Introduction to Programming Concepts (VRH 1.9-1.17)

Carlos Varela
RPI

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Adapted with permission from:
Seif Haridi
KTH
Peter Van Roy
UCL

Introduction

- An introduction to programming concepts
- Declarative variables
- Functions
- Structured data (example: lists)
- Functions over lists
- Correctness and complexity
- Lazy functions
- Higher-order programming
- Concurrency and dataflow
- State, objects, and classes
- Nondeterminism and atomicity

Higher-order programming

- Assume we want to write another Pascal function, which instead of adding numbers, performs exclusive-or on them
- It calculates for each number whether it is odd or even (parity)
- Either write a new function each time we need a new operation, or write one generic function that takes an operation (another function) as argument
- The ability to pass functions as arguments, or return a function as a result is called *higher-order programming*
- Higher-order programming is an aid to build generic abstractions

Variations of Pascal

- Compute the parity Pascal triangle

```
fun {Xor X Y} if X==Y then 0 else 1 end end
```

```
        1                  1
      1   1              1   1
    1   2   1          1   0   1
  1   3   3   1      1   1   1   1
1   4   6   4   1  1   0   0   0   1
```


Higher-order programming

```
fun {GenericPascal Op N}
  if N==1 then [1]
  else L in L = {GenericPascal Op N-1}
    {OpList Op {ShiftLeft L} {ShiftRight L}}
  end
end
fun {OpList Op L1 L2}
    case L1 of H1|T1 then
        case L2 of H2|T2 then
            {Op H1 H2}|{OpList Op T1 T2}
        end
    else nil end
end
```

```
fun {Add N1 N2} N1+N2 end
fun {Xor N1 N2}
    if N1==N2 then 0 else 1 end
end

fun {Pascal N} {GenericPascal Add N} end
fun {ParityPascal N}
    {GenericPascal Xor N}
end
```

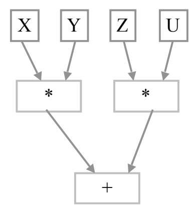

Concurrency

- How to do several things at once
- Concurrency: running several activities each running at its own pace
- A *thread* is an executing sequential program
- A program can have multiple threads by using the thread instruction
- {Browse 99*99} can immediately respond while Pascal is computing

```
thread
  P in
  P = {Pascal 21}
  {Browse P}
end
{Browse 99*99}
```

Dataflow

- What happens when multiple threads try to communicate?
- A simple way is to make communicating threads synchronize on the availability of data (data-driven execution)
- If an operation tries to use a variable that is not yet bound it will wait
- The variable is called a *dataflow variable*



Dataflow (II)

- Two important properties of dataflow
  - Calculations work correctly independent of how they are partitioned between threads (concurrent activities)
  - Calculations are patient, they do not signal error; they wait for data availability
- The dataflow property of variables makes sense when programs are composed of multiple threads

```
declare X
thread
   {Delay 5000} X=99
End
{Browse 'Start'} {Browse X*X}
```

```
declare X
thread
   {Browse 'Start'} {Browse X*X}
end
{Delay 5000} X=99
```


State

- How to make a function learn from its past?
- We would like to add memory to a function to remember past results
- Adding memory as well as concurrency is an essential aspect of modeling the real world
- Consider {FastPascal N}: we would like it to remember the previous rows it calculated in order to avoid recalculating them
- We need a concept (memory cell) to store, change and retrieve a value
- The simplest concept is a (memory) cell which is a container of a value
- One can create a cell, assign a value to a cell, and access the current value of the cell
- Cells are not variables

```
declare
C = {NewCell 0}
{Assign C {Access C}+1}
{Browse {Access C}}
```


Example

- Add memory to Pascal to remember how many times it is called
- The memory (state) is global here
- Memory that is local to a function is called *encapsulated state*

```
declare
C = {NewCell 0}
fun {FastPascal N}
   {Assign C {Access C}+1}
   {GenericPascal Add N}
end
```


Objects

- Functions with internal memory are called *objects*
- The cell is invisible outside of the definition

```
declare
local C in
  C = {NewCell 0}
  fun {Bump}
    {Assign C {Access C}+1}
    {Access C}
  end
end
```

```
declare
fun {FastPascal N}
   {Browse {Bump}}
   {GenericPascal Add N}
end
```


Classes

- A class is a 'factory' of objects where each object has its own internal state
- Let us create many independent counter objects with the same behavior

```
fun {NewCounter}
   local C Bump in
      C = {NewCell 0}
      fun {Bump}
            {Assign C {Access C}+1}
            {Access C}
      end
      Bump
   end
end
```

Classes (2)

