DESIGN OF PROGRAMMING LANGUAGES

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Session 1

Definitions

- A **computational model** is collection of values and operations.
- A **computation** is the application of a sequence of operations to values to yield another value.
- A **programme** is a specification of a computation.
- A **programming language** is a notation for writing programmes.

IMPORTANT CALCULATION MODELS

1. Functional Model

Values: functions

Operations: function operations

Example:

```
Sd(xs) = sqrt (v)
  Where
        n= length(xs)
        v= fold(plus , map(sqr , xs) ) /n - sqr(fold(plus , xs) / n)
```

*Pure functional lang: Haskell
*functional langs: ML – Lisp …
*This language is "Declarative".
*Functional and Logical languages are Declarative.

2. Logic Model

Values: facts, definitions of relations

Operations: logical inferences

Example:

1. Human(Socrates)
2. Human(Penelope)
3. Mortal(x) if Human(x)

4. ¬mortal(y)	Assumption
5. x=y	(3),(4) and unification and Modus Tollens
6. ¬human(y)	(3),(4) and unification and Modus Tollens
7. y=Socrates	(1),(5),(6) and unification
8. y=Penelope	(1),(5),(6) and unification

9. Contradiction(¬human(Socrates) and human(Socrates))

*"Prolog" is a logical language or framework.

3. Imperative Model

Values: states

Operations: state transitions

Example:

constant pi = 3.14

input (radius)

circumference := 2 * pi * radius

output(circumference)

*languages: Pascal - C - C++ - Java – Assembly

Summary

COMPUTATIONAL MODEL	VALUE	OPERATION	EXAMPLE
IMPERATIVE	state	State transition	C
FUNCTIONAL	functional	Function application	Haskell
LOGIC	Facts and relations	rules	Prolog

Session 2

SYNTAX

A language: **Syntax**, **Semantics**, **Pragmatics**.

*The amount of expressiveness of a language.

*Chomsky, The linguist said the following

Grammar

A grammar (∑, N, P, S) consists of four parts;

1- ∑ : terminal symbols or alphabet

2- N : nonterminal symbols or syntactic alphabet

3- P : productions or rules

4- S : the start symbol

BNF (Backus-Naur Form):

<declaration>::=**var**<variable list>**:**<type>**;**

*BNF is called a metalanguage, because it defines languages.

Example

var x,y : int ;

Definition

Vocabulary: terminals and nonterminals.

A production **α::= β**

***α** must have at least one nonterminal.

Types of Grammars

Type 0 (Unrestricted grammars):

At least one nonterminal occurs on the left side of a rule.

Example

a<thing>**b** ::= **b**<another thing>

Type 1 (Context-sensitive grammars):

The right side contains no fewer symbols than the left.

Example

<thing>**b** ::= **b**<thing>

rules would be like this:

α <B> ɣ ::= α β ɣ

Type 2 (Context-free grammars):

The left side is a single nonterminal.

Example

<A> ::= β

rules would be like this:

<expression> ::= <expression> **a** <term>

*BNF is a rule for specifying Type 2 languages and programming languages are defined by it.

Type 3 (Regular grammars):

The left side is a single nonterminal.

Example

<A> ::= β

rules would be like this:

<A> ::= **a**

or

<A> ::= **a** <B>

*These languages would be accepted by Finite automata.

Example

A grammar for binary numbers

<binary number> ::= **0**

<binary number> ::= **1**

<binary number> ::= **0** <binary number>

<binary number> ::= **1** <binary number>

or

<binary number> ::= **0**|**1**|**0**<binary number>|**1**<binary number>

Example

A grammar for a natural language

<sentence> ::= <noun phrase><verb phrase> **.**

<noun phrase> ::= <determiner><noun>|<determiner><noun><prepositional phrase>

<verb phrase>::=<verb>|<verb><noun phrase>|<verb><noun phrase><prepositional phrase>

<prepositional phrase>::=<preposition><noun phrase>

<noun>::=**boy | girl | cat | telescope**

<determiner>::=**a | the**

<verb>::=**say | go | shop | saw**

<preposition>::= ***by | with***

*The latter language is Ambiguous.

Example

A context-sensitive grammar

<sentence> ::= **a b c** |**a** <thing> **b c**

<thing> **b** ::= **b** <thing>

<thing> **c** ::= <thing> **b c c**

a <other> ::= **a a** | **a a** <thing>

b <other> ::= <other> **b**

The language would be like this:

$\{a^n\ b^n\ c^n \mid n \in Z^+\}$

Definition

A grammar is **Ambiguous** if some phrases in the language generated by the grammar has two or more distinct derivation trees.

