Practical Examples

(Ch 5-9 [BenA 06])

Example Problem
Problem Features
System Features
Various Concurrency Solutions

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A Bear, Honey Pot and Bees

- Friendly bees are feeding a trapped bear by collecting honey for it. The life of the trapped bear is just eating and sleeping.
- There are $N$ bees and one bear. The size of the pot is $H$ portions.
- The bees carry honey to a pot, one portion each bee each time until the pot is full. Or maybe more?
- When the pot is full, the bee that brought the last portion wakes up the bear.
- The bear starts eating and the bees pause filling the pot until the bear has eaten all the honey and the pot is empty again. Then the bear starts sleeping and bees start depositing honey again.

[Andrews 2000, Problem 4.36]
Problem Features

- Thousands or millions of bees (N bees), one bear
  - Collecting honey (1 portion) may take very long time
  - Eating a pot of honey (H portions) may take some time
  - Filling up the pot with one portion of honey is fast
  - Same solution ok with N=1000 or N=100 000 000 ?
  - Same solution ok with H=100 or H=1 000 000 ?
  - Same solution ok for wide range of N & H values?

- Unspecified/not well defined feature
  - Could (should) one separate permission to fill the pot, actually filling the pot, and possibly signalling the bear
  - If (one bee) filling the pot is real fast, this may not matter
  - If (one bee) filling the pot takes time, then this may be crucial for performance
  - Can pot be filled from far away?

- What if more than one bears?
Maximize Parallelism

- All bees concurrently active, no unnecessary blocking
- Bees compete only when filling up the pot
  - Must wake up bear when H portions of honey in pot
  - Must fill up the pot one bee at a time
    - Is this important or could we modify specs?
    - How big is the mouth of the pot?
  - Competing just to update the counter would be more efficient?
    - Is waking up the bear part of critical section?
  - What is the real critical section?
Maximize Parallelism (contd)

- Bear wakes up only to eat and only when pot is full
- Bees blocked (to fill the pot) only
  - When bear is eating
  - When waiting for their turn to fill the pot
    - Or to synchronize with other bees
Concurrency Needs

- **When is mutex (critical section) needed?**
  - A bee is filling the pot or the bear is eating

- **When is synchronization needed?**
  - Bees wait for earlier bee to fill the pot
    - Each bee may wait before filling the pot
  - Bees wake up the bear to eat
    - Last (H\textsuperscript{th}) bee wakes up bear after filling the pot
  - Bear lets all bees to resume filling the pot
    - Bear allows it after emptying the pot

- **When is communication needed?**
  - Must know when pot is full? Nr portions in pot now?
  - What if “honey” would be information in buffer?
Environment

• Computational object level
  – Bees and bear are **threads** in one application?
    • Threads managed by programming language?
    • Threads managed by operating system?
  – Bees and bear are **processes**?
    • Communication with progr. language utilities?
    • Communication with oper. system utilities?

• System structure
  – Shared memory uniprocessor/multiprocessor?
  – Distributed system?
  – Networked system?
Busy Wait or Suspended Wait

- Bear waits a long time for full pot?
  - Suspended wait would be better
    (unless lots of processors)
- Bees wait for their turn to fill the pot?
  - Waiting for turn takes relatively long time
    - Earlier bees fill the pot
    - Bear eats the honey
  - Suspended wait ok
- Bees wait for their turn only to update counters?
  - Relatively long time to wait for turn
  - Suspended wait ok
  - If mutex is only for updating counters (not for honey fill-up turn, or bear eating), busy wait might be ok
Evaluate Solutions

- Does it work correctly?
  - Mutex ok, no deadlock, no starvation

- Does it allow for maximum parallelism?
  - Minimally small critical sections
  - Could bees fill up the jar in parallel?

- Is this optimal solution?
  - Overall processing time? Overall communication time?
  - Processor utilization? Memory usage?
  - Response time? Investments/return ratio?

- Is this solution good for current problem/environment?
  - Bees and bear are threads in Java application in 4-processor system running Linux?
  - There are 20000 bees, collecting honey takes 15 min, depositing one portion in pot takes 10 sec, 5000 portions fill the pot, and bear eats the honey in pot in 10 minutes?
Solution with Locks

- Can use locks both for mutex and for synchronization
  - Problem: busy wait for bear
    - Bear waits a long time for full honey pot
      (some bears do not like waiting!)

```c
int portions = 0;  // portions in the pot
lock_var D = 0 = "open";  // mutex to deposit honey in pot
  E = 1 = "closed";  // permission to eat honey

impl. dependent:
lock_var D = 1;  // open
  E = 0;  // locked
```
process bee [i=1 to N] () {
    while (true) {
        collect_honey();
        lock (D);  # only one bee advances at a time
        portions++;
        fill_pot();
        if (portions == H) unlock (E); # wakeup bear, keep lock
        else unlock (D)  # let next bee deposit honey
    }
}

process bear () {
    while (true) {
        lock (E);        # busy-wait, hopefully OK?
        eat_honey();
        portions = 0;
        unlock (D);  # let next bee deposit honey
    }
}

