7. Specification of Dynamic Semantics

The **effect of executing a program** is called its dynamic semantics. It can be described by **composing the effects** of executing the elements of the program, according to its **abstract syntax**. For that purpose the **dynamic semantics of executable language constructs** are specified.

Informal specifications are usually formulated in terms of an abstract machine, e. g.

> *Each **variable has a storage cell**, suitable to store values of the type of the variable. An **assignment v := e** is **executed** by the following steps: determine the storage cell of the variable v, **evaluate the expression** e yielding a value x, an storing x in the storage cell of v.*

The effect of common operators (like arithmetic) is usually not further defined (pragmatics).

The effect of an **erroneous program construct is undefined**. An erroneous program is not executable. The language specification often does not explicitly state, what happens if an erroneous program construct is executed, e. g.

> *The **execution of an input statement is undefined** if the next value of the the input is **not a value of the type** of the variable in the statement.*

A **formal calculus** for specification of dynamic semantics is **denotational semantics**.
It **maps language constructs to functions**, which are then **composed** according to the abstract syntax.

Denotational semantics

Formal calculus for specification of dynamic semantics.

The executable constructs of the **abstract syntax are mapped on functions**, thus defining their effect.

For a given structure tree the functions associated to the tree nodes are **composed** yielding a semantic function of the whole program - **statically**!

That calculus allows to

- **prove dynamic properties** of a program formally,
- reason about the **function of the program** - rather than about is operational execution,
- reason about **dynamic properties of language constructs** formally.

A **denotational specification** of dynamic semantics of a programming language consists of:

- specification of **semantic domains**: in imperative languages they model the program state
- a function **E that maps all expression constructs** on semantic functions
- a function **C that maps all statement contructs** on semantic functions

Semantic domains

Semantic domains describe the **domains and ranges of the semantic functions** of a particular language. For an imperative language the central semantic domain describes the **program state**.

Example: semantic domains of a very **simple imperative language**:

State = Memory × Input × Output	program state
Memory = Ident → Value	storage
Input = Value*	the input stream
Output = Value*	the output stream
Value = Numeral | Bool	legal values

Consequences for the language specified using these semantic domains:

- The language can allow **only global variables**, because a 1:1-mapping is assumed between identifiers and storage cells. In general the storage has to be modelled:

  Memory = Ident → (Location → Value)

- **Undefined values** and an **error state** are not modelled; hence, behaviour in **erroneous cases** and **exeption handling** can not be specified with these domains.

Mapping of expressions

Let **`Expr`** be the set of all **constructs of the abstract syntax** that represent expressions, then the function **`E`** maps **`Expr`** on functions which describe **expression evaluation**:

$$\mathbf{E: Expr} \rightarrow \mathbf{(State} \rightarrow \mathbf{Value)}$$

In this case the semantic expression functions **compute a value in a particular state**. **Side-effects** of expression evaluation can not be modelled this way. In that case the evaluation function had to return a potentially changed state:

$$\mathbf{E: Expr} \rightarrow \mathbf{(State} \rightarrow \mathbf{(State} \times \mathbf{Value))}$$

The mapping **`E`** is **defined by enumerating the cases of the abstract syntax** in the form

E[abstract syntax construct **]** state **=** functional expression
E[X] **s** **= F s**

for example:

```
E [e1 + e2] s = (E [e1] s) + (E [e2] s)
...
E [Number] s = Number
E [Ident] (m, i, o) = m Ident
```

the memory map applied to the identifier

Mapping of statements

Let **`Command`** be the set of all **constructs of the abstract syntax** that represent statements, then the function **`C`** maps **`Command`** on functions which describe **statement execution:**

`C: Command` $\rightarrow$ **`(State`** $\rightarrow$ **`State)`**

In this case the semantic statement functions **compute a state transition.**
Jumps and labels in statement execution can not be modelled this way. In that case an additional functional argument would be needed, which models the continuation after execution of the specified construct, **continuation semantics**.

