Design, Verification, and Testing of Synchronization and Communication Protocols with Java

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Introduction

Communication and Synchronization – an important part of the curriculum:

- Networking – all levels!
- Distance Education Systems
- Real-time & Embedded Systems
- Concurrent Systems Design
  - Operating Systems
  - Applications

Introduction

- Concurrent design: an important part of software engineering:
  - Modular design, with
  - small, simple modules…
  - that run concurrently, and
  - interact infrequently.
- Much easier than a single, large program!!

Introduction

Possible platforms:

- Visual C++
  - Complex concurrency features
  - A year or more of experience
  - .. and some OS experience
- Java
  - Simple concurrency model
  - Widely taught at the introductory level

Java Concurrency

Concurrency support:

- Simple thread model
- Mutual exclusion via *synchronized*:
  - Objects
  - Methods
- A limited conditional wait
- Shared variables
- Message-passing libraries
- Many texts

Java Concurrency

The Java *synchronized* primitive

- Each object has a hidden lock controlling access to code marked as *synchronized*.
- Only one thread at a time may execute a *synchronized* block of code.

Java Concurrency

Conditional Wait

- If a condition is not satisfied, *wait*() can be called – releasing the lock.
- *notify* (or *notifyAll*) wakes the waiting threads.

Java Concurrency

- Caution!
  - Java does not require that access to shared resources be synchronized.
  - The Java specification does not say which thread is awakened on a *notify*.
- These operations must be used very carefully!

CSP

- CSP: a process algebra for dealing with interactions between processes.
- The notation is simple and intuitive.
- CSP does not deal (easily) with the internal behavior of processes.

CSP

The two components of CSP systems:

- *Processes*: indicated by upper-case: `P`, `Q`, `R`, …
- *Events*: indicated by lower-case: `a`, `b`, `c`, …

CSP

Example: a process *P* engages in events *b*, *c*, *a*, and then refuses any further action:

$$P = b \rightarrow c \rightarrow a \rightarrow STOP$$

"→" is the *prefix* operator; `STOP` is a special process that never engages in any event.

CSP

A practical example: a simple pop machine accepts a coin, returns a can of pop, and then repeats forever:

$$PM = coin \rightarrow pop \rightarrow PM$$

CSP

A customer who purchases only one can, consumes it, and then terminates:

`Cust = coin → pop → drink → STOP`

CSP

The pop machine and the customer run in parallel:

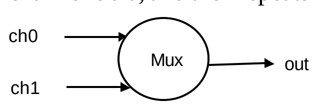
`System = PM [| A |] Cust`

and synchronize on the alphabet

`A = {coin, pop}`

CSP

A multiplexer that accepts an input from either channel 0 or channel 1, passes it out over the channel `out`, and then repeats:




```
Mux =  ch0?x → out!x → Mux
       []
       ch1?x → out!x → Mux
```


CSP and Java Design Procedure

- Design in CSP
- Verify the CSP with the FDR CASE tools:
  - Correctness
  - Deadlock
  - Livelock
- Implement and test in Java

Shared Memory Synchronization – the bank balance problem

Original balance = $1000

Interleaving 1:

	ATM	Payroll Computer
t1	fetch $1000	
t2	balance = $1000 - $100	
t3	store $900	
t4		fetch $900
t5		balance = $900 + $1000
t6		store $1900

Final balance = $1900: Correct!

The bank balance problem

Original balance = $1000

Interleaving 2:

	ATM	Payroll Computer
t1	fetch $1000	
t2		fetch $1000
t3		balance = $1000 + $1000
t4		store $2000
t5	balance = $1000 - $100	
t6	store $900	

Final balance = $900: WRONG!

Bank Balance: Java

Solution:

force the fetch-store-update sequence to be executed atomically.

In Java: use a synchronized method (which returns the new balance):

```
public synchronized
  float update_balance(float deposit);
```


Bank Balance: Modeling in CSP

Create a CSP process that will synchronize with all customers and force the update to be done atomically.

