Programming Language Concepts, cs2104 Lecture 12 (2003-11-07)



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Reading Suggestions

- Chapters 5
- And of course the handouts!

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Exam Rules and Tips



- 120 minutes are 40 points!
- Read the entire exam first!
- Carefully study tutorials!
- Write your Matric. No. on each sheet!!!!!!

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Overview



- Previous lecture
 - agents with state
 - cells
 - state encapsulation
 - objects and classes
- This lecture
 - repetition
 - overview
 - outlook
 - questions & answers

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Agents With State



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Agent Ingredients



- Agents
 - thread independent computation
 - port delivery addressstream ordered mailboxrecord message, state
 - higher-order procedure

separate functionality from generic abstraction

 Also: active objects (object plus thread), servers

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LCO Essential for Agents



Last call-optimization is essential for agents...

...as they are supposed to run forever!

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Why Do Agents Matter?



- Model to capture communicating entities
- Each agent is simply defined in terms of how it replies to messages
- Each agent has a thread of its own
 - no screwup with concurrency
 - we can possible have state for each agent easily!
- Extremely useful to model systems!

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Agents as State Transformers



- Receive messages
- To be useful they need to maintain state
 - changing over time
- Model: agent a is modeled by function

state × message → state

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Defining an Agent



- Agent
 - how it reacts to messages
 - how it transforms the state
 - from which initial state it starts
- Additionally
 - agent might compute by sending messages to other agents

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Example: A Cell Agent



```
fun {CellProcess S M}
   case M
   of assign(New) then
       New
   [] access(Old) then
       Old=S S
   end
end
```

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The NewAgent Abstraction



- To create a new agent with state
 - create a port for receiving messages
 - create a thread that executes agent
 - start agent by applying its function on an initial state
 - agent made available by the port

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```
NewAgent
```

Executing the Agent

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13

```
thread
  proc {Execute State Stream}
  case Stream of M|Rest then
        NewState={Process State M}
  in
        {Execute NewState Rest}
  end
  end
in
  {Execute InitState Stream}
end
```

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Executing With FoldL



thread FinalState in
 FinalState ={FoldL Stream Process InitState}
end

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Complete NewAgent



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Creating a Cell Agent



declare

CA = {NewAgent CellProcess 0}

- Cell agent
 - initialized with zero as state

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State and Concurrency



- Difficult to guarantee that state is maintained consistently in a concurrent setting
- Typically needed: atomic execution of several statements together
- Agents guarantee atomic execution

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Other Approaches



- Atomic exchange
 - Low-level
 - hardware: test-and-set
- Locks: allow only one thread in a "critical section"
 - monitor: allows multiple threads within a critical section, but only one active at a time
 - generalizations to single writer/multiple reader

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Maintaining State



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Maintaining State



- Agents maintain implicit state
 - state maintained as values passed as arguments
- Agents encapsulate state
 - state is only available within one agent
 - in particular, only one thread
- With cells we can have explicit state
 - programs can manipulate state by manipulating cells

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Explicit State



- So far, the models considered do not have explicit state
- Explicit state is of course useful
 - algorithms might require state (such as arrays)
 - the right model for the task

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Using State



- Programs should be modular
 - composed from components
- Some components can use state
 - use only, if necessary
- Components from outside (interface) can still behave like functions

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State: Example



- Lab assignment 3: computing the frequency map
 - consider all bytes, increase frequency by creating a new record with a just a single field changed
- Much more efficient: using state with dictionaries

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State: Abstract Datatypes



- Many useful abstractions are abstract datatypes using encapsulated state
 - arrays
 - dictionaries
 - queues
 - ...

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Cells One of the state of the





- C={NewCell X}
 - creates new cell C
 - with initial value x
- X={Access C}

X=@C (alternative notation)

- returns current value of C
- {Assign C X}

C := X (alternative notation)

- assigns value of C to be X
- {Exchange C X Y}

 $\dot{X} = C := Y$ (alternative notation)

atomically assigns C to Y and returns old value X

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Cells



- Are a model for explicit state
- Useful in few cases on itself
- Device to explain other stateful data types such as arrays

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Array Model



- Simple array
 - fields indexed from 1 to n
 - values can be accessed, assigned, and exchanged
- Model: tuple of cells

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Arrays

- A={NewArray N I}
 - \bullet create array with fields from 1 to ${\tt N}$
 - all fields initialized to value I
- X={ArrayAccess A N}
 - X=A.N (alternative notation)
 - return value at position N in array A
- {ArrayAssign A N X}
 - A.N:=X (alternative notation)
 - set value at position N to X in array A
- {ArrayExchange A N X Y} X=A.N:=Y
 - exchange value at position N in A from X to Y

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Homework



- Implement array abstract datatype
 - use tuple of cells

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Ports Revisited



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Ports



- Provide send operation
- Always maintain tail of stream
- Sending is appending cons with message

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How to Program Ports?



- Idea: cell keeps current tail of stream
 - invariant: cell keep unassigned variable!
- Sending
 - access current tail of stream
 - appending message
 - assign current tail of stream

...must of course to be atomic with exchange! what could happen otherwise?

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Ports from Cells: Bad



