

CSGE602055 Operating Systems

CSF2600505 Sistem Operasi

Week 06: Concurrency: Processes & Threads

Rahmat M. Samik-Ibrahim (ed.)

University of Indonesia

<https://os.vlsm.org/>

Always check for the latest revision!

REV194 14-Feb-2019

Operating Systems 2019-1

A (Rm 3114) [Tu/Th 10-12] — B (Rm 3114) [Tu/Th 13-15] — C (Rm 3114)

[Tu/Th 16-18] — D (Rm 2401) [Tu/Th 10-12] — E (Rm 2306) [Tu/Th 13-15]

Week	Schedule	Topic	OSC10
Week 00	07 Feb - 13 Feb 2019	Overview 1, Virtualization & Scripting	Ch. 1, 2, 18.
Week 01	14 Feb - 20 Feb 2019	Overview 2, Virtualization & Scripting	Ch. 1, 2, 18.
Week 02	21 Feb - 27 Feb 2019	Security, Protection, Privacy, & C-language	Ch. 16, 17
Week 03	28 Feb - 06 Mar 2019	File System & FUSE	Ch. 13, 14, 15
Week 04	12 Mar - 18 Mar 2019	Addressing, Shared Lib, & Pointer	Ch. 9
Week 05	19 Mar - 25 Mar 2019	Virtual Memory	Ch. 10
Mid-Term	23-30 Mar 2019 (tba)	MidTerm (UTS)	
Week 06	02 Apr - 08 Apr 2019	Concurrency: Processes & Threads	Ch. 3, 4
Week 07	09 Apr - 15 Apr 2019	Synchronization & Deadlock	Ch. 6, 7, 8
Week 08	16 Apr - 22 Apr 2019	Scheduling	Ch. 5
Week 09	23 Apr - 29 Apr 2019	Storage, BIOS, Loader, & Systemd	Ch. 11
Week 10	30 Apr - 06 May 2019	I/O & Programming	Ch. 12
Reserved	07 May - 17 May 2019		
Final	18-25 May 2019 (tba)	Final (UAS)	This schedule is subject to change.
Extra	27 Jun 2019	Extra assignment confirmation	

The Weekly Check List

- ☐ **Resources:** <https://os.vlsm.org/>
 - ☐ **Download Slides and Demos from GitHub.com**
<https://github.com/UI-FASILKOM-OS/SistemOperasi/>
 - ☐ **Problems** — <https://rms46.vlsm.org/2/>:
195.pdf (Week 00), 196.pdf (Week 01), 197.pdf (Week 02),
198.pdf (Week 03), 199.pdf (Week 04), 200.pdf (Week 05),
201.pdf (Week 06), 202.pdf (Week 07), 203.pdf (Week 08),
204.pdf (Week 09), 205.pdf (Week 10).
 - ☐ **Badak All in One** — [BADAK.cs.ui.ac.id:///extra/](http://badak.cs.ui.ac.id///extra/)
- ☐ **Text Book:** any recent/decent OS book. Eg. (**OSC10**) Silberschatz et. al.: **Operating System Concepts**, 10th Edition, 2018. See also <http://codex.cs.yale.edu/avi/os-book/OS10/>.
- ☐ Encode your **QRC** with size upto 7cm x 7cm (ca. 400x400 pixels):
"OS191 CLASS ID SSO-ACCOUNT Your-Full-Name"
- ☐ Write your Memo (with QRC) **every week**.
- ☐ Login to badak.cs.ui.ac.id via kawung.cs.ui.ac.id for at least **10 minutes** every week. Copy the weekly demo folders into your own badak home directory.
Eg.: `cp -r /extra/Demos/* ~/mydemos/`

Agenda I

- 1 Start
- 2 Schedule
- 3 Agenda
- 4 Week 06
- 5 Week 06
- 6 Process Map
- 7 Process State
- 8 Makefile
- 9 00-fork
- 10 01-fork
- 11 02-fork
- 12 03-fork
- 13 01-fork vs 02-fork vs 03-fork
- 14 04-sleeping
- 15 05-fork
- 16 06-fork

Agenda II

- 17 07-fork
- 18 08-fork
- 19 09-fork
- 20 10-fork
- 21 11-fork
- 22 12-fork
- 23 14-fork
- 24 15-fork
- 25 The End

Week 06 Concurrency: Topics¹

- States and state diagrams
- Structures (ready list, process control blocks, and so forth)
- Dispatching and context switching
- The role of interrupts
- Managing atomic access to OS objects
- Implementing synchronization primitives
- Multiprocessor issues (spin-locks, reentrancy)