Session 3

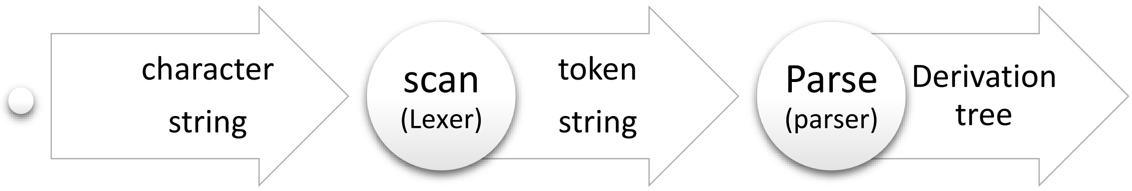
Wren Language

Syntaxes are either:

Lexical syntax → Lexical Analysis (scanning)

or

Phrase-Structure syntax → Syntactic Analysis (Parsing)



Ambiguity

Having more than one derivation tree for a statement in a language.

Example

if exp1 then if exp2 then cmd1 else cmd2

Session 4

static semantic

Example

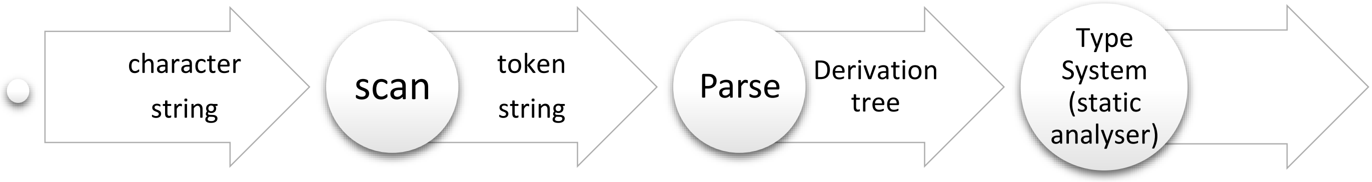
Program illegal **is**
var a : **boolean**;
begin
a := 5
end

There are two ideas about this problem:

It's a **syntactic** problem.

It's a **static semantic** problem.

so we are going to need a **static analyser:**

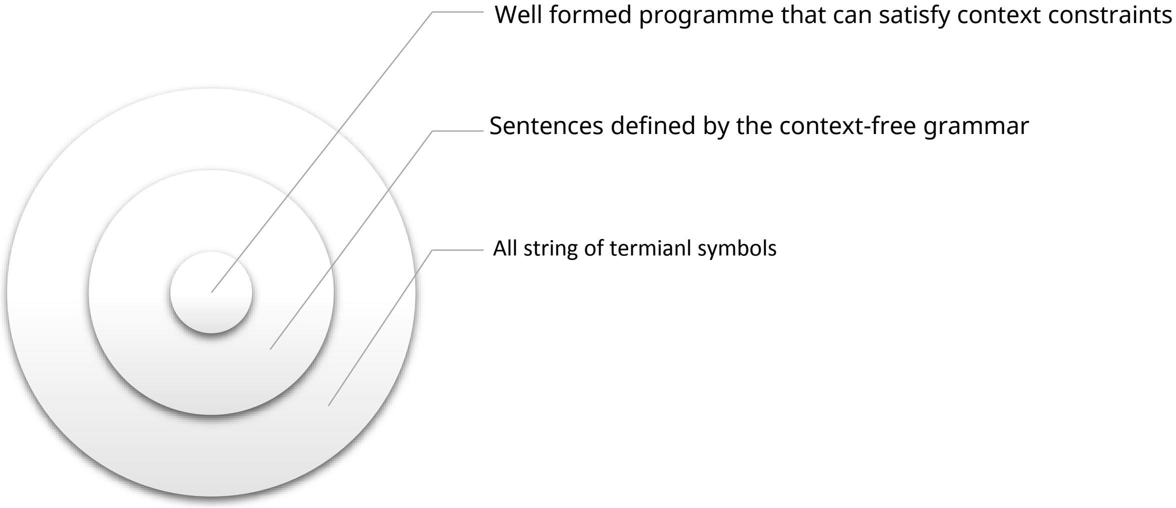


Static semantics cannot be analysed by context free machines.
We do not use a Type 1 (context sensitive) machine because it is much harder to have a context sensitive compiler.