```
fun {NewPort Stream}
    {NewCell Stream}
end
proc {Send P M}
    Old New
in
    Old = P := New % atomic exchange
    Old = M | New
end
```

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Why Bad?

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- Port is a cell in previous solution
- I can break the port abstraction...
- How: just put some junk into the cell {Assign P crash}

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Real Ports...



- Abstraction cannot be compromised
 - sending messages always works
- However: everybody is allowed to send messages to a port

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How to Fix Ports from Cells



- Confine the cell to the send operation
 - by lexical scoping
- Invariant can never be broken

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Ports from Cells



```
fun {Port Stream}
    C={NewCell Stream}
    proc {Send M}
        Old New
    in
        Old = C := New
        Old = M|New
    end
in
    port(send:Send)
end
```

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Ports from Cells

```
fun {Port Stream}
    C={NewCell Stream}
    proc {Send M}
        Old New
    in
        Old = C := New
        New = M|Old
    end
in
```

port(send:Send)

only Send can use cell

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end

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Ports from Cells



- Returns the send procedure
- Example of use:

```
S={Port Xs}
{Browse Xs}
{S.send a}
{S.send b}
```

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State Encapsulation



- State is encapsulated by construction of Port
- Encapsulation
 - guarantees invariant (cells maintains stream tail)
 - makes the abstraction "secure"

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Objects and Classes



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Objects

- Object is one convenient way of encapsulating state
 - only methods can access state
 - important invariants can be secured
- As well as very useful to model objects of the real world

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Model for Objects



- Methods are procedures
 - have access to state
 - restrict access to state
- State of an object
 - record of cells
 - similar to our construction of arrays

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Classes



- Describe how objects are constructed
 - initial state
 - methods
- Classes can be constructed from other classes by inheritance

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Classes and Objects



 A full-blown object system can be obtained easily from

records state field-namecells state field-value

procedures methods

lexical scoping access from methods to state

- First-class procedures are very powerful
 - allow to program inheritance and object creation

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State: Abstract Datatypes



- Many useful abstractions are abstract datatypes using encapsulated state
 - arrays
 - dictionaries
 - queues
 - ...

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Course Summary



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Content

- Study of programming models
 - declarative programming model
 - declarative concurrency
 - message sending and state
- Study of programming techniques
 - recursion
 - iterative computations
 - generic programs: higher-order programming
- Tools for analyzing and understanding programs
 - abstract machines
 - ..
 - ...

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Declarative **Programming Model**



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Most Important Concepts



- Single-assignment variables
 - partial values
- Abstract machine
 - a *tool* for understanding computations
 - a model of computation
 - based on environments
 - supports last call optimization
- Procedures with contextual environment
- Full versus kernel language

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Abstract Machine



- General approach to explain how programming language computes
 - model for computation
- Can serve as base for implementation

pioneered by Prolog
 D.H.D. Warren, 1980's

many other languages including Oz

• recent: JVM (Java) SUN

CLR (C#, ...) Microsoft

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Declarative means...



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• Programs returns

same result

for

same arguments

Always, always, always...
 regardless of any other computations

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Declarative Programming Properties



- Independence
 - write programs independently
 - test and debug independently
 - other components of program do not matter
- Simple reasoning
 - declarative programs only compute values
 - no hidden state, no history, ...
- This means simple development...

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Be as Declarative as You Can



- Many program components can be written in a declarative style
 - use the benefits as much as possible
- For the rest, use other techniques
 - concurrency
 - state
 - objects

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Significance



- Some languages are better than others at declarative programming (Oz versus C++)
- Declarative programming techniques are useful whatever language you program in
 - this course wants to sharpen your mind
 - this course uses a language that is good at declarative programming and the other techniques to come

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Important Techniques and Concepts



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Language Syntax



- Describe syntax of computer languages
 - lexical words
 - syntactical sentences
- Defined by grammars

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Language Semantics



