Declarative Computation Model

Kernel language semantics revisited (VRH 2.4.5)
From kernel to practical language (VRH 2.6)
Exceptions (VRH 2.7)

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Sequential declarative computation model

- The kernel language semantics revisited.
  - Suspendable statements:
    - if,
    - case,
    - procedure application.
  - Procedure values
  - Procedure introduction
  - Procedure application.

Conditional

- The semantic statement is

  (if $\langle x \rangle$ then $\langle s_1 \rangle$ else $\langle s_2 \rangle$ end , E)

- If the activation condition ($E(\langle x \rangle)$ is determined) is true:
  - If $E(\langle x \rangle)$ is not Boolean (true, false), raise an error
  - $E(\langle x \rangle)$ is true, push ($\langle s_1 \rangle$, E) on the stack
  - $E(\langle x \rangle)$ is false, push ($\langle s_2 \rangle$, E) on the stack
- If the activation condition ($E(\langle x \rangle)$ is determined) is false:
  - Suspend

Case statement

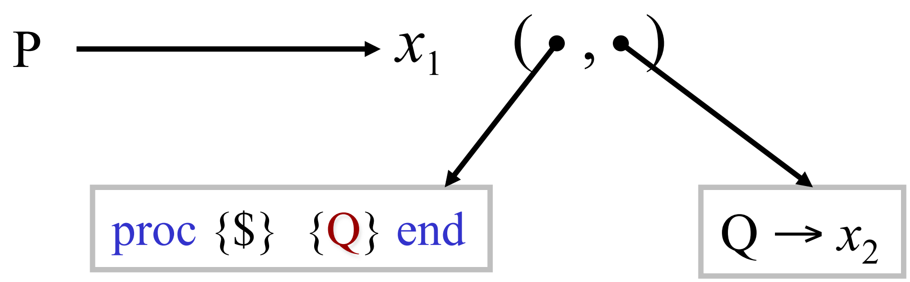
- The semantic statement is
  (case $\langle x \rangle$ of $\langle l \rangle$ $(\langle f_1 \rangle : \langle x_1 \rangle \ldots \langle f_n \rangle : \langle x_n \rangle)$
  then $\langle s_1 \rangle$
  else $\langle s_2 \rangle$ end , E)
- If the activation condition ($E(\langle x \rangle)$ is determined) is true:
  - If $E(\langle x \rangle)$ is a record, the label of $E(\langle x \rangle)$ is $\langle l \rangle$ and its arity is $[\langle f_1 \rangle \ \ldots \ \langle f_n \rangle]$, and $\langle x_1 \rangle \ldots \langle x_n \rangle$ are independent:
    push (local $\langle x_1 \rangle = \langle x \rangle.\ \langle f_1 \rangle \ldots \langle x_n \rangle = \langle x \rangle.\ \langle f_n \rangle$ in $\langle s_1 \rangle$ end, E)
    on the stack
  - Otherwise, push ($\langle s_2 \rangle$, E) on the stack
- If the activation condition ($E(\langle x \rangle)$ is determined) is false:
  - Suspend

Procedure values

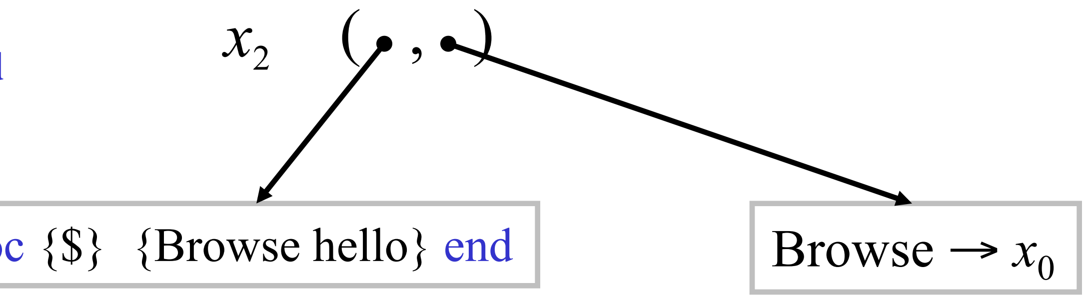
- Constructing a procedure value in the store is not simple because a procedure may have external references

```
local P Q in
   Q = proc {$} {Browse hello} end
   P = proc {$}  {Q} end
   local Q in
         Q = proc {$} {Browse hi} end
         {P}
   end
end
```

Procedure values (2)




```
local P Q in
    Q = proc {$} {Browse hello} end
    P = proc {$}  {Q} end
    local Q in
        Q = proc {$} {Browse hi} end
        {P}
    end
end
```



