INF4140 - Models of concurrency

Fall 2016

November 28, 2016

Abstract

This is the "handout" version of the slides for the lecture (i.e., it's a rendering of the content of the slides in a way that does not waste so much paper when printing out). The material is found in [Andrews, 2000]. Being a handout-version of the slides, some figures and graph overlays may not be rendered in full detail, I remove most of the overlays, especially the long ones, because they don't make sense much on a handout/paper. Scroll through the real slides instead, if one needs the overlays.

This handout version also contains more remarks and footnotes, which would clutter the slides, and which typically contains remarks and elaborations, which may be given orally in the lecture.

1 Active Objects

28.11.2016

Aims for this lecture

Distributed object-oriented systems and introduction to Creol/ABS

- Consider the combination of OO, concurrency, and distribution
- Understanding active objects
    - interacting by *asynchronous method calls*
- A short introduction of (a variant of) *Creol*[1] using small example programs

Note: Inheritance and dynamic object creation not considered here.

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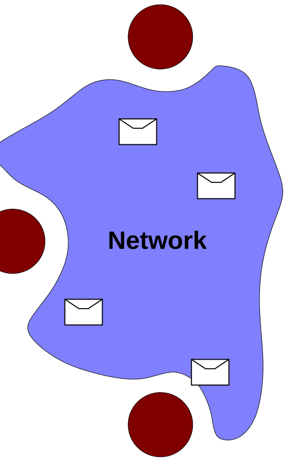
[1] References:

- `http://heim.ifi.uio.no/~creol/`
- `http://tools.hats-project.eu/`
- Johnsen & Owe: An Asynchronous Communication Model for Distributed Concurrent Objects Software and Systems Modeling, 6(1): 39-58, 2007. Springer
- Johnsen, Blanchette, Kyas & Owe: Intra-Object versus Inter-Object Concurrency and Reasoning in Creol. Electron. Notes Theor. Comput. Sci. 243 (2009), 89-103.

- **Openness** : encapsulation
  - Implementation of other objects is not necessary known.
  - Interaction with other objects is through interfaces.

Open Distributed Systems

- ODS *dominate* critical infrastructure in society: bank systems, air traffic control, etc.
- ODS: *complex*, *error prone*, and robustness is *poorly understood*



Challenges with OO languages for modern systems

Modern systems are often large and complex, with distributed, autonomous units connected through different kinds of networks.

- OO + concurrency

  synchronization, blocking, deadlock
- OO + asynchronous communication

  messages on top of OO or method-based communication? better than RPC/RMI?
- OO + distribution

  efficient interaction (passive/active waiting),
- OO + openness

  restricted knowledge of other objects
- OO + scalability

  management of large systems

Active and Passive Objects

Passive objects

- Execute their methods in the caller's thread of control (e.g., Java)
- In multithreaded applications, must take care of synchronization
  - Shared variable interference for non-synchronized methods
- If two objects call the same object, race condition may occur

Active (or concurrent) objects

- Execute their methods in their own thread of control (e.g., Actors)
- Communication is asynchronous
- Call and return are decoupled (future variables)
- Cooperative multitasking, specified using schedulers

Creol: A Concurrent Object Model

- OO modeling language that targets open distributed systems
- All objects are **active** (or concurrent), but may receive requests
  - Need easy way to combine active and passive/reactive behavior
- We don't always know how objects are implemented
  - Separate specification (interface) from implementation (class)
  - Object variables are **typed by interface**, not by class
- **No assumptions** about the (network) environment
  - Communication may be unordered
  - Communication may be delayed
  - Execution should adapt to possible delays in the environment
- Synchronization decided by the caller
  - **Method invocations** may be *synchronous* or *asynchronous*

Interfaces as types

- Object variables (pointers) are *typed by interfaces* (other variables are typed by data types)
- *Mutual dependency*: An interface may require a *cointerface*
  - Only objects of cointerface type may call declared methods
  - Explicit keyword *caller* (identity of calling object)
  - Supports callbacks to the caller through the cointerface
  - **The cointerface is the minimal type of *caller***
- All object interaction is *controlled* by interfaces
  - *No explicit hiding* needed at the class level
  - Interfaces provide behavioral specifications
  - A class may implement a number of interfaces
- **Type safety**: no "method not understood" errors, and all parameters are type correct

Interface syntax

- Declares a set of method signatures
- With *cointerface* requirement

interface I **inherits** $\overline{I}$ **begin**

  with J // cointerface J

  $\overline{MtdSig}$

end

- Method signatures ($MtdSig$) of the form:

  op m (**in** $\overline{x : I}$ **out** $\overline{y : I}$)

  - method name m with in-parameters $\overline{x}$ and out-parameters $\overline{y}$
- Local data structures inside an object is defined by data types,
  - including lists, sets and user-defined data types and
  - predefined types such as $Bool$, Int, $String$...