Context constraints

1. All identifiers that appear in a block must be declared in that block
2. No identifier may be declared more than once in a block.
3. An identifier occur in a read command must be an integer variable.

.
.
.



Semantic Errors

Example

1. An attempt is made to divide by zero.
2. A variable that has not been initialised has been accessed.
3. A read command is executed when the input file is empty.
4. type mismatch.

Abstract Syntax

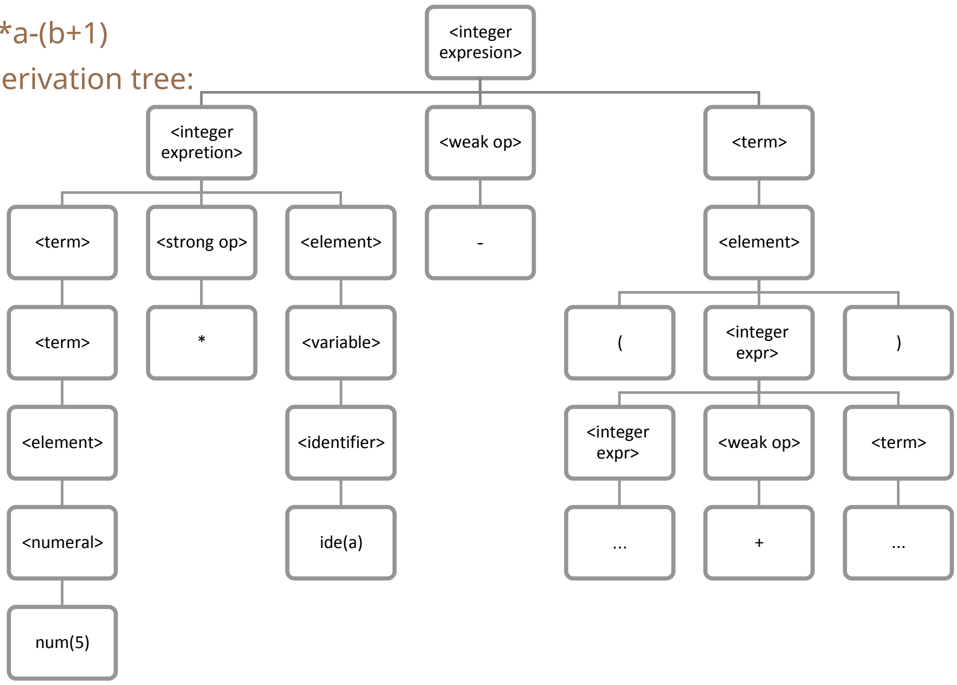
Is a way of fixing the redundancy in a concrete syntax.

***Concrete** is the opposite of Abstract.

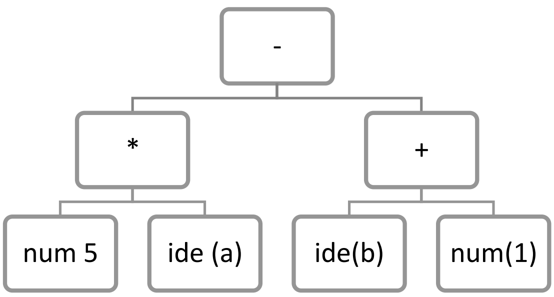
Example

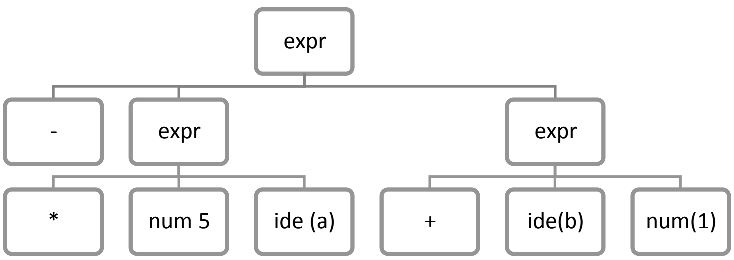
5*a-(b+1)

Derivation tree:



AST : Abstract Syntax Tree





<expression> → … → operations
numerals
identifiers
boolean constants

Syntactic Categories: Expression , Numeral , Identifier

Now we can define an abstract syntax by removing **unit rules** (rules without terminals) unless they have a basic component.

Session 5

Attribute Grammars

(Sebesta book P.134)

Concepts:

- Attribute
- Attribute computation functions (semantic functions)
- Predicate functions (conditions)

To Avoid Static semantic problems, attribute grammars are used.

A(X) : The set of attributes associated with symbol X.