Procedure values (3)

- The semantic statement is
  $(\langle x \rangle = \text{proc}\ \{\$\ \langle y_1 \rangle \ldots \langle y_n \rangle\}\ \langle s \rangle\ \text{end}, E)$
- $\langle y_1 \rangle \ldots \langle y_n \rangle$ are the (*formal*) parameters of the procedure
- Other free identifiers in $\langle s \rangle$ are called *external references* $\langle z_1 \rangle \ldots \langle z_k \rangle$
- These are defined by the environment E where the procedure is declared (lexical scoping)
- The contextual environment of the procedure CE is $E|_{\{\langle z_1 \rangle \ldots \langle z_k \rangle\}}$
- When the procedure is called CE is used to construct the environment for execution of $\langle s \rangle$

(proc $\{\$\ \langle y_1 \rangle \ldots \langle y_n \rangle\ \}$
$\langle s \rangle$
end ,
CE)

Procedure introduction

- The semantic statement is

  $(\langle x\rangle = \texttt{proc}\ \{\$\ \langle y_1\rangle \ldots \langle y_n\rangle\}\ \langle s\rangle\ \texttt{end}, E)$

- Create a contextual environment:

  $CE = E\,|_{\{\langle z_1\rangle \ldots \langle z_k\rangle\}}$ where $\langle z_1\rangle \ldots \langle z_k\rangle$ are external references in $\langle s\rangle$.

- Create a new procedure value of the form: $(\texttt{proc}\ \{\$\ \langle y_1\rangle \ldots \langle y_n\rangle\}\ \langle s\rangle\ \texttt{end}, CE)$, refer to it by the variable x_P
- Bind the store variable $E(\langle x\rangle)$ to x_P
- Continue to next execution step

Procedure application

- The semantic statement is
  $(\{ \langle x \rangle \langle y_1 \rangle \dots \langle y_n \rangle \} , E)$
- If the activation condition ($E(\langle x \rangle)$ is determined) is true:
  - If $E(\langle x \rangle)$ is not a procedure value, or it is a procedure with arity that is not equal to n, raise an error
  - If $E(\langle x \rangle)$ is (proc {$ $\langle z_1 \rangle \dots \langle z_n \rangle$} $\langle s \rangle$ end, CE) ,
    push
    $(\langle s \rangle , CE + \{\langle z_1 \rangle \rightarrow E(\langle y_1 \rangle) \dots \langle z_n \rangle \rightarrow E(\langle y_n \rangle)\})$
    on the stack
- If the activation condition ($E(\langle x \rangle)$ is determined) is false:
  - Suspend

Execution examples

```
              local Max C in
                 proc {Max X Y Z}
⟨s⟩1   ⟨s⟩2      ⟨s⟩3  if X >= Y then Z=X else Z=Y end
                 end
                 {Max 3 5 C}
              end
```

Execution examples (2)

$$\langle s \rangle_1 \begin{cases} \text{local Max C in} \\ \langle s \rangle_2 \begin{cases} \text{proc \{Max X Y Z\}} \\ \quad \langle s \rangle_3 \quad \text{if X >= Y then Z=X else Z=Y end} \\ \text{end} \\ \langle s \rangle_4 \ \text{\{Max 3 5 C\}} \end{cases} \\ \text{end} \end{cases}$$

- Initial state $([(\langle s \rangle_1, \varnothing)], \varnothing)$
- After local Max C in …
  $([(\langle s \rangle_2, \ \{\text{Max} \rightarrow m, \text{C} \rightarrow c\})], \{m, c\})$
- After Max binding
  $([(\langle s \rangle_4, \ \{\text{Max} \rightarrow m, \text{C} \rightarrow c\})],$
  $\{m = (\text{proc}\{\$ \text{ X Y Z}\} \ \langle s \rangle_3 \ \text{end} \ , \varnothing) \ , c\} \ )$

Execution examples (3)

$$\langle s\rangle_1 \begin{cases} \text{local Max C in} \\ \quad \langle s\rangle_2 \begin{cases} \text{proc \{Max X Y Z\}} \\ \quad \langle s\rangle_3 \ \text{if X >= Y then Z=X else Z=Y end} \\ \text{end} \\ \langle s\rangle_4 \ \text{\{Max 3 5 C\}} \end{cases} \\ \text{end} \end{cases}$$