- How do programs compute?
- Model here: abstract machine
- Essential for:
 - understanding
 - transformations (accumulator, state invariants)
 - determining memory and runtime

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Iterative Computations



- Iterative computations
 - computations that run with constant stack space
- Making computations iterative
 - using accumulators
 - understanding and design with state invariants
- Last call optimization
 - needed for iterative computations
 - special case: tail-recursion

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Abstract Data Types



- Separate interface from implementation
- Sufficient to understand interface only
- Independence of implementation
 - as long as only interface is used
 - less knowledge required
 - independent development
 - software evolution

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Generic Programs



- Make common program patterns generic
 - sorting
 - mapping
 - filtering
 - agent creation
 - ...
- Use higher-order procedures
 - higher-order procedures are first-class citizens

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Declarative Concurrency



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The World Is Concurrent!



- Concurrent programs
 several activities execute
 simultaneously (concurrently)
- Most of the software you use is concurrent
 - operating system: IO, user interaction, many processes, ...
 - web browser, Email client, Email server, ...
 - telephony switches handling many calls
 - ...

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Thread-based Concurrency



- Threads
 - · compute independently
 - share common abstract store
 - are lightweight
 - are scheduled fairly
 - have interleaving semantics
- Statements
 - automatically suspend and resume
 - computations triggered by dataflow variables
- Makes computations incremental

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Semantics for Threads



- We insist on interleaving semantics
 - model: only one thread executes at a time
 - implementation: might execute several threads in parallel, however must execute as if one thread at a time
- Important property: monotonicity
 - if a thread becomes runnable:
 - ...it stays runnable
 - ...doesn't matter when it is actually run

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Demand-driven Execution



- Execute computations only if needed
 - infinite data structures
 - complex computations described easily
 - avoid computation as much as possible
- Expressed with "by-need" triggers
 - Computation executed at most once
 - Setup: threads + functions

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Techniques and Concepts



- Producer, transducer, consumer
- Lazy functions
- Lazy streams
- Soft real-time programming

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Agents and Message Sending



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- Model problems as collection of multiple independent communicating entities
 - independent concurrent, private threadcommunicating unique address, port
- Is not declarative: introduces
 - nondeterminism
 - state

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71

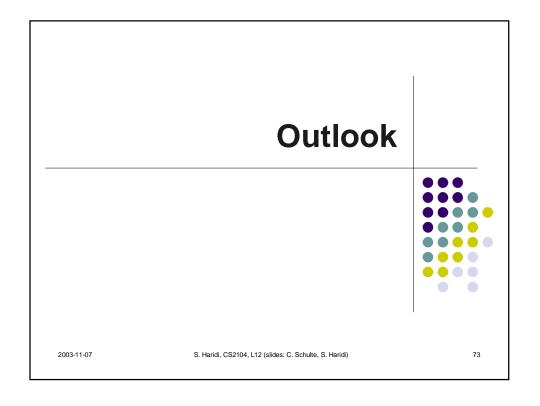
Techniques and Concepts

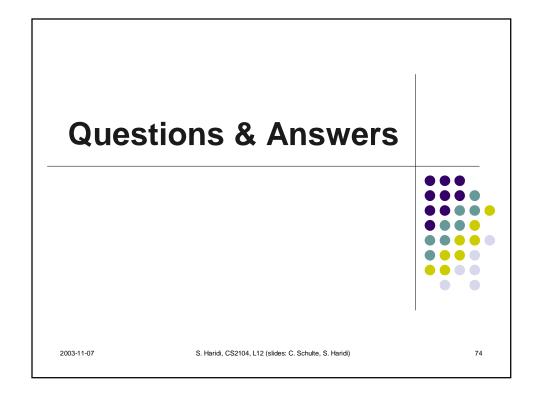


- Agents with state
 - agents are state transformers
 - encapsulation of state
 - consistent management of state
- Protocols: rules for communication
 - involve multiple agents
 - simplicity is important (avoiding deadlocks)

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Which Thread Terminates First?



- Write a function
 - runs two computations
 - tells which one terminates first
- How?
 - passing computation
 - running computations
 - termination
 - finding out termination

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Guarantee Execution



- Given: two statements
- How to guarantee that both are executed?

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Asymptotic Complexity



 Valid statements only for particular computers?

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Abstract Machine



- When is contextual environment computed?
 - procedure definition, or
 - procedure call
- Variable identifiers are always mapped to the same store variable
 - true or false?

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Abstract Machine



- How is the environment constructed upon procedure call?
- What is environment adjunction/projection?
- Where is environment adjunction/projection used?

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Higher-Order Programs



 Given: two unary functions F and G.
 Compute a unary function that executes the composition of F and G.

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Accumulators



 Does asymptotic complexity always improve when making procedures tail-recursive?

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Questions



Activation condition for

(if
$$\langle x \rangle$$
 then $\langle s \rangle_1$ else $\langle s \rangle_2$ end, E)

- Do all semantic statements share one environment?
- How many external references has a recursive procedure at least?

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Questions



- Is there a guarantee that \(\s \) in thread \(\s \) end is actually executed?
- Is there a guarantee that $\langle s \rangle_2$ in thread $\langle s \rangle_1 \langle s \rangle_2$ end is actually executed?

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Questions



• Is there a guarantee that $\langle s \rangle_2$ in thread $\langle s \rangle_1$ thread $\langle s \rangle_2$ end end is actually executed?

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Questions



• What does function compute?