A(X) = S(X) U I(X)

S(X) : synthesised   I(X) : Inherited

$X_0 ::= X_1 \dots X_n$ (a production)

$S(X_0) = f(A(X_1), \dots, A(X_n))$

$i(X_j) = f(A(X_0), \dots, A(X_n)) \rightarrow i(X_j) = f(A(X_0), \dots, A(X_{j-1}))$

$P(A(X_0), \dots, A(X_n))$ or $P(\cup_{i=0}^{n} A(X_i))$ is a predicate over $\cup_{i=0}^{n} A(X_i)$

A Fully attributed tree

Intrinsic attributes are some kind of synthetic Attributes, which are given to leaves of a tree.

Example

<proc_def> ::= **Procedure** <proc_name>[1] <proc_body> **end** <proc_name>[2]

Predicate : <proc_name> [1].string == <proc_name> [2].string

Example

<assign> ::= <var> = <expr>

<expr> ::= <var> + <var> | <var>

<var> ::= A | B | C

actual_type: A synthesised attribute associated with the nonterminals <var> and <expr>

expected_type: An inherited Attribute associated with the nonterminal <expr>

so the attribute grammar would be like this:

<assign> ::= <var> = <expr>

<expr>.expected_type = <var>.actual_type

<expr> ::= <var>[1] + <var>[2]

<expr>.actual_type = if(<var>[1].actual_type = int
and<var>[2].actual_type = int)
then int else real endif

predicate : <expr>.actual_type == <expr>.expected_type

<expr> ::= <var>

<expr>.actual_type=<var>.actual_type

predicate : <expr>.actual_type == <expr>.expected_type

<var> ::= A | B | C

<var>.actual_type = look_up(<var>.string)

Session 6

SEMANTICS

1- Operational Semantics
2- Denotational Semantics (معنا شناسی دلالتی) →John Michel's book (The Bible of Denotational Semantics :)
3- Axiomatic Semantics

1.Operational Semantics

Example

t ::= true | false | if t then t else t | 0 | succ t | pred t | iszero t

Inductive Definitions (judgment of **t term**):

$$\frac{}{\text{true term}} \quad \text{(Axiom)}$$

$$\frac{}{\text{false term}} \quad \text{(Axiom)}$$

$$\frac{t_1 \text{ term} \quad t_2 \text{ term} \quad t_3 \text{ term}}{\text{if } t_1 \text{ then } t_2 \text{ else } t_3 \text{ term}} \quad \text{(proper machine)}$$

v ::= true | false values

Evaluation: (Small-Step)

$$\frac{}{\text{if true then } t_2 \text{ else } t_3 \rightarrow t_2}$$

$$\frac{}{\text{if false then } t_2 \text{ else } t_3 \rightarrow t_3}$$

$$\frac{\text{if } t_1 \rightarrow t_1'}{\text{if } t_1 \text{ then } t_2 \text{ else } t_3 \rightarrow \text{if } t_1' \text{ then } t_2 \text{ else } t_3}$$

Theorem - Determinacy of one-step evaluation

if $t \rightarrow t'$ and $t \rightarrow t''$, then $t' = t''$

Definition

A term **t** is in **normal form** if no evaluation rule applies to it.

Theorem

In our language (the above language) If t is normal form, then t is a value.

Definition

The **Multistep evaluation** relation $\rightarrow^*$ is the reflexive and transitive closure of $\rightarrow$.

if $t \rightarrow t'$, then $t \rightarrow^* t'$

$t \rightarrow^* t$

if $t \rightarrow^* t'$ and $t' \rightarrow^* t''$, the $t \rightarrow^* t''$

Theorem

For every term t, there is some normal form t' such that $t \to^* t'$.

v ::= true | false | nv
nv ::= 0 | succ nv

$$\frac{t_1 \to t_1'}{\text{succ } t_1 \to \text{succ } t_1'}$$

$$\frac{}{\text{pred } 0 \to 0}$$

$$\frac{}{\text{pred(succ } nv_1) \to nv_1}$$

$$\frac{t_1 \to t_1'}{\text{pred } t_1 \to \text{pred } t_1'}$$

$$\frac{}{\text{iszero } 0 \to \text{true}}$$

$$\frac{}{\text{iszero (succ } nv_1) \to \text{false}}$$

$$\frac{t_1 \to t_1'}{\text{iszero } t_1 \to \text{iszero } t_1'}$$

Definition

A closed term is **stuck** if it is normal form but not a value.