- After Max binding
  $([(\langle s\rangle_4, \ \{\text{Max} \rightarrow m, \text{C} \rightarrow c\})],$
  $\{m = (\text{proc}\{\$ \text{ X Y Z}\} \ \langle s\rangle_3 \ \text{end} , \varnothing) , c\} \ )$
- After procedure call
  $([(\langle s\rangle_3, \ \{\text{X} \rightarrow t_1, \text{Y} \rightarrow t_2, \text{Z} \rightarrow c\})],$
  $\{m = (\text{proc}\{\$ \text{ X Y Z}\} \ \langle s\rangle_3 \ \text{end} , \varnothing) , t_1\text{=}3, t_2\text{=}5, \text{c}\} \ )$

Execution examples (4)

$$\langle s\rangle_1 \begin{cases} \text{local Max C in} \\ \quad \langle s\rangle_2 \begin{cases} \text{proc \{Max X Y Z\}} \\ \quad \langle s\rangle_3 \;\; \text{if X >= Y then Z=X else Z=Y end} \\ \text{end} \\ \langle s\rangle_4 \; \text{\{Max 3 5 C\}} \end{cases} \\ \text{end} \end{cases}$$

- After procedure call
  $([(\langle s\rangle_3, \; \{X \rightarrow t_1, Y \rightarrow t_2, Z \rightarrow c\})],$
  $\{m = (\text{proc}\{\$ \text{ X Y Z}\} \langle s\rangle_3 \text{ end} , \emptyset) , t_1{=}3, t_2{=}5, c\})$
- After T = (X>=Y)
  $([(\langle s\rangle_3, \; \{X \rightarrow t_1, Y \rightarrow t_2, Z \rightarrow c, T \rightarrow t\})],$
  $\{m = (\text{proc}\{\$ \text{ X Y Z}\} \langle s\rangle_3 \text{ end} , \emptyset) , t_1{=}3, t_2{=}5, c, t{=}\text{false}\})$
- $([(Z{=}Y , \; \{X \rightarrow t_1, Y \rightarrow t_2, Z \rightarrow c, T \rightarrow t\})],$
  $\{m = (\text{proc}\{\$ \text{ X Y Z}\} \langle s\rangle_3 \text{ end} , \emptyset) , t_1{=}3, t_2{=}5, c, t{=}\text{false}\})$

Execution examples (5)

$\langle s \rangle_1$ $\langle s \rangle_2$

```
local Max C in
   proc {Max X Y Z}
   ⟨s⟩3  if X >= Y then Z=X else Z=Y end
   end
⟨s⟩4 {Max 3 5 C}
end
```

- $([(Z{=}Y\ ,\ \{X \rightarrow t_1, Y \rightarrow t_2, Z \rightarrow c, T \rightarrow t\})\ ],$
  $\{m = (\textsf{proc}\{\$\ X\ Y\ Z\}\ \langle s \rangle_3\ \textsf{end}\ ,\ \varnothing)\ ,\ t_1{=}3,\ t_2{=}5,\ c,\ t{=}\text{false}\}\ )$
- $(\ [\ ],$
  $\{m = (\textsf{proc}\{\$\ X\ Y\ Z\}\ \langle s \rangle_3\ \textsf{end}\ ,\ \varnothing)\ ,\ t_1{=}3,\ t_2{=}5,\ c{=}5,\ t{=}\text{false}\}\ )$

Procedures with external references

$$\langle s \rangle_1 \begin{cases} \texttt{local LB Y C in} \\ \langle s \rangle_2 \begin{cases} \texttt{Y = 5} \\ \texttt{proc \{LB X Z\}} \\ \quad \langle s \rangle_3 \; \texttt{if X >= Y then Z=X else Z=Y end} \\ \texttt{end} \\ \texttt{\{LB 3 C\}} \end{cases} \\ \texttt{end} \end{cases}$$

Procedures with external references

$\langle s \rangle_1$ $\langle s \rangle_2$ $\langle s \rangle_3$

```
local LB Y C in
   Y = 5
   proc {LB X Z}
      if X >= Y then Z=X else Z=Y end
   end
   {LB 3  C}
end
```

- The procedure value of LB is
- (proc{\$ X Z} $\langle s \rangle_3$ end , {Y $\rightarrow$ y})
- The store is $\{y = 5, \ldots\}$

Procedures with external references

```
                 local LB Y C in
                   Y = 5
⟨s⟩1   ⟨s⟩2         proc {LB X Z}
                     ⟨s⟩3   if X >= Y then Z=X else Z=Y end
                    end
                    {LB 3 C}
                 end
```