¹Source: ACM IEEE CS Curricula 2013

Week 06 Concurrency: Learning Outcomes (1)¹

- Describe the need for concurrency within the framework of an operating system. [Familiarity]
- Demonstrate the potential run-time problems arising from the concurrent operation of many separate tasks. [Usage]
- Summarize the range of mechanisms that can be employed at the operating system level to realize concurrent systems and describe the benefits of each. [Familiarity]
- Explain the different states that a task may pass through and the data structures needed to support the management of many tasks. [Familiarity]

¹Source: ACM IEEE CS Curricula 2013

Week 06 Concurrency: Learning Outcomes (2)¹

- Summarize techniques for achieving synchronization in an operating system (e.g., describe how to implement a semaphore using OS primitives). [Familiarity]
- Describe reasons for using interrupts, dispatching, and context switching to support concurrency in an operating system. [Familiarity]
- Create state and transition diagrams for simple problem domains. [Usage]

¹Source: ACM IEEE CS Curricula 2013

Week 06: Concurrency: Processes & Threads

- Reference: (OSC10-ch03 OSC10-ch04 demo-w06)
- Process Concept
 - Program (passive) \leftrightarrow Process (active)
 - Process in Memory: | *Stack* \cdots *Heap* | *Data* | *Text* |
 - Process State: | *running* | *waiting* | *ready* |
 - Process Control Block (PCB)
 - /proc/, Process State, Program Counter, Registers, Management Information.
- Process Creation
 - PID: Process Identifier (uniq)
 - The Parent Process forms a tree of Children Processes
 - `fork()`, new process system call (clone)
 - `exec1p()`, replaces the clone with a new program.
- Process Termination
 - `wait()`, until the child process is terminated.
- PCB (Context) Switch

A PROCESS IN MEMORY



(c) 2017 VauLSMorg

Figure: A Process in (**logical**) Memory

Process State



Figure: A Process State

Process Scheduling

- Scheduling Queue
- Schedulers
 - Long Term (non VM) vs Short Term (CPU)
 - (I/O vs CPU) Bound Processes
- Context Switch
- I/O Queue Scheduling
- Android Systems
 - Dalvik VM Performance Problem: Replaced with ART (Android Runtime).
 - Foreground Processes: with an User Interface (UI) for Videos, Images, Sounds, Texts, etc.
 - Background Processes: with a service with no UI and small memory footprint.

Inter-Process Communication (IPC)

- Independent vs Cooperating Processes.
 - Cooperation: Information Sharing, Computational Speedup, Modularity, Convenience.
- Shared Memory vs Message Passing.
 - Message Passing: Direct vs Indirect Communication
- Client-Server Systems
 - Sockets
 - RPC: Remote Procedure Calls
 - Pipes

- Single vs Multithreaded Process
 - MultiT Benefits: Responsiveness, Resource Sharing, Economy, Scalability
- Multicore Programming
 - Concurrency vs. Parallelism
- Multithreading Models (Kernel vs User Thread)
 - Many to One
 - One to One
 - Many to Many
 - Multilevel Models
- Threading Issues
 - Parallelism on a multi-core system.
- Pthreads

Makefile

```
CC=gcc
P00=00-fork
P01=01-fork
...
P14=14-fork
P15=15-fork

EXECS= \
    $(P00) \
    $(P01) \
    ...
    $(P14) \
    $(P15) \

all: $(EXECS)

$(P00): $(P00).c
    $(CC) $(P00).c -o $(P00)

$(P01): $(P01).c
    $(CC) $(P01).c -o $(P01)

...

$(P14): $(P14).c
    $(CC) $(P14).c -o $(P14)

$(P15): $(P15).c
    $(CC) $(P15).c -o $(P15)

clean:
    rm -f $(EXECS)
```

```
/*
 * (c) 2016-2017 Rahmat M. Samik-Ibrahim
 * https://rahmatm.samik-ibrahim.vlsm.org/
 * This is free software.
 * REV04 Mon Oct 30 10:28:12 WIB 2017
 * START Mon Oct 24 09:42:05 WIB 2016
 */

#include <stdio.h>
#include <unistd.h>
#include <sys/types.h>

void main(void) {
    printf("  [[[ This is 00-fork: PID[%d] PPID[%d] ]]]\n",
           getpid(), getppid());
}

>>>> $ 00-fork

[[[ This is 00-fork: PID[5777] PPID[1350] ]]]
```


