# 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.

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# 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

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# 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.

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# 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**:

**`E: Expr → (State → 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:

**`E: Expr → (State → (State × 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 → (State → 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
...
```

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# 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

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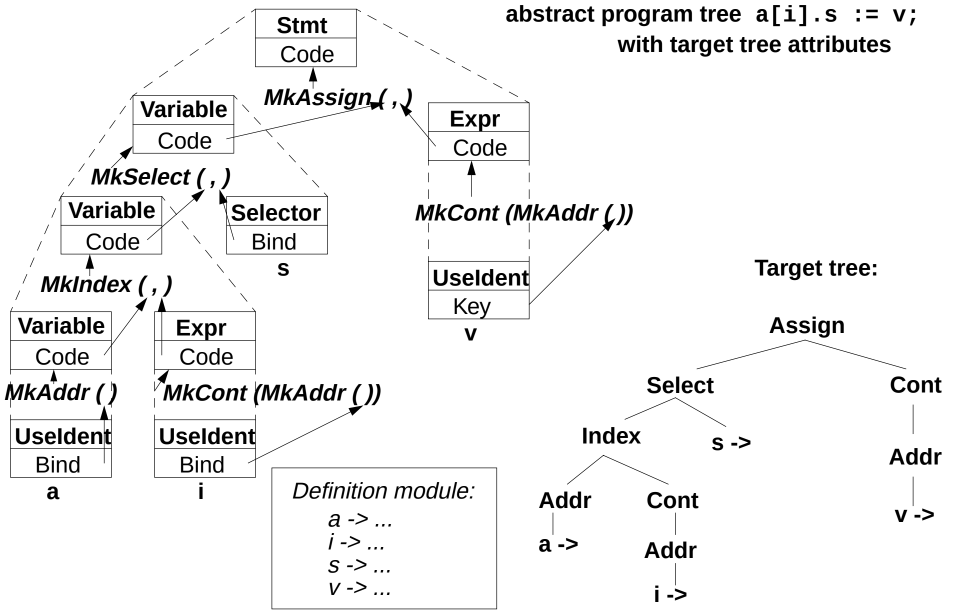
# Example: Target tree construction



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

*Definition module:*
*a -> ...*
*i -> ...*
*s -> ...*
*v -> ...*

---

# 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);`

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# 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

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# 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