- The procedure value of LB is
- (proc{\$ X Z} $\langle s \rangle_3$ end , {Y $\rightarrow$ y})
- The store is $\{y = 5, \ldots\}$
- STACK: [({LB T C} , {Y $\rightarrow$ y , LB $\rightarrow$ lb, C $\rightarrow$ c, T $\rightarrow$ t})]
- STORE: {$y = 5$, lb = (proc{\$ X Z} $\langle s \rangle_3$ end , {Y $\rightarrow$ y}) , $t = 3$, c}

Procedures with external references

$\langle s \rangle_1$ $\langle s \rangle_2$ $\langle s \rangle_3$

```
local LB Y C in
   Y = 5
   proc {LB X Z}
      if X >= Y then Z=X else Z=Y end
   end
   {LB 3 C}
end
```

- STACK: $[(\{LB\ T\ C\},\ \{Y \rightarrow y,\ LB \rightarrow lb,\ C \rightarrow c,\ T \rightarrow t\})]$
- STORE: $\{y = 5,\ lb = (\text{proc}\{\$\ X\ Z\}\ \langle s \rangle_3\ \text{end},\ \{Y \rightarrow y\}),\ t = 3,\ c\}$
- STACK: $[(\langle s \rangle_3,\ \{Y \rightarrow y,\ X \rightarrow t,\ Z \rightarrow c\})]$
- STORE: $\{y = 5,\ lb = (\text{proc}\{\$\ X\ Z\}\ \langle s \rangle_3\ \text{end},\ \{Y \rightarrow y\}),\ t = 3,\ c\}$

Procedures with external references

$$\langle s\rangle_1 \begin{cases} \textbf{local}\ \text{LB Y C}\ \textbf{in} \\ \quad \langle s\rangle_2 \begin{cases} \text{Y = 5} \\ \textbf{proc}\ \{\text{LB X Z}\} \\ \quad \langle s\rangle_3 \quad \textbf{if}\ \text{X >= Y}\ \textbf{then}\ \text{Z=X}\ \textbf{else}\ \text{Z=Y}\ \textbf{end} \\ \textbf{end} \\ \{\text{LB 3 C}\} \end{cases} \\ \textbf{end} \end{cases}$$

- STACK: $[(\langle s\rangle_3 ,\ \{\mathsf{Y} \rightarrow y ,\ \mathsf{X} \rightarrow t ,\ \mathsf{Z} \rightarrow c\})\ ]$
- STORE: $\{y = 5,\ lb = (\mathsf{proc}\{\$\ \mathrm{X}\ \mathrm{Z}\}\ \langle s\rangle_3\ \mathsf{end} ,\ \{\mathsf{Y} \rightarrow y\}) ,\ t = 3,\ c\}$
- STACK: $[(\mathrm{Z{=}Y} ,\ \{\mathsf{Y} \rightarrow y ,\ \mathsf{X} \rightarrow t ,\ \mathsf{Z} \rightarrow c\})\ ]$
- STORE: $\{y = 5,\ lb = (\mathsf{proc}\{\$\ \mathrm{X}\ \mathrm{Z}\}\ \langle s\rangle_3\ \mathsf{end} ,\ \{\mathsf{Y} \rightarrow y\}) ,\ t = 3,\ c\}$
- STACK: [ ]
- STORE: $\{y = 5,\ lb = (\mathsf{proc}\{\$\ \mathrm{X}\ \mathrm{Z}\}\ \langle s\rangle_3\ \mathsf{end} ,\ \{\mathsf{Y} \rightarrow y\}) ,\ t = 3,\ c\ = 5\}$

From the kernel language to a practical language

- Interactive interface
  - the declare statement and the global environment
- Extend kernel syntax to give a full, practical syntax
  - nesting of partial values
  - implicit variable initialization
  - expressions
  - nesting the if and case statements
  - andthen and orelse operations
- Linguistic abstraction
  - Functions
- Exceptions

The interactive interface (declare)