Interfaces: Example

- Consider the mini bank example from last week
- We have `Client`, `MiniBank`, and `CentralBank` objects
- Clients may support the following interface:

```
interface Client begin
  with MiniBank          -- the cointerface
    op pin(out p : Int)
    op amount(out a : Int)
end
```

- only `MiniBank` objects may call the `pin` and `amount` methods

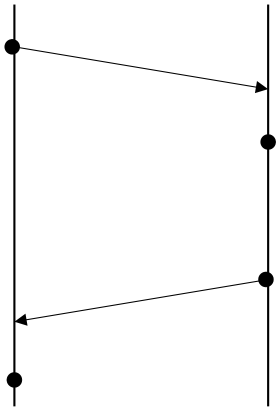
Interfaces: Example (cont.)

`MiniBank` and `CentralBank` interfaces:

```
interface MiniBank begin
  with Client
    op withdraw(in name : String out result : Bool)
end

interface CentralBank begin
  with MiniBank
    op request(in name : String, pin : Int, amount : Int
               out result : Bool)
end
```

Asynchronous Communication Model



$o1$ $o2$

- Object $o1$ calls some method on object $o2$
- In $o2$: Arbitrary delay after invocation arrival and method startup
- In $o1$: Arbitrary delay after completion arrival and reading the return

$o1$ may do something else while waiting for $o2$ to respond

Main ideas of Creol: Programming perspective

Main ideas: Overall

- interaction by method calls
- method executions (processes) may be suspended
- queue of suspended method executions (the process queue)

Main ideas: Method interaction

- Asynchronous communication
- Avoid undesired inactivity
  - Other processes may execute while a process waits for a reply
- Combine active and reactive behavior

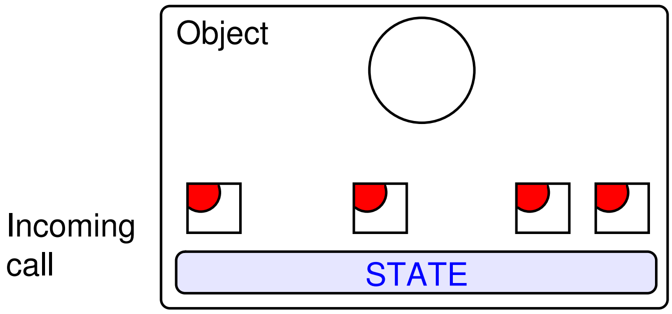
In the language, this is achieved by statements for

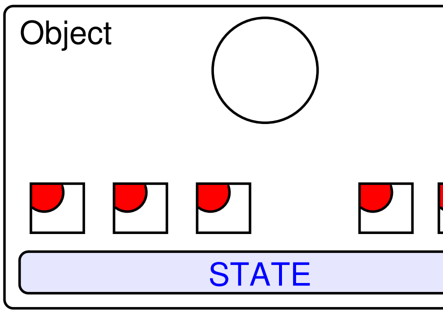
- asynchronous method calls and
- processor release points

Release points enable *interleaving* of *active* and *reactive* code **Note:** No need for signaling / notification

Execution inside a Creol Object

- **Concurrent objects** encapsulate a processor
- Execution in objects should *adapt* to environment delays
- At most *one active process* at a time
- *Implicit scheduling* between internal processes inside an object





Internal Processes in Concurrent Objects

- **Object**: *state* + *active process* + *suspended processes*
- **Process** (method activation):
  - code + local variable bindings (local state)
- **Asynchronous** invocation: $t!o.m(In)$, In a list of expressions
  - The *label* t identifies the call

  Reading the result: $t?(Out)$, Out a list of variables
- **Processor release points**
  - Declared by **await** statements: **await** *guard*
  - *Guards* can be
    - $t?$
    - Boolean condition
    - and also method call
  - If a *guard* evaluates to false, the active process is *suspended*
  - If no process is active, any suspended process may be *activated* if its guard evaluates to true.