First the customer:

```
Customer =   enter!deposit ->
             exit?new_balance ->
             Customer
```


Bank Balance: CSP

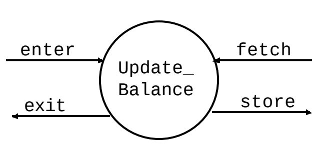
The synchronization process:

accept enter request from the customer

fetch old balance

store new balance

return new balance to customer



Bank Balance: CSP

The synchronization process:

```
Update_Balance =
        enter?deposit ->
        fetch?balance ->
        store!(balance + deposit) ->
        exit!(balance + deposit)->
        Update_Balance
```


Bank Balance: CSP

Multiple customers interleave –
and do not interact with each other:

```
Customers =
            Customer1 |||
            Customer2 |||
            … ||| CustomerN
```


Bank Balance: CSP

The complete system consists of the customers running in parallel with the update process and synchronizing on the enter and exit events:

```
System =    Customers
            [| A |]
            Update_Balance
where A = {enter, exit}
```

Bank Balance: Check the CSP

Correct operation: only one customer is in the critical update section at a time; enforce by requiring the enter and exit events to alternate:

```
Safety_Spec =     enter.x ->
                  exit.y ->
                  Safety_Spec
```


Bank Balance: Check the CSP

The CSP CASE tool FDR will verify that all possible behaviors of the System satisfy the safety specification.

Bank Balance: CSP

A more robust version:

add a customer ID and require that successive `enter`s and `exit`s have the same ID.

Message Passing

CSP-style message-passing libraries for Java:

- JCSP (University of Kent at Canterbury)
- CTJ (University of Twente)

… available on the web:

- **http://www.cs.ukc.ac.uk/projects/ofa/jcsp/**
- **http://www.rt.el.utwente.nl/javapp/**

Nagle Mode Enhancement

TCP messages:

- Messages broken into packets for transmission
- Each packet requires ACK
- Save bandwidth via Nagle mode: ACK only after every second or third packet– or timeout (0.2 s)

Nagle Mode Enhancement

TCP messages

- But: if message is not a multiple of the packet size, we have a “small tail” at the end;
- – a waste of bandwidth, so hold until another message arrives or timeout.
- This may result in a significant delay!
- Short messages: max 5 per second!

Nagle Mode Enhancement

The Doupnik solution:

- Transmit small tail immediately if it is the last of the application's data;
- otherwise hold the tail for arrival of more application data.
- Result: significant improvement in performance!!

Nagle Mode Enhancement

- The problem:
  - Verify improvement with CSP
- The approach:
  - Assume a clock that produces regular *tocks*.
  - Nagle mode will not be able to transmit a short tail until a timeout (a tock) occurs
  - Enhanced mode will transmit the short tail prior to the tock.

Nagle Mode Enhancement

- Assume 1 packet = 2 "chunks"
- A 3-chunk message: 1 packet plus a short tail
- A transmission of 2 chunks (one packet):

```
send!2
```


Nagle Mode Enhancement

- The original Nagle mode will not transmit the third chunk until the 200 ms timeout (a tock) occurs.
- Thus the original Nagle mode cannot transmit the message with no intervening tocks.

Nagle Mode Enhancement

The specification:

Under the enhanced mode, a message with a short packet must be able to be transmitted with no intervening tocks:

```
TCP_SPEC =
  start -> send?2 -> send?1 ->
  finish -> STOP
```


Nagle Mode Enhancement

Verification with FDR:

- FDR verifies that the original Nagle mode cannot meet the spec.
- FDR verifies that the enhanced Nagle mode can transmit the 3-chunk message with no intervening tocks.

Conclusions

- CSP provides an intuitive method for describing synchronization and communication protocols.
- FDR supplies the tools to verify the correctness of the protocols.
- Java + CSP libraries provides the means for implementing and testing the protocols.

The fast track to success:

- Design with CSP
- Verify with FDR
- Implement in Java with little pain!
- Students readily handle systems with up to 60 or so concurrent processes.