- Here is a class with two operations: Bump and Read

```
fun {NewCounter}
   local C Bump Read in
      C = {NewCell 0}
      fun {Bump}
            {Assign C {Access C}+1}
            {Access C}
      end
      fun {Read}
            {Access C}
      end
      [Bump Read]
   end
end
```


Object-oriented programming

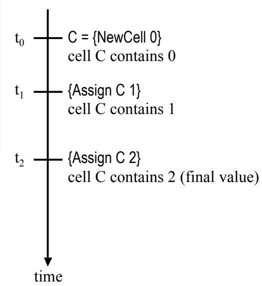
- In object-oriented programming the idea of objects and classes is pushed farther
- Classes keep the basic properties of:
  - State encapsulation
  - Object factories
- Classes are extended with more sophisticated properties:
  - They have *multiple* operations (called *methods*)
  - They can be defined by taking another class and extending it slightly (*inheritance*)

Nondeterminism

- What happens if a program has both concurrency and state together?
- This is very tricky
- The same program can give different results from one execution to the next
- This variability is called *nondeterminism*
- Internal nondeterminism is not a problem if it is not observable from outside

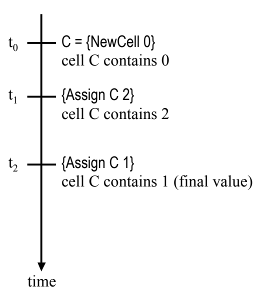
Nondeterminism (2)

```
declare
C = {NewCell 0}

thread {Assign C 1} end
thread {Assign C 2} end
```



Nondeterminism (3)

```
declare
C = {NewCell 0}

thread {Assign C 1} end
thread {Assign C 2} end
```



Nondeterminism (4)

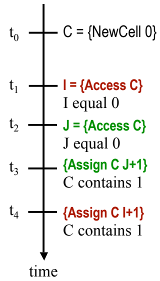
```
declare
C = {NewCell 0}

thread I in
   I = {Access C}
   {Assign C I+1}
end
thread J in
   J = {Access C}
   {Assign C J+1}
end
```

- What are the possible results?
- Both threads increment the cell C by 1
- Expected final result of C is 2
- Is that all?

Nondeterminism (5)

- Another possible final result is the cell C containing the value 1

```
declare
C = {NewCell 0}
thread I in
    I = {Access C}
    {Assign C I+1}
end
thread J in
    J = {Access C}
    {Assign C J+1}
end
```



Lessons learned

- Combining concurrency and state is tricky
- Complex programs have many possible *interleavings*
- Programming is a question of mastering the interleavings
- Famous bugs in the history of computer technology are due to designers overlooking an interleaving (e.g., the Therac-25 radiation therapy machine giving doses 1000's of times too high, resulting in death or injury)
- If possible try to avoid concurrency and state together
- Encapsulate state and communicate between threads using dataflow
- Try to master interleavings by using *atomic operations*

Atomicity

- How can we master the interleavings?
- One idea is to reduce the number of interleavings by programming with coarse-grained atomic operations
- An operation is *atomic* if it is performed as a whole or nothing
- No intermediate (partial) results can be observed by any other concurrent activity
- In simple cases we can use a *lock* to ensure atomicity of a sequence of operations
- For this we need a new entity (a lock)

Atomicity (2)

```
declare
L = {NewLock}

lock L then
  sequence of ops 1      } Thread 1
end

lock L then
  sequence of ops 2      } Thread 2
end
```


The program

```
declare
C = {NewCell 0}
L = {NewLock}

thread
   lock L then I in
      I = {Access C}
      {Assign C I+1}
   end
end
thread
   lock L then J in
      J = {Access C}
      {Assign C J+1}
   end
end
```

The final result of C is always 2

Memoizing FastPascal

- <u>{FasterPascal N} New Version</u>
  1. Make a store S *available* to FasterPascal
  2. Let K be the number of the rows stored in S (i.e. max row is the K[th] row)
  3. if N is less or equal to K retrieve the N[th] row from S
  4. Otherwise, compute the rows numbered K+1 to N, and store them in S
  5. Return the N[th] row from S
- Viewed from outside (as a black box), this version behaves like the earlier one but faster

```
declare
S = {NewStore}
{Put S 2 [1 1]}
{Browse {Get S 2}}
{Browse {Size S}}
```

Exercises

17. VRH Exercise 1.6 (page 24)
    c) Change GenericPascal so that it also receives a number to use as an identity for the operation Op: {GenericPascal Op I N}. For example, you could then use it as:
       {GenericPascal Add 0 N}, or
       {GenericPascal fun {$ X Y} X*Y end 1 N}
18. Prove that the alternative version of Pascal triangle (not using ShiftLeft) is correct. Make AddList and OpList commutative.
19. *Write the memoizing Pascal function using the store abstraction (available at 4.oz).