*further studies: middle weight Java and its Operational semantics.

Session 7

2. Denotational Semantics

Christopher Strachey and Dana Scott had introduced it back in 1960s.
Denotational Semantics consists of **:**

Object language (programme)
and **Meta language (mathematics)**.

Example

Object language: x :=0; y := 0; while x<=z do (y := y + x; x:= x+1)
Meta language: F(z)=1+2+3+...+z

Compositionality is a feature of this kind of semantics meaning that if elements of two phrases are the same then the phrases are the same.

Example

B≡B' , P≡P' , Q≡Q' → if B then P else Q ≡ if B' then P' else Q'

Example

Denotational semantics for binary numbers:

e::=n|e+e|e-e
n::=b|nb
b::=0|1

*[[e]] = The parse tree of e

E[[e]] is the meaning of e
E[[0]]=$\mathbb{0}$
$\mathbb{0}$ is from the meta language(the mathematical language).
E[[1]]=$\mathbb{1}$
E[[nb]]=E[[n]]$\circledast\mathbb{2}\oplus$E[[b]]
E[[e_1+e_2]]=E[[e_1]]$\oplus$E[[e_2]]

Some arithmetic expressions:

e::= v| n| e+e |e-e
n::= d|nd
d::=0|1|...|9
v::=x|y|z|...

A **programme** is a function from states to states. P: states → states

A **State** is a function from variables to values. S: Variables → values

Now we define E[[e]](S)

E[[x]](S) = S(x)

E[[0]](S) = $\mathbb{0}$

...

E[[9]](S) = $\mathbb{9}$

E[[nd]](S)=E[[n]](S)$\ast\mathbb{10}+$E[[d]](S)

E[[e_1+e_2]](S)=E[[e_1]](S)$+$E[[e_2]](S)

E : Parse tree → (states → $\mathbb{N}$)

E([[e]],S)

E: parse tree → $\mathbb{N}^{\text{states}}$ parse tree→(states → $\mathbb{N}$)

E[[e]](S)

C : Parse tree → (state → state)

*both E and C give us a function from states in return.

A While Language

P::= x:=e|P;P| if e then P else P | while e do P

State = Variables → Values

Command = States → States

modify(s,x,a) = λv ϵ variables [if v=x then a else s(v)] *s(v) is the value of v in the state s

C[[P]](s) is supposed to be a meaning function

C[[x:=e]](s)=modify(s, x, E[[e]](s))

C[[P_1;P_2]](s)=C[[P_2]] (C[[P_1]](s))

C[[if e then P_1 else P_2]](s) = if E[[e]](s) then C[[P_1]](s) else C[[p_2]](s)

C[[while e do P]](s) = if not E[[e]](s) then s else C[[while e do p]](C[[P]](s))

Session 8

Example

if x>y then x:=y else y:=x

s_0(x) =1 , s_0(y)=2
s_1(x) =1 , s_1(y)=1

C[[if x>y then x:=y else y:=x]](s_0) = if E[[x>y]](s_0) then C[[x:=y]](s_0) else C[[y:=x]](s_0)
= C[[y:=x]](s_0)
=modify (s_0, y, E[[x]](s_0))=modify(s_0,y,1)=s_1

Example

P= x:=0; y:=0; while x<=z do (y:=y+x; x:=x+1)

s_0(z) =2
s_1=modify(s_0,x,0)
s_2=modify(s_1,y,0)

C[[P]](s_0)
= C[[while x<=z do (y:=y+x; x:=x+1)]](s_2)
= if not E[[x<=z]](s_2) then s_2 else C[[while x<=z do (y:=y+x; x:=x+1)]](C[[y:=y+x; x:=x+1]](s_2))
= C[[while x<=z do (y:=y+x; x:=x+1)]](s_3)
= ...
=s' which s'(x)=3, s'(y)=3, s'(z)=2

C is a **partial function** meaning that it is undefined for some programmes.

Example

C[[while x=x do x:=x]] (s) = ?
or
C[[while x=y do x:=y]](s) = s if s(x) $\neq$ s(y)
undefined otherwise

Nonstandard Semantics

They are used in **programme analysis** (Data flow analysis, ... , Abstract interpretation).

Abstract interpretation

Example

To check programmes to make sure that every variable is initialised before it is used.