- The interactive interface is a program that has a single global environment

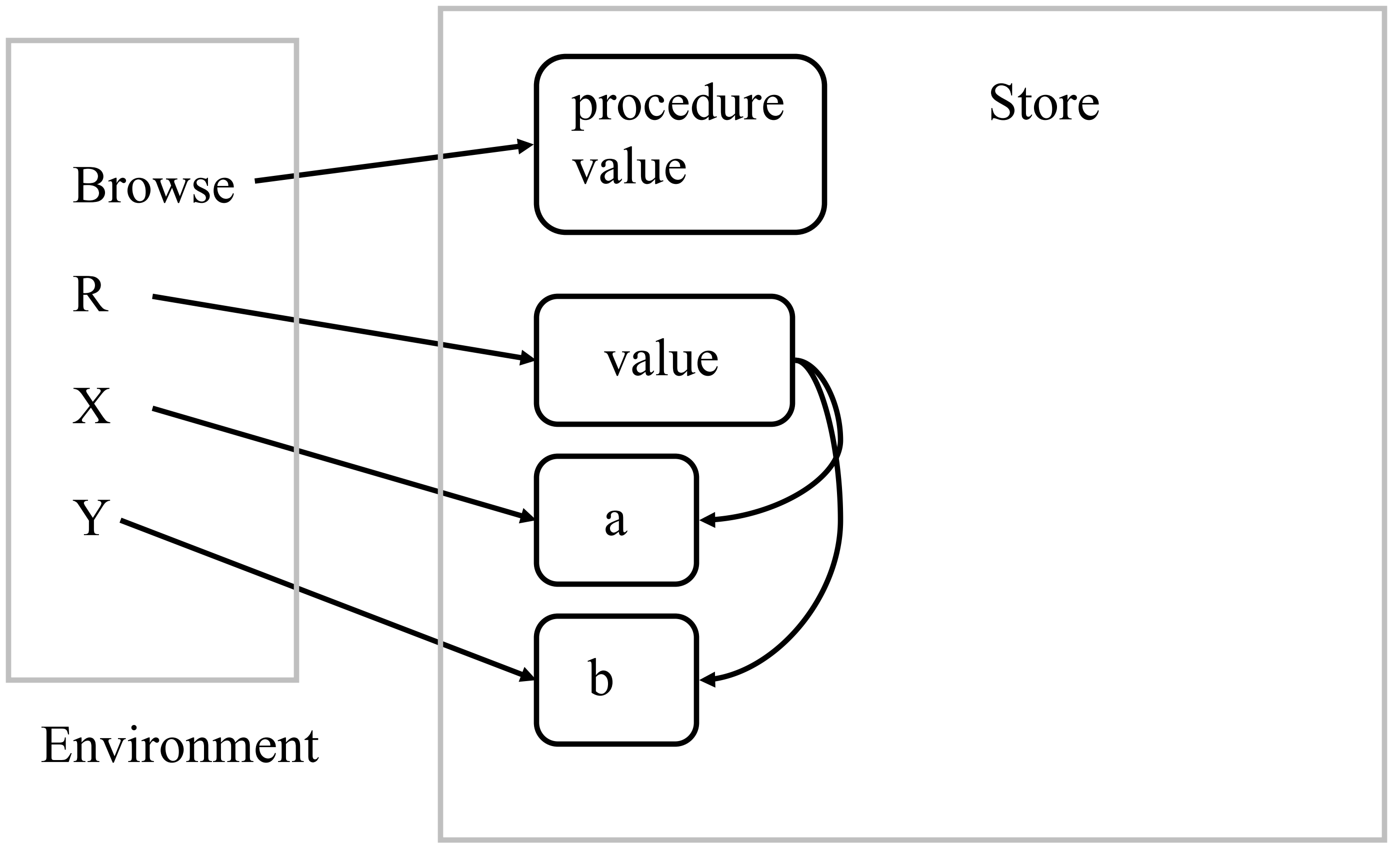
```
declare X Y
```

- Augments (and overrides) the environment with new mappings for X and Y

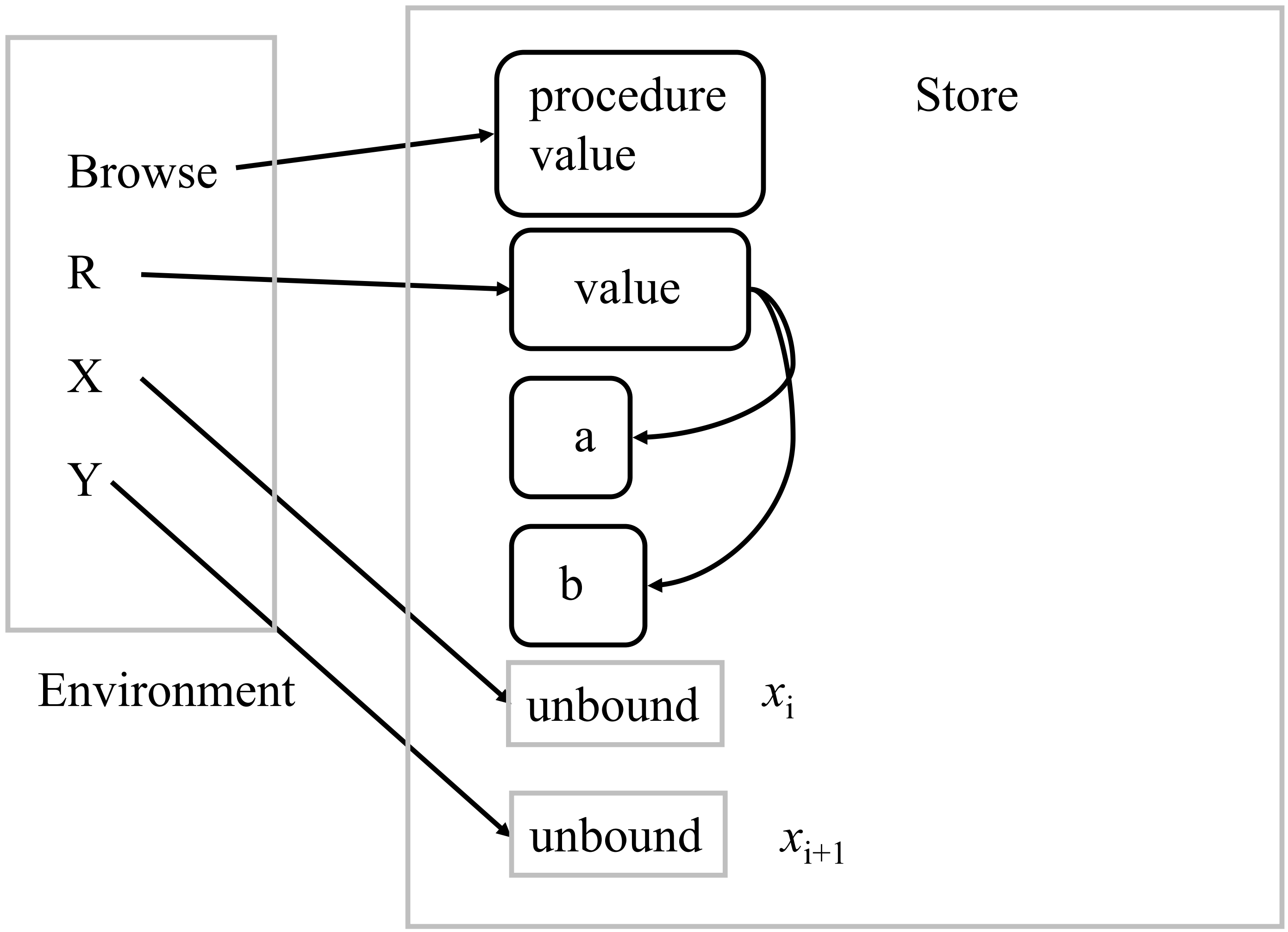
```
{Browse X}
```

- Inspects the store and shows partial values, and incremental changes

The interactive interface (declare)



declare X Y



procedure value
Store
Browse
R
value
X
a
Y
b
Environment
unbound
x_i
unbound
x_{i+1}

Syntactic extensions

- **Nested partial values**
  - person(name: "George" age:25)

    local A B in A= "George" B=25 person(name:A age:B) end
- **Implicit variable initialization**
  - local ⟨pattern⟩ = ⟨expression⟩ in ⟨statement⟩ end
- **Example:**

  assume T has been defined, then

  local tree(key:A left:B right:C value:D) = T in ⟨statement⟩ end

  is the same as:

```
local A B C D in
        T = tree(key:A left:B right:C value:D) <statement>
end
```

Extracting fields in local statement

```
declare T
    :
    T = tree(key:seif age:48 profession:professor)
    :
local
    tree(key:A ...) = T
in
    ⟨statement⟩
end
```

Nested if and case statements

- Observe a pair notation is: 1 # 2, is the tuple '#' (1 2)

```
case Xs # Ys
of  nil # Ys then ⟨s⟩1
[]  Xs # nil then ⟨s⟩2
[]  (X|Xr) # (Y|Yr) andthen X=<Y then ⟨s⟩3
else ⟨s⟩4 end
```

- Is translated into (assuming X,Xr,Y,Yr not free in $\langle s \rangle_4$)

```
case Xs of nil then ⟨s⟩1
else
    case Ys of nil then ⟨s⟩2
    else
         case Xs of X|Xr then
            case Ys of Y|Yr then
                  if  X=<Y then ⟨s⟩3 else ⟨s⟩4 end
            else ⟨s⟩4 end
        else ⟨s⟩4 end
    end
end
```

Expressions

- An expression is a sequence of operations that returns a value
- A statement is a sequence of operations that does not return a value. Its effect is on the store, or outside of the system (e.g. read/write a file)
- $\underbrace{11*11}_{\text{expression}}$ $\qquad\qquad$ $\underbrace{X=11*11}_{\text{statement}}$

