Anomaly;
    Result visit(IASTbinaryOperation iast, Data data)
         throws Anomaly;
    Result visit(IASTblock iast, Data data)
        throws Anomaly;
...
    Result visit(IASTinvocation iast, Data data)
         throws Anomaly;
    Result visit(IASToperator iast, Data data)
         throws Anomaly;
}

public interface IASTvisitable {
    <Result, Data, Anomaly extends Throwable>
    Result accept(IASTvisitor<Result, Data, Anomaly> visitor,
                  Data data) throws Anomaly;
}
```

Raffinement, spécialisation (*override*)

```
public class C {
   public void crunch (C c) {
      // utiliser this et c
   }
}
public class Sc extends C {
   @Overriding
   public void crunch (C c) {
      // utiliser this, c et super.crunch()
   }
}
```

Surcharge (*overload*)

Facilité d'écriture !

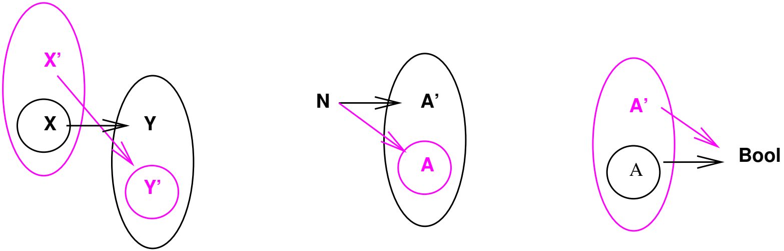
```
public class C {
   public Truc crunch(Integer i) {..}
   public Chose crunch(String d) {..}
   public Muche crunch(Object d) {..}
   void utilisation (Object o) {
      crunch(3); // boxing automatique
      if ( o instanceof Integer ) {
        crunch(o);
}
```

Peut se réécrire **statiquement** en :

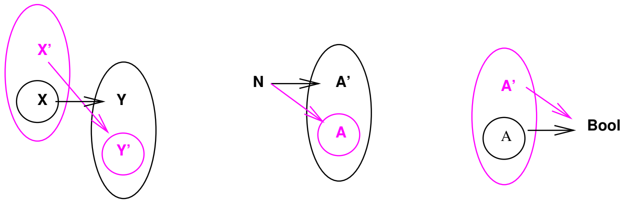
```
public class C {
   public Truc crunch_integer(Integer i) {..}
   public Chose crunch_double(String d) {..}
   public Muche crunch_object(Object d) {..}
   void utilisation (Object o) {
      crunch_integer(new Integer(3));
      if ( o instanceof Integer ) {
        crunch(o); // != crunch_integer(o)
                   // = crunch_object(o)
}
```

Contravariance

A est un sous-type de B si un $a \in A$ peut remplacer un $b \in B$ dans tous ses emplois possibles.
Une fonction $X' \to Y'$ est un sous-type de $X \to Y$ ssi $X \subset X'$ et $Y' \subset Y$.



NB : J'utilise l'inclusion ensembliste comme notation pour le sous-typage.
N est l'ensemble des entiers.



Cas des tableaux : si $A \subset A'$ alors $N \rightarrow A$ sous-type de $N \rightarrow A'$ donc `A[]` sous-type de `A’[]`.

Attention, en Java, le type d’un tableau est statique et ne dépend pas du type réel de ses éléments.

A est un sous-type de B si un $a \in A$ peut remplacer un $b \in B$ **dans tous ses emplois possibles**.

Emplois possibles : A, A.length, instanceof A[], A[i] alors

```
PointColore[] pcs = new PointColore[]{ new PointColore(
assert pcs[0] instanceof Point; // OK
ps[0] = new PointColore();      // OK
Point[] ps = (Point[]) pcs;     // OK
```

Mais pour un tableau, en fait, les emplois sont A, A.length, instanceof A[], A[i] et A[i] = v

```
Point[] ps = new Point[]{ new PointColore() };
assert ps[0] instanceof Point; // OK
ps[0] = new PointColore();      // OK

// PointColore[] pcs = (PointColore[]) ps;   // FAUX!
PointColore[] pcs = new PointColore[ps.length];
for ( int i=0 ; i<pcs.length ; i++ ) {
   pcs[i] = (PointColore) ps[i];
}
ps = (Point[]) pcs;             // OK
ps[0] = new Point(); // ArrayStoreException
```

Génériques

http://java.sun.com/j2se/1.5/pdf/generics-tutorial.pdf

```
public interface List<E, T extends Exception> {
  void add(E x);
  Iterator<E> iterator();
  E getOne() throws T;
}
public interface PointIterator<E extends Point>
extends Iterator<E> {
  boolean isFull();
}
// PointIterator<Color> < Iterator<Color>
// Iterator<Color> < Iterator<?>
```

Généricité

∀ E sous-type de Exception, alors la méthode frobnicate doit prendre une liste de E et rendre une liste de E :

```
public interface Igeneric<E extends Exception> {
    List<E> frobnicate (List<E> es) throws E;
    <T extends E> Collection<T> crunch(List<E> es);
}
```

∀ T sous-type de E, la méthode crunch doit prendre une liste de E et rendre une collection de T.

Généricité suite

```
public class Generic implements Igeneric<IOException> {
    public AbstractList<IOException>
        frobnicate (List<IOException> es)
    throws EOFException { ... }
    public <T extends IOException> Collection<T>
        crunch(List<IOException> es) { ... }
}
```

Sont erronées les méthodes :

```
public Collection<IOException> crunch(List<IOException> es) {
 // The method crunch(List<IOException>) of type Generic
 // has the same erasure as crunch(List<E>) of type
 // IGeneric<E> but does not override it. => The type
 // Generic must implement the inherited abstract method
 // IGeneric<IOException>.crunch(List<IOException>)
public <T extends IOException>
    Collection<IOException> crunch(List<IOException> es) {
 // The return type is incompatible with
 // IGeneric<IOException>.crunch(List<IOException>)
```

Généricité suite

La généricité en Java est implantée à l'exécution par effacement de types. La question `o instanceof List<Point>` n'a donc pas de sens. On peut cependant écrire `o instanceof List<?>`
Il n'est pas non plus possible d'écrire :

```
public void crunch(Set<Integer> si) { ...}
public void crunch(Set<String> ss) { ...}
```