```
fun {Guess Xs Ys}
  case Xs
  of nil then Ys
  [] X|Xr then X|{Guess Ys Xr}
  end
end
```

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Abstract Data Types



```
fun {NewBag}
    nil
end
fun {IsMember B X}
    ...
end
fun {Add B X}
    X|B
end
```

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Abstract Data Types: Use



```
fun {Extend B X}
  if {IsMember B X} then B
  else X|B
  end
```

• violates the abstract data type. Why?

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end

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87

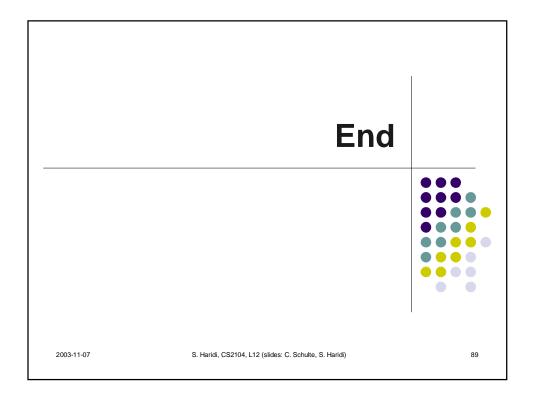
Abstract Data Types: Correct Use



```
fun {Extend B X}
  if {IsMember B X} then B
  else {Add B X}
  end
end
```

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The End



- Thank you for your kind attention
- It has been a pleasure for me!
- I hope...
 - ...you learned something
 - ...you enjoyed the course

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Wishes



• Good luck with the exam

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91

Have a Nice Weekend



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