Statements for object communication

- Objects communicate through method invocations *only*
- *Different ways to invoke* a method m
- Decided by caller — *not* at method declaration site
- **Guarded** invocation:

$$t!o.m(In); \dots ; \textbf{await } t?; t?(Out)$$

- **Label-free abbreviations** for standard patterns:
  - $o.m(In; Out) \equiv t!o.m(In); t?(Out)$ — **synchronous call**
  - $\textbf{await } o.m(In; Out) \equiv t!o.m(In); \textbf{await } t?; t?(Out)$
  - $!o.m(In)$ — no reply needed (one-way message passing)
- **Internal calls:** $m(In; Out)$, $t!m(In)$, $!m(In)$ Internal calls may also be asynchronous/guarded

From now on: only label-free calls

Creol syntax

Syntactic categories.	*Definitions.*
	$g ::= \phi \mid t? \mid g_1 \wedge g_2$
t in Label	$p ::= o.m \mid m$
g in Guard	$\mathrm{S} ::= s \mid s; \mathrm{S}$
p in MtdCall	$s ::= \textbf{skip} \mid \textbf{begin}\ \mathrm{S}\ \textbf{end} \mid \mathrm{S}_1 \Box \mathrm{S}_2 \mathrm{S}_1 \Box \mathrm{S}_2$
S in ComList	$\mid x := e \mid x := \textbf{new}\ classname(e)$
s in Com	$\mid \textbf{if}\ b\ \textbf{then}\ \mathrm{S}_1\ \textbf{else}\ \mathrm{S}_2\ \textbf{end}$
x in VarList	$\mid \textbf{while}\ b\ \textbf{do}\ \mathrm{S}\ \textbf{end}$
e in ExprList	$\mid\ !p(e) \mid t!p(e) \mid t?(x) \mid p(e; x)$
m in Mtd	$\mid \textbf{await}\ g \mid \textbf{await}\ p(e; x)!p(e) \mid t!p(e) \mid t?(x) \mid p(e; x)$
o in ObjExpr	$\mid \textbf{await}\ g \mid \textbf{await}\ p(e; x)$
b in BoolExpr	$\mid \textbf{releaserelease}$
	$e ::= x \mid this \mid caller \mid null \mid e = e \mid f(e) \mid \dots$

- Omit the functional language for expressions **e** here: booleans, integers, strings, lists, sets, maps, etc

Example: `CentralBank` implementation

```
class Bank implements CentralBank begin
  var pin -- pin codes, indexed by name
  var bal -- balances, indexed by name

  with MiniBank
   op request(in name : String, pin : Int, amount : Int
              out result : Bool) ==
     result:= (pin[name] = pin && bal[name] >= amount)
end
```

Note: The last statement may be rewritten as if (pin[name] = pin && bal[name] >= amount) then result := true else result := false end

Example: `MiniBank` implementation

```
class MiniBank(bank : CentralBank) implements MiniBank begin
  with Client
   op withdraw(in name : String out result : Bool) ==
     var amount : Int, pin : Int;
     caller.pin(;pin); caller.amount(;amount)
     await bank.request(name, pin, amount; result)
end
```

- method calls `caller.pin(...)` and `caller.amount(...)` are type safe by cointerface requirements
- **await** statement: passive waiting for reply from `CentralBank`

Example: `Client` implementation

Optimistic client:

```
class Person(m : MiniBank) implements Client begin
  var name : String, pin : Int;

 op init == !run()

  op run() == success : Bool;
    await m.withdraw(name;success); -- active behavior
    if (success = false) then !run() end

  with MiniBank
    op pin(out p : Int) == p := pin
    op amount(out a : Int) == a := 1000
end
```

- Assuming communication with a fixed minibank `m`

Main ideas of Creol: Programming perspective

- concurrent objects (each with its own virtual processor)
- a notion of asynchronous methods calls, avoids blocking, using processor release points
- high level process control
  - no explicit signaling/notification
  - busy waiting avoided!
- openness by a notion of multiple interfacing
- type-safe call-backs due to cointerfaces

  Remark: abstraction by behavioral interfaces

Example: Buffer

```
interface Buffer begin
  with Producer op put(in x : Int)
  with Consumer op get(out x : Int)
end

class OneSlotBuffer implements Buffer begin
  var value : Int, full : Bool;
  op init == full := false
  with Producer
    op put(in x:Int) == await ¬full; value:= x; full:= true
  with Consumer
    op get(out x:Int) == await full; x:= value; full:= false
end
```

- `init`: initialization code executed at object creation
- synchronization by boolean await

Example: Buffer (cont.)

