Introduction to Programming Concepts (VRH 1.9-1.17)

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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
```

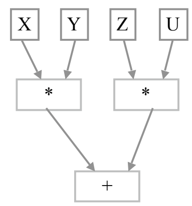

Concurrency

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

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

t_0 — C = {NewCell 0}
cell C contains 0

t_1 — {Assign C 1}
cell C contains 1

t_2 — {Assign C 2}
cell C contains 2 (final value)

time

Nondeterminism (3)

```
declare
C = {NewCell 0}

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

t_0 — C = {NewCell 0}
cell C contains 0

t_1 — {Assign C 2}
cell C contains 2

t_2 — {Assign C 1}
cell C contains 1 (final value)

time

Nondeterminism (4)

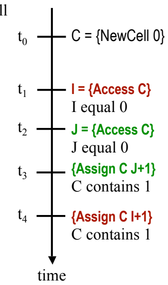
```
declare
C = {NewCell 0}

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                    lock L then
  sequence of ops 1  } Thread 1   sequence of ops 2  } Thread 2
end                            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

- {FasterPascal N} New Version
  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

36. 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}
37. Prove that the alternative version of Pascal triangle (not using ShiftLeft) is correct. Make AddList and OpList commutative.
38. Write the memoizing Pascal function using the store abstraction (available at store.oz).