Functions as linguistic abstraction

- R = {F X1 ... Xn}
- {F X1 ... Xn R}

```
fun {F X1 ... Xn}
    ⟨statement⟩
    ⟨expression⟩
end
```

⟨statement⟩

```
F = proc {$ X1 ... Xn R}
    ⟨statement⟩
    R = ⟨expression⟩
  end
```

⟨statement⟩

Nesting in data structures

- Ys = {F X}|{Map Xr F}
- Is unnested to:
- ```
  local Y Yr in
      Ys = Y|Yr
      {F X Y}
      {Map Xr F Yr}
  end
  ```
- The unnesting of the calls occurs after the data structure
  ```

Functional nesting

- Nested notations that allows expressions as well as statements
- local R in

```
local R in
    {F X1 ... Xn R}
    {Q R ...}
end
```

- Is written as (equivalent to):
- {Q {F X1 ... Xn} ...}

$$\underbrace{\{Q\ \underbrace{\{F\ X1\ \dots\ Xn\}}_{\text{expression}}\ \dots\}}_{\text{statement}}$$

Conditional expressions

```
R = if ⟨expr⟩1 then
         ⟨expr⟩2
    else ⟨expr⟩3  end
```

$\underbrace{\qquad\qquad\qquad}_{\langle \text{expression} \rangle}$

```
if ⟨expr⟩1 then
    R = ⟨expr⟩2
else R = ⟨expr⟩3  end
```

$\underbrace{\qquad\qquad\qquad}_{\langle \text{statement} \rangle}$

```
fun {Max X Y}
   if X>=Y then X
   else Y end
end
```

```
Max = proc {$ X Y R}
   R =  ( if X>=Y then X
          else Y end )
   end
```

Example

```
fun {Max X Y}
    if X>=Y then X
    else Y end
end
```

⇒

```
Max = proc {$ X Y R}
    R = ( if X>=Y then X
             else Y end )
    end
```

⇒

```
Max = proc {$ X Y R}
    if X>=Y then R = X
    else R = Y end
end
```

andthen and orelse

$\langle \text{expr} \rangle_1$ andthen $\langle \text{expr} \rangle_2$ ⇒

```
if ⟨expr⟩1 then
    ⟨expr⟩2
else false end
```

$\langle \text{expr} \rangle_1$ orelse $\langle \text{expr} \rangle_2$ ⇒

```
if ⟨expr⟩1 then
    true
else ⟨expr⟩2 end
```

Function calls

Observe

```
{F1 {F2 X} {F3 Y}}
```

⇒

```
local R1 R2 in
    {F2 X R1}
    {F3 Y R2}
    {F1 R1 R2}
end
```

The arguments of a function are evaluated first from left to right

A complete example

```
fun {Map Xs F}
   case Xs
   of nil then nil
   []  X|Xr then {F X}|{Map Xr F}
   end
end
```

```
proc {Map Xs F Ys}
   case Xs
   of nil then Ys = nil
   []  X|Xr then Y Yr in
         Ys = Y|Yr
         {F X Y}
         {Map Xr F Yr}
   end
end
```

Exceptions

- How to handle exceptional situations in the program?
- Examples:
  - divide by 0
  - opening a nonexistent file
- Some errors are programming errors
- Some errors are imposed by the external environment
- Exception handling statements allow programs to handle and recover from errors

Exceptions

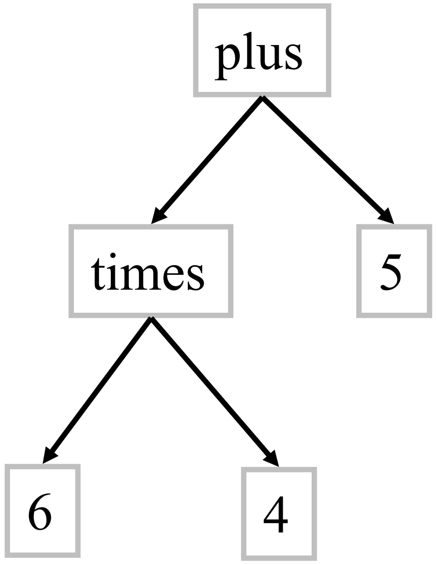
- The error confinement principle:
  - Define your program as a structured layers of components
  - Errors are visible only internally and a recovery procedure corrects the errors: either errors are not visible at the component boundary or are reported (nicely) to a higher level
- In one operation, exit from arbitrary depth of nested contexts
  - Essential for program structuring; else programs get complicated (use boolean variables everywhere, etc.)

Basic concepts

- A program that encounters an error (*exception*) should transfer execution to another part, the *exception handler* and give it a (partial) value that describes the error
- try $\langle s \rangle_1$ catch $\langle x \rangle$ then $\langle s \rangle_2$ end
- raise $\langle x \rangle$ end
- Introduce an exception marker on the semantic stack
- The execution is equivalent to $\langle s \rangle_1$ if it executes without raising an error
- Otherwise, $\langle s \rangle_1$ is aborted and the stack is popped up to the marker, the error value is transferred through $\langle x \rangle$, and $\langle s \rangle_2$ is executed

Exceptions (Example)

