

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

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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

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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
```

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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
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
```

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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

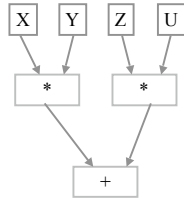
```
thread
  P in
  P = {Pascal 21}
  {Browse P}
end
{Browse 99*99}
```

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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*



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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
  
```

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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}}
  
```

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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
  
```

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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
  
```

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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
  
```

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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
end
  
```

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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*)

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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

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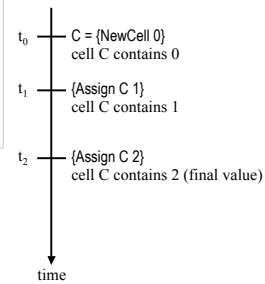
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Nondeterminism (2)

```

declare
  C = {NewCell 0}

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



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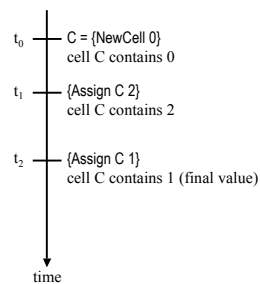
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Nondeterminism (3)

```

declare
  C = {NewCell 0}

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



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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?

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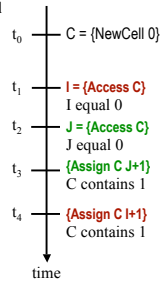
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Nondeterminism (5)

- 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
    
```



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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*

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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)

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Atomicity (2)

```

declare
L = {NewLock}

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

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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

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Memoizing FastPascal

- {FasterPascal N} New Version**
 - Make a store *S* available to FasterPascal
 - Let *K* be the number of the rows stored in *S* (i.e. max row is the *K*th row)
 - if *N* is less or equal to *K* retrieve the *N*th row from *S*
 - Otherwise, compute the rows numbered *K*+1 to *N*, and store them in *S*
 - 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}}
    
```

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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 I 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](#)).