*Methods of programme analysis can only be **conservative** so they wouldn't have a false positive which means they're sound, because of the halting problem being unsolvable.

error   error state
variables →{ init , uninit }
states ={ { error } U { variables →{ init , uninit } } }
C[[P]](s)

E[[e]](s) =err   if e contains any variable y with s(y) = uninit
E[[e]](s) = OK   otherwise

for example
C[[x:=e]](s) = if E[[e]](s)= OK then modify(s, x, init) else error
C[[P1;P2]](s)= if C[[P1]](s) = error then error else C[[P2]](C[[P1]](s))

$s_1 * s_2 = \lambda v \in \text{Variables if } s_1(v)=s_2(v)=\text{init then init else uninit}$

C[[if e then P1 else P2]](s) = if E[[e]](s)=err or C[[P1]](s)=error or C[[P2]](s)=error
then error else C[[P1]](s) * C[[P2]](s)

C[[if 0=1 then x:=0 else x:=1; y:=2]](s_0) = modify(s_0, x, init)

Session 9
Michel's book chapter 4

IMPERATIVE AND DECLARATIVE

There are four kinds of sentences in natural languages:

- Imperative
- Declarative
- Interrogative
- Exclamatory

Programming languages are one of the first two.

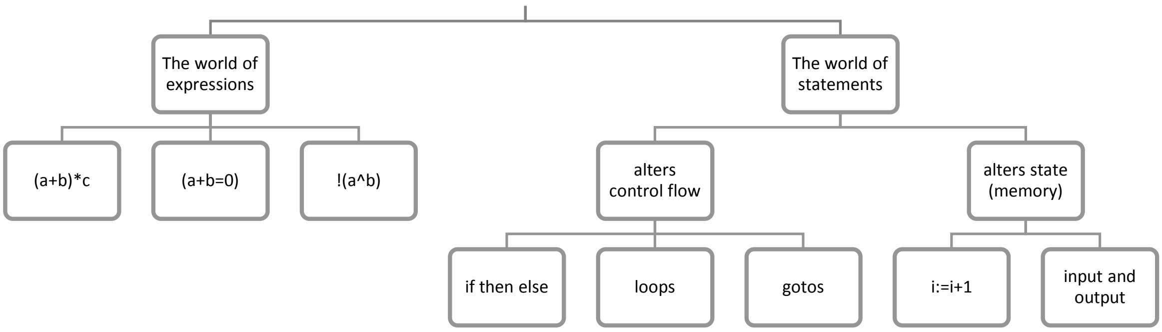
Functional language

A programming language in which most computation is done by evaluation of expressions that contain functions. Like *Lisp, Haskell* and *ML* languages.

Declarative Language Test

Within the scope of specific declaration of $x_1,\dots,x_n$, all occurrences of an expression *e* containing only variables $x_1,\dots,x_n$ have the same value.

The World Of Expressions and The World Of Statements



Example

z:=(z*a*y+b)*(z*a*y+c)
⇨ t:=z*a*y
z:=(t+b)*(t+c)
this is OK in the world of expressions

y:=(z*a*y+b); z:=(z*a*y+c);
⇨ t:=z*a*y
y:=t+b z:=t+c
but this is not OK in the world of statements

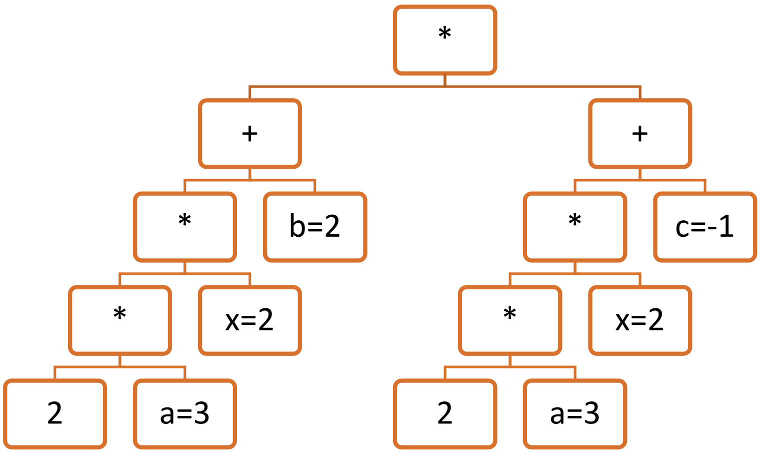
Church-Rosen Property (Confluence)

No matter what the order of decoration, as long as we obey the structure of the tree, we will always get the same.

*a language with this property is called **confluential.**

* It doesn't matter which leaf we start from.