Illustrating alternation between active and reactive behavior

```
class Consumer(buf: Buffer) implements Consumer begin
  var sum : Int := 0;

  op init == !run()

  op run() == var j : Int;
    while true do await buf.get(;j); sum := sum + j end
  with Any op getSum(out s : Int) == s := sum
end
```

- Call to `buf.get`:
  - Asynchronous
  - **await**: processor release
  - Incoming calls to `getSum` can be served while waiting for reply from `buf`
- Interface `Any`: supertype of all interfaces
  - Any object can call `getSum`

Readers/Writers example (Simple implementation)

interface RW **begin with** RWClient **op** OR() — open read **op** OW() — open write **op** CR() — close read **op** CW() — close write **end**

class RW **implements** RW **begin var** r: Int:=0; **var** w: Int:=0; **with** RWClient **op** OR() == **await** w=0; r:= r+1 **op** OW() == **await** w=0 and r=0; w:= w+1 **op** CR() == r:= r-1 **op** CW() == w:= w-1
end

Note: A client may do asynchronous calls to OR/OW and synchronous calls to CR/CW.

Readers/Writers example (version 2)

```
class RW(db : DataBase) implements RW begin
  var readers : Set[Reader] := ∅, writer : Writer := null,
    pr : Int := 0; // number of pending calls to db.read

  with Reader
    op OR() == await writer = null; readers := readers ∪ caller
    op CR() == readers := readers \ caller
    op read(in key : Int out result : Int) ==
      await caller ∈ readers;
      pr := pr + 1; await db.read(key;result); pr := pr - 1;

  with Writer
    op OW() == await (writer = null && readers = ∅ && pr = 0);
      writer := caller
    op CW() == await caller = writer; writer := null
    op write(in key : Int, value : Int) ==
      await caller = writer; db.write(key,value);
end
```

RW example, remarks (version 2)

- `read` and `write` operations on database may be declared with cointerface `RW`
- Weaker assumptions about `Reader` and `Writer` behavior than in the first version
  - Here we actually check that only registered readers/writers do read/write operations on the database
- The database is assumed to store integer values indexed by `key`
- Counting the number of pending calls to db.read (variable `pr`)

- A reader may call `CR` before all `read` invocations are completed
- For writing activity, we know that there are no pending calls to `db.write` when `writer` is **null**. Why?
- The solution is unfair: writers may starve
- Still, after completing `OW`, we assume that writers will eventually call `CW`. Correspondingly for readers

Summary: Active Objects

- Passive objects usually execute their methods in the thread of control of the caller (Java)
- In multithreaded applications, we must take care of proper synchronization
- Active objects execute their methods in their own thread of control
- Communication is asynchronous
- synchronous communication possible by means of asynchronous communication primitives
- Call and return are decoupled by the use of *labels*
- Usually, active objects use *cooperative* multitasking.
- Cooperative multitasking is specified using *schedulers*. Our scheduler will just randomly pick a next process.

Other versions of Creol/ABS

- with time
- with probabilities
- dynamic class upgrades
- futures (call labels as first class citizens)
- (single and) multiple inheritance
- traits and deltas for software product lines
- groups (sharing a CPU)
- abstract objects defined by object sets
- awareness and modeling of (different) underlying networks
- cloud awareness
- security awareness

For Hoare-style reasoning see [Din and Owe, 2014, Din et al., 2012]

Other PMA Courses

Spring:

- INF3230/INF4231 - Formal modeling and analysis of communicating systems rewriting logic - language and tool Maude
- INF5110 - Compiler construction (each spring)
- INF5140/INF9140 - Specification and verification of parallel systems. ('15, '17,..) Automatic verification using model checking techniques
- INF5906/INF9906 - Selected topics in static analysis. ('16, '18...) analysis of programs at compile time

Fall:

- INF5130/INF9130 - Selected topics in rewriting logic ('15, '17...)

References

[Andrews, 2000] Andrews, G. R. (2000). *Foundations of Multithreaded, Parallel, and Distributed Programming.* Addison-Wesley.

[Din et al., 2012] Din, C. C., Dovland, J., Johnsen, E. B., and Owe, O. (2012). Observable behavior of distributed systems: Component reasoning for concurrent objects. *J. Log. Algebr. Program.*, 81(3):227–256.

[Din and Owe, 2014] Din, C. C. and Owe, O. (2014). A sound and complete reasoning system for asynchronous communication with shared futures. *J. Log. Algebr. Meth. Program.*, 83(5-6):360–383.