Int portions = 0; # portions in the pot
Lock_var D = 0; # mutex to deposit honey in pot
E = 1; # permission to eat honey
Semaphore Solution

```plaintext
process bee[i=1 to N] {
    while (true) {
        collect_honey();
        into_pot();  # deposit one honey portion into the honey pot
    }
}

process bear {
    while (true) {
        sleep();  # wait until the pot is full
        empty_pot();  # eat all the honey
    }
}
```
Semaphore Solution (contd)

```c
sem mutex = 1,    // mutual exclusion
    pot_full = 0;  // is the pot full of honey?
int portions;     // portions in the pot

procedure into_pot() { # bee deposits one honey portion
    P(mutex);
    fill_pot(); portions++;
    if (portions == H) V(pot_full);  // let bear eat honey, pass baton
    else V(mutex);       // let other bees fill the pot
}

procedure empty_pot() {  // bear eats all honey from the pot
    eat_all_honey();
    portions = 0;
    V(mutex);  // let bees fill the pot again
}
```

procedure sleep () {
    P(pot_full);
}
Semaphore Solution (combined)

process bee [i=1 to N] {
    while (true) {
        collect_honey();
        P (mutex);
        fill_pot();
        portions++;
        if (portions == H)
            V (pot_full);  # let the bear eat honey, pass mutex baton
        else
            V (mutex);                        # let other bees to fill the pot
    }
}

process bear {
    while (true) {
        P (pot_full); # wait until the pot is full   -- sleep
        eat_all_honey();  # -- eat
        portions=0;
        V (mutex);      # let bees start filling the pot again
    }
}

sem mutex = 1,    # mutual exclusion
pot_full = 0;  # synchr bear/bees
int portions;          # portions in the pot

Discussion B
Monitor Solution

- Use monitor only for mutex and synchronization
  - Automatic mutex
  - Use of monitor condition variables for synchronization
    solution for bees and bear

- What type of signalling semantics is in use?
  - E < S < W, i.e., IRR? Assume now no-IRR.

```c
process bee [i=1 to N] {
  while (true) {
    collect_honey();
    pot.into_pot();
  }
}
```

```c
process bear() {
  while (true) {
    pot.wait_full();
    eat_honey();
    pot.empty_pot();
  }
}
```
monitor pot {
    int portions=0; cond pot_full, pot_empty;

    procedure into_pot () {
        while (portions == H) waitC (pot_empty);
        portions++; fill_pot(); # deposit honey in pot
        if (portions == H) signalC (pot_full);
    }

    procedure wait_full () {
        if (portions < H) waitC (pot_full);
    }

    procedure empty_pot () {
        portions = 0;
        signal_allC (pot_empty) # wake up all waiting bees
    }
}
monitor pot {
    int portions=0;
    cond pot_full, pot_empty;

    procedure collect_into_pot() {
        collect_honey();
        while (portions==H) waitC(pot_empty);
        portions=portions+1; fill_pot();
        if (portions==H) signalC(pot_full);
    }

    procedure sleep_and_eat() {
        if (portions < H) waitC(pot_full);
        eat_honey();
        portions=0;
        signal_allC(pot_empty)
    }
}

process bee [i=1 to N] {
    while (true) 
        pot.collect_into_pot();
}

process bear() {
    while (true) 
        pot.sleep_and_eat();
}

Which is better?

What is the problem?
Better Monitor Solution?

- Use monitor only for mutex and synchronization
  - Do fill_pot and all other real work outside monitor?

```java
process bee [i=1 to N] {
  while (true) {
    collect_honey();
    pot.fill_perm();
    fill_pot();
    pot.fill_done();
  }
}

process bear() {
  while (true) {
    pot.wait_full();
    eat_honey();
    pot.empty_pot();
  }
}
```
monitor pot {  # no IRR
    int fill=0, portions=0; cond pot_full, pot_empty;

    procedure fill_perm () {
        while (fill+portions == H) waitC (pot_empty);
        fill++;   # nr of bees with fill permission
    }

    procedure fill_done () {
        fill--; portions++;
        if (portions == H) signalC (pot_full);
    }

    procedure wait_full () {
        if (portions < H) waitC (pot_full);
    }

    procedure empty_pot () {
        portions = 0;
        signal_allC (pot_empty)  # wake up all
    }
}