Example



(2ax+b)(2ax+c)

a=3 , b=2 ,c=-1, x=2

In this tree, to decorate (calculate) every node, we need to decorate its children first.

Example

a+2*F(b)

function F(x: integer) L integer
begin
*F:=x*x;*
end

this id pure functional

function F(x: integer) L integer
begin
a:=a+1;
*F:=x*x;*
end

but this is not pure functional

Referential Transparency

Example

"I saw Walter get into his car."
"I saw Walter get into his Ferrari."

This sentence is referentially transparent.

"He was called William Rufus because of his red beard."
"He was called William IV because of his red beard."

This sentence is **not** referentially transparent.

Session 10

LAMBDA-CALCULUS

(Pierce's book – season 5)

Core calculus is the basic language which other languages have been built on it.

Lambda-calculus (λ-calculus) is the core of functional languages. (Introduced by Alonso Church)

Pi-calculus (π-calculus) is the core of concurrent languages.

Object-calculus is the core of object-oriented languages.

Untyped λ-calculus:

t ::= x | λx.t | tt

rules:

- Application associates to left.

  s u t = ((s u) t)

- The bodies of abstractions are taken to extend as far to the right as possible.

  λx. λy.xyx= λx.(λy.(xy)x)

scope

binding: an element can be bound or free and free elements are variables.

for every x , x>y. "y" is a variable and "for every" is a binder

in λ-calculus **λ** is the **binder**.

Example

in λz.λx.λy.x(yz) there is no variable because all of the elements have a binder.

this term is closed.

Closed terms are also called combinatory.

The most famous closed term is the identity function: id=λx.x

Operational Semantics

(λx.t)t' → [x↦t']t (beta-reduction)

or

[t'/x] t

Example

(λx.x)y → y

(λx.x(λx.x))(ur)→(ur)(λx.x)

redex = reducible expression : (λx.t)t'

Evaluate Strategies

Consider this term:

$(\lambda x.x)((\lambda x.x)(\lambda z.(\lambda x.x)z))$

or $\quad id\ (\ id\ (\lambda z.id\ z))$

1. Full beta-reduction

$$
\begin{aligned}
id\ (\ id\ (\lambda z.id\ z)) &\to id\ (\ id\ (\lambda z.z)) \\
&\to id\ (\lambda z.z)) \\
&\to \lambda z.z \\
&\not\to
\end{aligned}
$$

2. Normal order

Starting from the outmost.

$$
\begin{aligned}
id\ (\ id\ (\lambda z.id\ z)) &\to id\ (\lambda z.id\ z) \\
&\to \lambda z.id\ z \\
&\to \lambda z.z \\
&\not\to
\end{aligned}
$$

3. Call by name (non-strict or lazy)

Starting from the outmost.

No reductions inside abstractions.

$$
\begin{aligned}
id\ (\ id\ (\lambda z.id\ z)) &\to id\ (\lambda z.id\ z) \\
&\to \lambda z.id\ z \\
&\not\to
\end{aligned}
$$

4. Call by value (strict)

Starting from the outmost.

No reductions inside abstractions.

Reduction can only be applied when the argument is a value (a λ abstraction).

$$
\begin{aligned}
id\ (\ id\ (\lambda z.id\ z)) &\to id\ (\lambda z.id\ z) \\
&\to \lambda z.id\ z \\
&\not\to
\end{aligned}
$$

Session 11

Programming in λ

+ : R*R → R
+(2,3)=5

Currying:

+ : R → R^R a function that gives back another function
(+(2))(3)=5 +(2) is a function that gets 3 as an argument.

Church Boolean

tru = λt.λf.t tru v w =v
fls = λt.λf.f fls v w =w

we need to have a *test* like this:

test b v w = v b is tru
w b is fls

so the definition of *test* would be like:

test = λl.λm.λn.lmn

now if we give true v w to *test*:

test true v w →(λm.λn.tru m n) v w
→(λn.tru v n) w
→(tru v w)
→(λt.λf.t) v w
→(λf.v) w
→v

and = λb.λc. b c fls
and tru tru = tru tru fls = tru
or= λb.λc. b tru c
or fls tru = fls tru tru= tru
neg=λb. b fls tru
pair = λf.λs.λb. b f s
fst=λp.p tru
scd=λp. p fls
fst(pair v w)=fst(λb. b v w) = (λp. p true) (λb. b v w)= tru v w = v