The mapping **`C`** is defined by enumerating the cases of the abstract syntax in the form

`C[` abstract syntax construct**`]`** state **`=`** functional expression
`C[ X]                s    = F s`

for example:

`C [stmt1; stmt2] s = (C [stmt2]` o **`C [stmt1]) s`** function composition
`C [v := e] (m, i, o) = (M [(E [e] (m, i, o)) / v], i, o)`
e is evaluated in the given state and the memory map is changed at the cell of v

```
C [if ex then stmt1 else stmt2] s = E[ex]s -> C[stmt1]s, C[stmt2]s
C [while ex do stmt] s =
  E[ex]s -> (C[while ex do stmt] o C[stmt])s, s
...
```

8. Source-to-source translation

Source-to-source translation:

Translation of a **high-level source language** into a **high-level target language**.

Source-to-source translator:

Specification language (SDL, UML, ...)
Domain specific language (SQL, STK, ...)
high-level programming language

↓ **Analysis**
Transformation

high-level programming language

Compiler:

Programming language

↓ **Analysis**
Transformation

Intermediate language

↓ **Optimization**
Code generation

Machine language

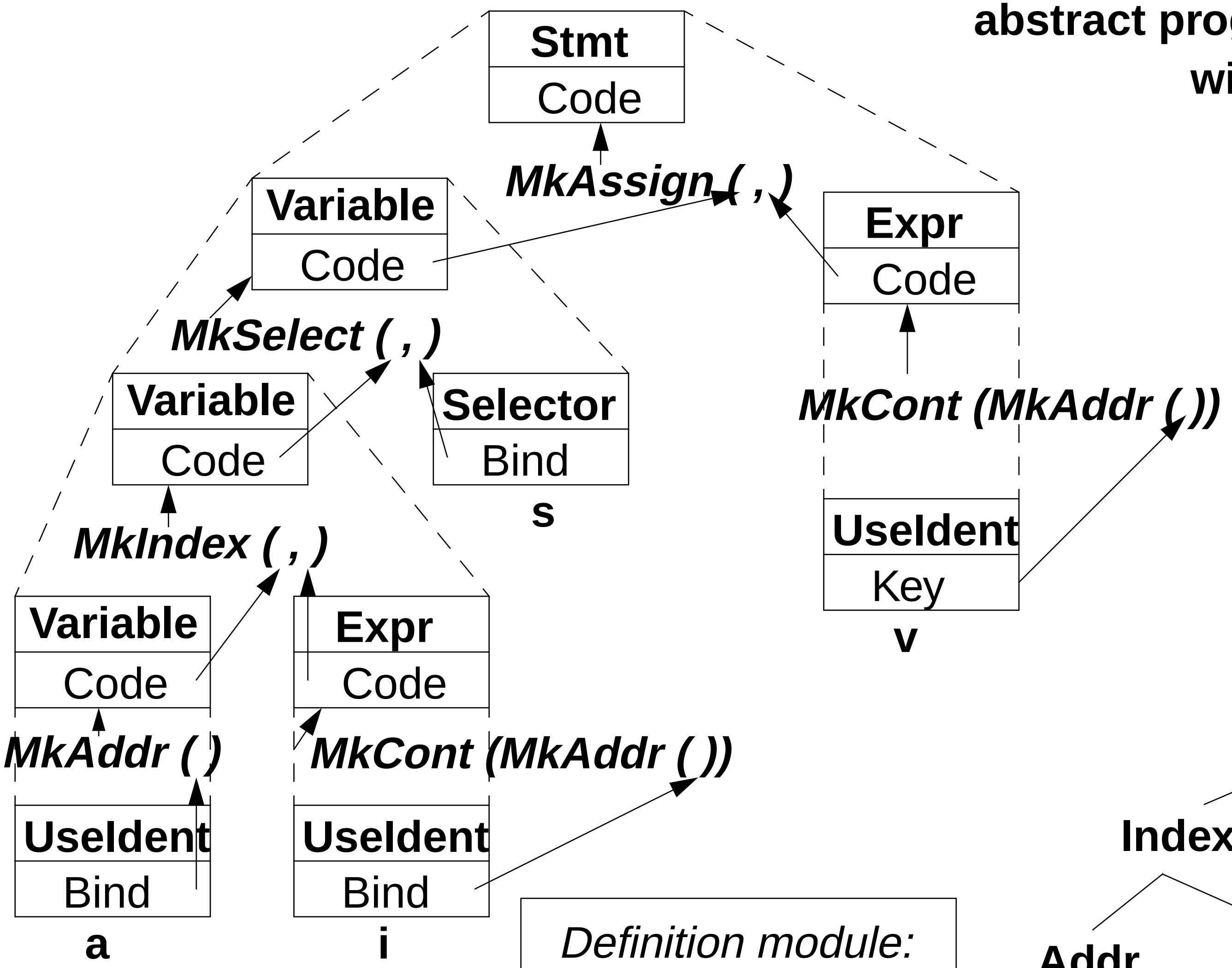
Transformation task:

input: structure tree + properties of constructs (attributes), of entities (def. module)

output: **target tree** (attributes) in textual representation

Example: Target tree construction

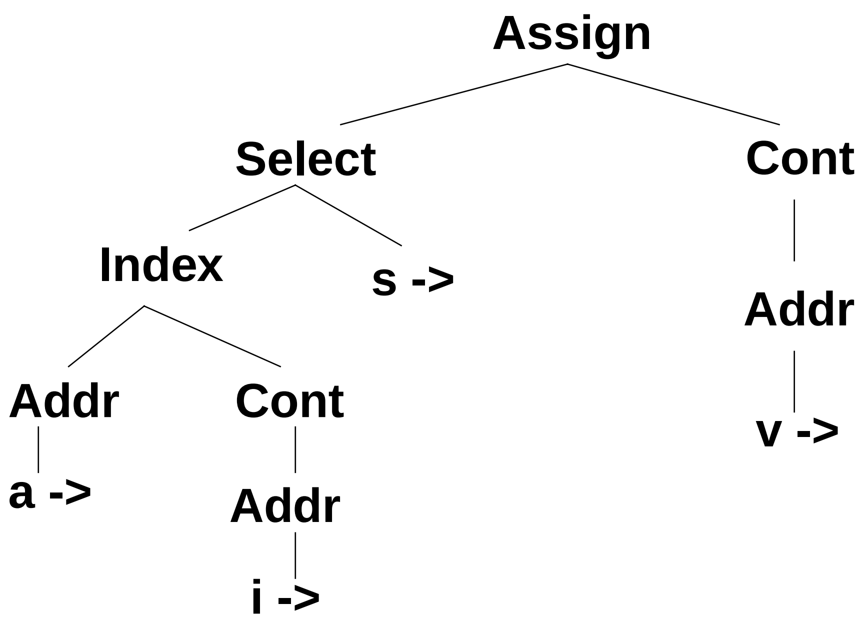
abstract program tree `a[i].s := v;`
with target tree attributes



Definition module:

a -> ...
i -> ...
s -> ...
v -> ...