```
fun {Eval E}
   if {IsNumber E} then E
   else
      case E
      of plus(X Y) then {Eval X}+{Eval Y}
      []  times(X Y) then {Eval X}*{Eval Y}
      else raise illFormedExpression(E) end
      end
   end
end
```



Exceptions (Example)

```
try
    {Browse {Eval plus(5 6) }}
    {Browse {Eval plus(times(5 5) 6) }}
    {Browse {Eval plus(minus(5 5) 6) }}
catch illFormedExpression(E) then
    {System.showInfo  ”***** illegal expresion ****” # E}
end
```

Try semantics

- The semantic statement is
  (try $\langle s \rangle_1$ catch $\langle$y$\rangle$ then $\langle s \rangle_2$ end, E)
- Push the semantic statement (catch $\langle$y$\rangle$ then $\langle s \rangle_2$ end, E) on ST
- Push ($\langle s \rangle_1$, E) on ST
- Continue to next execution step

Raise semantics

- The semantic statement is
  (raise ⟨x⟩ end, E)
- Pop elements off ST looking for a catch statement:
  - If a catch statement is found, pop it from the stack
  - If the stack is emptied and no catch is found, then stop execution with the error message "Uncaught exception"
- Let (catch ⟨y⟩ then ⟨s⟩ end, E_c) be the catch statement that is found
- Push (⟨s⟩ , $E_c + \{\langle y\rangle \rightarrow E(\langle x\rangle)\}$) on ST
- Continue to next execution step

Catch semantics

- The semantic statement is
  (catch $\langle$x$\rangle$ then $\langle s \rangle$ end, E)
- Continue to next execution step (like skip)

Full exception syntax

- Exception statements (expressions) with multiple patterns and finally clause

- Example:

```
:
FH = {OpenFile "xxxxx"}
:
try
   {ProcessFile FH}
catch X then
   {System.showInfo "***** Exception when processing *****" # X}
finally {CloseFile FH} end
```

finally syntax

try $\langle s \rangle_1$ finally $\langle s \rangle_2$ end

is converted to:

```
try ⟨s⟩1
catch X then
   ⟨s⟩2
   raise X end
end
⟨s⟩2
```

Case statement revisited

- The semantic statement is
  (case ⟨x⟩ of ⟨l⟩ (⟨f_1⟩ : ⟨x_1⟩ … ⟨f_n⟩ : ⟨x_n⟩)
  then ⟨s_1⟩
  else ⟨s_2⟩ end , E)
- If the activation condition (E(⟨x⟩) is determined) is true:
  - If E(⟨x⟩) is a record, the label of E(⟨x⟩) is ⟨l⟩ and its arity is [⟨f_1⟩ … ⟨f_n⟩]:
    push (try local ⟨x_1⟩ = ⟨x⟩. ⟨f_1⟩ … ⟨x_n⟩ = ⟨x⟩. ⟨f_n⟩ in ⟨s_1⟩* end
    catch user(E) then raise E end [] E then ⟨s_2⟩ end, E)
    on the stack, where ⟨s_1⟩* is the same as ⟨s_1⟩ except
    raise E end is changed to raise user(E) end
  - Otherwise, push (⟨s_2⟩, E) on the stack
- If the activation condition (E(⟨x⟩) is determined) is false:
  - Suspend

Exercises

49. VRH Exercise 2.9.3 (page 107).
50. VRH Exercise 2.9.7 (page 108) –translate example to kernel language and execute using operational semantics.
51. Write an example of a program that suspends. Now, write an example of a program that never terminates. Use the operational semantics to prove suspension or non-termination.
52. VRH Exercise 2.9.12 (page 110).
53. Change the semantics of the `case` statement, so that patterns can contain variable labels and variable feature names.

Exercises

54. Restrict the kernel language to make it strictly functional (i.e., without dataflow variables)
    - Language similar to Scheme (dynamically typed functional language)

    This is done by disallowing variable declaration (without initialization) and disallowing procedural syntax
    - Only use implicit variable initialization
    - Only use functions