Church Numerals

$C_0 = \lambda s.\lambda z.z$
$C_1 = \lambda s.\lambda z.sz$
$C_2 = \lambda s.\lambda z.s(sz)$
$C_3 = \lambda s.\lambda z.s(s(sz))$

scc = λn.λs.λz.s(nsz) successor
scc $C_n = \lambda s.\lambda z.s(s(s\ldots(sz)))\ldots)) = C_{n+1}$
plus = λm.λn.λs.λz.ms(nsz)
times = λm.λn.m(plus n)C_0
iszero = λm.m (λx.fls) tru

zz= pair C_0 C_0
ss= λ_p.pair (snd p) (plus C_1 (snd p))
prd = λm. fst (m ss zz) predecessor

Session 12

Recursion

Fixed Point

f: A→A

Its Fixed point is *xϵA : f(x)=x*

*if x is a fixed point in f then, f(f(f(.....f(x)...)=x

Factorial is:

f(0)=1

*f(n+1) = (n+1) * f(n)*

or

$$f(n) = \begin{cases} 1 & if\ n = 0 \\ n \times f(n-1) & otherwise \end{cases}$$

or

$$f:\ n \mapsto \begin{cases} 1 & if\ n = 0 \\ n \times f(n-1) & otherwise \end{cases}$$

Let's define the functional F(f) = f':

$$f':\ n \mapsto \begin{cases} 1 & if\ n = 0 \\ n \times f(n-1) & otherwise \end{cases}$$

The only fixed point of F is the factorial function.

Call-by-name y combinator (or fixed point combinator)

Now we need a combinator fix: F →the fixed point of F

y = λh.(λx.h(xx)) (λx.h(xx)) this is introduced by Church

Example

yF = (λx.F(xx)) (λx.F(xx)) = F((λx.F(xx)) (λx.F(xx))) = F (yF)

so yF is the fixed point of F

Now for the factorial:

fct = λf.λn. if n=0 then 1 else times n f(n-1)

factorial = y fct meaning the fixed point of fct

Example

y fct 2 = fct (y fct) 2
= (λf.λn. if n=0 then 1 else times n f(n-1)) (y fct) 2
= (λn. if n=0 then 1 else n * (y fct) (n-1))2
= if 2=0 then 1 else 2 * (y fct) (2-1)
= 2 * (y fct) (1)
= ...

Call-by-value Z combinator

Z= λh. (λx.h (λy.xxy))(λx.h (λy.xxy)) this is introduced by Gordon Plotkin

which ZF = F(ZF) (to prove this we need to accept λx.mx=m which is called Etha-equivalence.)

Session 13

SOME PROGRAMMING LANGUAGES

Lisp

Abbreviation of "List Processor"
Developed in MIT at late 50s (by John McCarthy's team)
Motivating application: for symbolic computations and exploratory programming.

Example

Integ x^2 dx > x^3/+C
2x^2+x^3 > x^2 (2+x)

Some products:

- emacs
- gtk

Some developments and branches:

- Maclisp (MIT 1960s)
- Scheme (MIT 1970s)
- Common Lisp

Lisp project:

- Motivating application
- Abstract machine (IBM 704)

*concrete ←→ abstract : concrete programme are less portable and abstract ones are less efficient.

- Theoretical foundation

An Article to read:
Recursive functions of symbolic expressions and their computation by machine.
CACM, 3(4), 184-195 (1960)

Historical Lisp structure

Prefix

(+ 1 2 3 4) → 1+2+3+4

Atom

<atom> ::= <symbol> | <number>
<smbl> ::= <char> | <smbl> <char> | <smbl> <digit>
<num> ::= <digit> | <num> <digit>

S-expressions and Lists

dotted pair : a.a
<sexp> ::=<atom> | (<sexp>.<sexp>)

Functions and special forms

cons, car , cdr , eq , atom

cond, lambda, define, quote, eval

+, - , *

Until the above section Lisp is pure functional
here are some functions that make Lisp inpure.

rplaca, rplacd, set, setq

* T true
nil false

Examples

(quote cons)	→ Makes an atom "cons"
(cons a b)	→ A pair containing the values of **a** and **b**
(cons (quote a)(quote b))	→ A pair containing the atom "a" and "b"
'(+ 1 2) or (quote (+ 1 2))	→ the list (+ 1 2)
(+ 1 2)	→ 3

Examples

A function to find something in a list

```
 (define  find (lambda(x y)
        ( cond  ( ( equal y nil ) nil )
                ( ( equal x (car y) ) x )
                ( true ( find x (cdr y ) ) )
        )
))
```

now to use it we can say:

(find 'apple '(pear peach apple banana fig))