Target tree:



Attribute grammar for target tree construction

```
RULE: Stmt ::= Variable ':=' Expr            COMPUTE
    Stmt.Code = MkAssign (Variable.Code, Expr.Code);
END;
RULE: Variable ::= Variable '.' Selector     COMPUTE
    Variable[1].Code = MkSelect (Variable[2].Code, Selector.Bind);
END;
RULE: Variable ::= Variable '[' Expr ']'     COMPUTE
    Variable[1].Code = MkIndex (Variable[2].Code, Expr.Code);
END;
RULE: Variable ::= UseIdent                  COMPUTE
    Variable.Code = MkAddr (UseIdent.Bind);
END;
RULE: Expr ::= UseIdent                      COMPUTE
    Expr.Code = MkCont (MkAddr (UseIdent.Bind));
END;
```

Generator for creation of structured target texts

Tool PTG: Pattern-based Text Generator

Creation of structured texts in arbitrary languages. Used as computations in the abstract tree, and also in arbitrary C programs. Principle shown by examples:

1. Specify output pattern with insertion points:

```
ProgramFrame:   $
                "void main () {\n"
                $
                "}\n"

Exit:           "exit (" $ int ");\n"

IOInclude:      "#include <stdio.h>"
```

2. PTG generates a function for each pattern; calls produce target structure:

```
PTGNode a, b, c;
a = PTGIOInclude ();
b = PTGExit (5);
c = PTGProgramFrame (a, b);
```

correspondingly with attribute in the tree

3. Output of the target structure:

`PTGOut (c);` or `PTGOutFile ("Output.c", c);`

PTG Patterns for creation of HTML-Texts

concatenation of texts:

```
      Seq:           $ $
```

large heading:

```
      Heading:       "<H1>" $1 string "</H1>\n"
```

small heading:

```
      Subheading:    "<H3>" $1 string "</H3>\n"
```

paragraph:

```
      Paragraph:     "<P>\n" $1
```

Lists and list elements:

```
      List:          "<UL>\n" $ "</UL>\n"
      Listelement:   "<LI>" $ "</LI>\n"
```

Hyperlink:

```
      Hyperlink:     "<A HREF=\"" $1 string "\">" $2 string "</A>"
```

Text example:

```
<H1>My favorite travel links</H1>
<H3>Table of Contents</H3>
<UL>
<LI> <A HREF="#position_Maps">Maps</A></LI>
<LI> <A HREF="#position_Train">Train</A></LI>
</UL>
```

PTG functions build the target tree (1)

Attributes named Code propagate target sub-trees

Write the target text to a file

```
ATTR Code: PTGNode;

SYMBOL Program COMPUTE

   PTGOutFile
      (CatStrStr (SRCFILE, ".java"),
         PTGFrame
            (CONSTITUENTS Declaration.Code
             WITH (PTGNode, PTGSeq, IDENTICAL, PTGNull),

             CONSTITUENTS Statement.Code SHIELD Statement
             WITH (PTGNode, PTGSeq, IDENTICAL, PTGNull)));

END;
```

PTG pattern with 2 arguments

Access 2 target sub-trees

PTG functions build the target tree (2)

```
RULE: Declaration ::= Type VarNameDefs ';' COMPUTE
   Declaration.Code =
      CONSTITUENTS VarNameDef.Code
      WITH (PTGNode, PTGSeq, IDENTICAL, PTGNull);
END;

SYMBOL VarNameDef COMPUTE
   SYNT.Code =
      IF (EQ (INCLUDING TypedDefinition.Type, intType),
         PTGIntDeclaration (SYNT.NameCode),
      ...
      PTGNULL))));
END;
```

Generate and store target names

```
SYMBOL VarNameDef: NameCode: PTGNode;

SYMBOL VarNameDef COMPUTE
   SYNT.NameCode =
      PTGAsIs
         (StringTable
            (GenerateName (StringTable (TERM))));

   SYNT.GotTgtName =
      ResetTgtName (THIS.Key, SYNT.NameCode);
END;

SYMBOL VarNameUse COMPUTE
   SYNT.Code = GetTgtName (THIS.Key, PTGNULL)
      <- INCLUDING Program.GotTgtName;
END;

SYMBOL Program COMPUTE
   SYNT.GotTgtName =
      CONSTITUENTS VarNameDef.GotTgtName;
END;
```

Create a new name from the source name

Store the name in the definition module

Access the name from the definition module

All names are stored before any is accessed