Another Monitor Solution
(only synchronization, many bees can fill at a time)

process bee [i=1 to N] {
    while (true) {
        collect_honey();
        pot.fill_perm();
        fill_pot();
        pot.fill_done();
    }
}

process bear() {
    while (true) {
        pot.wait_full();
        eat_honey();
        pot.empty_pot();
    }
}

Discussion C
monitor \textit{pot} \{  \texttt{# no IRR}
    int fill=0, portions=0; cond pot_full, pot_empty;
    boolean bee_filling=false; cond fill_turn;

    procedure \textit{fill\_perm} () {
        while (fill+portions == H) \textit{wait} (pot_empty);
        fill++;
        if (bee_filling) \textit{wait} (fill\_turn);
        bee_filling = true;
    }
    procedure \textit{fill\_done} () {
        fill--; portions++; bee_filling = false;
        if (portions == H) \textit{signal} (pot_full);
        else \textit{signal} (fill\_turn);
    }
    procedure \textit{wait\_full} () {
        if (portions < H) \textit{wait} (pot_full);
    }
    procedure \textit{empty\_pot} () {
        portions = 0;
        \textit{signal\_all} (pot_empty);  \texttt{# wake up all
    }
\}

process \texttt{bear} () \{  
    while (true) {
        \textit{collect\_honey}();
        \textit{pot\_fill\_perm}();
        \textit{eat\_honey}();
        \textit{pot\_empty\_pot}();
    }
\}

process \texttt{bee [i=1 to N]} \{  
    while (true) {
        \textit{collect\_honey}();
        \textit{pot\_fill\_perm}();
        \textit{fill\_pot}();
        \textit{pot\_fill\_done}();
    }
\}

Monitor Solution
(only sync, one bee fills at a time)
monitor `pot` {  # no IRR
    int portions=0; cond pot_full, fill_turn;
    boolean bee_filling=false;

    procedure `fill_perm` () {
        while (portions == H or bee_filling)
            `wait` (fill_turn);
        portions++;
        bee_filling = true;
    }
    procedure `fill_done` () {
        bee_filling = false;
        if (portions == H) `signal` (pot_full);
        else `signal` (fill_turn);
    }
    procedure `wait_full` () {
        if (portions < H) `wait` (pot_full);
    }
    procedure `empty_pot` () {
        portions = 0;
        `signal` (fill_turn);  # wake up one
    }
}

process bee [i=1 to N] {
    while (true) {
        `collect_honey();`
        `pot.fill_perm();`
        `fill_pot();`
        `pot.fill_done();`
    }
}

process bear() {
    while (true) {
        `pot.wait_full();`
        `eat_honey();`
        `pot.empty_pot();`
    }
}
private    portions := 0
...

protected body pot is
  entry into_pot when portions < H is
    begin
      portions = portions + 1; fill_pot()
      end deposit_into_pot;

  entry wait_full when portions == H is
    begin  # empty body
      end wait_full;

  procedure empty_pot is
    begin
      portions = 0;
      end empty_pot;
end pot;

process bee [i=1 to N] {
  while (true) {
    collect_honey();
    pot.into_pot;
  }
}  # not Ada syntax

process bear() {
  while (true) {
    pot.wait_full;
    eat_honey();
    pot.empty_pot;
  }
}  # not Ada syntax

What if lots of bees (>> H) waiting in into_pot?

How to modify to do fill_pot() in parallel??
Channel Solution

- Processes communicate via messages to/from channels
  - Difficult to do in distributed environment
  - OK in shared memory systems
- Automatic mutex in message primitives
- Synchronization occurs at message send/receive
  - Messages act as tokens
  - Messages used for synchronization and communication
    - Number of portions in pot is transmitted in messages

```c
chan deposit(); # bees receive from this channel
               # a permission to deposit
               # and nr of current portions in pot
chan wakeup(); # the bear receives from here
               # a permission to eat
```
Is it ok to do fill_pot() in distributed fashion?

process bee [i=1 to N] () {
    while (true) {
        collect_honey ();
        receive (deposit_perm, portions);  # only one bee advances at a time
        portions++;  fill_pot ();                              # deposit one portion
        if (portions == H) send (wakeup, dummy); # pot is full, wakeup bear
        else send (deposit_perm, portions);  # let next bee deposit honey
    }
}

process bear () {
    send (deposit_perm, 0);  # let first bee deposit honey

    while (true) {
        receive (wakeup, dummy);
        eat_honey ();
        send (deposit_perm, 0);  # let next bee deposit honey
    }
}
Message Solution

- Processes communicate via messages to/from processes
- Bear wakes up with wake-up message to it
  - Easy, just one bear
- Messages used only for synchronization or also for communication?
- How to keep track of honey portions
  - Must use messages
- How to send messages to other bees?
  - Too many receivers, not practical
  - Need msg server
Server Solution

- All synchronization problems solved by server
- Server process *pot* gives turns to bees and bear
- Correct bee must get permission to fill up pot
- Centralized solution, like monitor…

```c
chan pot_req (int id), # request from a bee
    pot_perm [i =1 to n] (), # permission for each bee
    bear_wakeup (), # permission to eat for the bear
    bear_done (); # bear finished eating
```
process bee [i=1 to N] () {
    while (true) {
        collect_honey();
        send pot_req(i); # request to deposit
        receive pot_perm[i](); # deposit done
        fill_pot(); bee needs to do it!
    }
}

process bear () {
    while (true) {
        receive bear_wakeup();
        empty_honeypot();
        send pot_perm[i];
    }
}

process pot () {  # server
    int id, # bee id
    portions=0; # portions in the pot
    while (true) {
        receive pot_req(id);
        portions++;
        send pot_perm[id];
        if (portions == H) { # pot is full
            send bear_wakeup();
            receive bear_done();
            portions=0;
        }
    }
}
Server Solution Comments

- Who actually deposits honey in pot and when?
- How to separate *permission to deposit honey* before honey is deposited and *waking up the bear* after honey is deposited?

```plaintext
chan pot_req (int id), # request from a bee
    pot_perm [i =1 to n] (), # permission to deposit
    bee_honey_in_pot (), # deposit done
    bee_can_proceed [i =1 to n] (), # bee can start
        # collecting again
    bear_wakeup (), # permission to eat for bear
    bear_done (); # bear finished eating
```

- What if just **one** request channel and multiple reply channels?
  - Request for turn to deposit, turn to collect, turn to eat, turn to sleep?
  - Replies to bees and bear
Correct Server Solution

- ?????
Rendezvous Solution

- Solution with Rendezvous-server Control_pot
  - Accepts all synchronization requests

```c
process bee [i=1 to N] {
    while (true) {
        collect_honey();
        call Control_pot.into_pot(); # blocks until accepted
        deposit_pot();
        call Control_pot.deposit_done();
    }
}

process bear() {
    while (true) {
        call Control_pot.sleep();
        eat_honey();
        call Control_pot.empty_pot();
    }
}
```
module Control_Pot
  op into_pot(), deposit_pot(), sleep(), empty_pot(); # services
body
  process Pot {
    int portions = 0, deposits=0;
    while (true)
      in  into_pot () and portions+deposits < MAXSIZE  → deposits++;
      [ ] deposit_done()  → deposits--; portions++ ;
      [ ] sleep () and portions == MAXSIZE  → ;
      [ ] empty_pot () and portions == MAXSIZE  → portions=0;
    ni
  }
end Control_pot

• Solution with Ada similarly
RPC Server Solution (2)

- Distributed system over LAN?

```plaintext
process bee [i=1 to N] {
    while (true) {
        collect_honey();
        call Remote_pot.into_pot();
        deposit_honey();
        call Remote_pot.deposit_done();
    }
}

process bear {
    while (true) {
        call Remote_pot.sleep();
        eat_honey();
        call Remote_pot.empty_pot();
    }
}
```
module Remote_pot
  op into_pot(),
    sleep(),
    empty_pot();
body
  int portions;
  sem mutex=1
  pot_full=0
  pot = M;
proc  into_pot() {
  P(pot);
}
proc sleep () {
  P(pot_full);
}
proc empty_pot() {
  portions=0;
  V(mutex);
  for (i=1 to M) V(pot)
}
proc deposit_done() {
  P(mutex);
  portions++;
  if (portions==M)
    V(pot_full)  # bear can eat
  else
    V(mutex);
}
Evaluate Your Solution

- Same problem – many solutions – all correct?
- Does it work correctly?
- Does it allow for maximum parallelism?
- Is this optimal solution?
- Is this solution good for current problem/environment?
  - 25 000 - 250 000 000 bees,
    collecting honey takes 30-60 min,
    depositing one portion in pot takes 1-3 mins,
    10000-100000 portions fill the pot,
    and bear eats the honey in pot in 5-50 minutes?
  - You might get another bear next year? What if much more bees?
  - What if the pot allows for 100-1000 simultaneous fill-ups?
  - Bees and bear are threads in Java application in 4-processor system running Linux?
  - “Honey” is an 80-byte msg to be used by “bear”?
Summary

- Specify first your requirements
- What concurrency tools do you have at your disposal?
- Does your solution match your environment?
- Will some known solution pattern apply here?
  - Readers-writers, producers-consumers, bakery?
- Does it work?
- Is it optimal in time/space?
- Does it allow for maximum parallelism?
- Does it minimize waiting?