01-fork

```
>>>> $ cat 01-fork.c ; echo "=====" ; ./01-fork
/* (c) 2016-2017 Rahmat M. Samik-Ibrahim
 * https://rahmatm.samik-ibrahim.vlsm.org/
 * This is free software.
 */

#include <stdio.h>
#include <unistd.h>
#include <sys/types.h>
#include <sys/wait.h>

void main(void) {
    char *iAM="PARENT";

    printf("PID[%d] PPID[%d] (START:%s)\n", getpid(), getppid(), iAM);
    if (fork() > 0) {
        sleep(1);          /* LOOK THIS ***** */
        printf("PID[%d] PPID[%d] (IFFO:%s)\n", getpid(), getppid(), iAM);
    } else {
        iAM="CHILD";
        printf("PID[%d] PPID[%d] (ELSE:%s)\n", getpid(), getppid(), iAM);
    }
    printf("PID[%d] PPID[%d] (STOP:%s)\n", getpid(), getppid(), iAM);
}

=====
PID[5784] PPID[1350] (START:PARENT)
PID[5785] PPID[5784] (ELSE:CHILD)
PID[5785] PPID[5784] (STOP:CHILD)
PID[5784] PPID[1350] (IFFO:PARENT)
PID[5784] PPID[1350] (STOP:PARENT)
>>>> $
```

02-fork

```
>>>>> $ cat 02-fork.c ; echo "=====" ; ./02-fork
/* (c) 2016-2017 Rahmat M. Samik-Ibrahim
 * https://rahmatm.samik-ibrahim.vlsm.org/
 * This is free software.
 */

#include <stdio.h>
#include <unistd.h>
#include <sys/types.h>
#include <sys/wait.h>

void main(void) {
    char *iAM="PARENT";

    printf("PID[%d] PPID[%d] (START:%s)\n", getpid(), getppid(), iAM);
    if (fork() > 0) {
        printf("PID[%d] PPID[%d] (IFFO:%s)\n", getpid(), getppid(), iAM);
    } else {
        iAM="CHILD";
        printf("PID[%d] PPID[%d] (ELSE:%s)\n", getpid(), getppid(), iAM);
        sleep(1);      /* LOOK THIS ***** */
    }
    printf("PID[%d] PPID[%d] (STOP:%s)\n", getpid(), getppid(), iAM);
}

=====
PID[5792] PPID[1350] (START:PARENT)
PID[5792] PPID[1350] (IFFO:PARENT)
PID[5792] PPID[1350] (STOP:PARENT)
PID[5793] PPID[5792] (ELSE:CHILD)
>>>>> $ PID[5793] PPID[1] (STOP:CHILD)
>>>>> $
```

03-fork

```
>>>>> $ cat 03-fork.c ; echo "=====" ; ./03-fork
/* (c) 2016-2017 Rahmat M. Samik-Ibrahim
 * https://rahmatm.samik-ibrahim.vlsm.org/
 * This is free software.
 */

#include <stdio.h>
#include <unistd.h>
#include <sys/types.h>
#include <sys/wait.h>

void main(void) {
    char *iAM="PARENT";

    printf("PID[%d] PPID[%d] (START:%s)\n", getpid(), getppid(), iAM);
    if (fork() > 0) {
        wait(NULL);          /* LOOK THIS ***** */
        printf("PID[%d] PPID[%d] (IFFO:%s)\n", getpid(), getppid(), iAM);
    } else {
        iAM="CHILD";
        printf("PID[%d] PPID[%d] (ELSE:%s)\n", getpid(), getppid(), iAM);
    }
    printf("PID[%d] PPID[%d] (STOP:%s)\n", getpid(), getppid(), iAM);
}

=====
PID[5799] PPID[1350] (START:PARENT)
PID[5800] PPID[5799] (ELSE:CHILD)
PID[5800] PPID[5799] (STOP:CHILD)
PID[5799] PPID[1350] (IFFO:PARENT)
PID[5799] PPID[1350] (STOP:PARENT)
>>>>> $
```

01-fork vs 02-fork vs 03-fork

```
>>>>> $ ./01-fork
PID[5803] PPID[1350] (START:PARENT)
PID[5804] PPID[5803] (ELSE:CHILD)
PID[5804] PPID[5803] (STOP:CHILD)
PID[5803] PPID[1350] (IFF0:PARENT)
PID[5803] PPID[1350] (STOP:PARENT)
>>>>> $ ./02-fork
PID[5805] PPID[1350] (START:PARENT)
PID[5805] PPID[1350] (IFF0:PARENT)
PID[5805] PPID[1350] (STOP:PARENT)
PID[5806] PPID[5805] (ELSE:CHILD)
>>>>> $ PID[5806] PPID[1] (STOP:CHILD)

>>>>> $ ./03-fork
PID[5807] PPID[1350] (START:PARENT)
PID[5808] PPID[5807] (ELSE:CHILD)
PID[5808] PPID[5807] (STOP:CHILD)
PID[5807] PPID[1350] (IFF0:PARENT)
PID[5807] PPID[1350] (STOP:PARENT)
>>>>> $
```

04-sleeping

```
#include <stdio.h>
#include <unistd.h>
void main(void) {
    int ii;
    printf("Sleeping 3s with fflush(): ");
    fflush(NULL);
    for (ii=0; ii < 3; ii++) {
        sleep(1);
        printf("x ");
        fflush(NULL);
    }
    printf("\nSleeping with no fflush(): ");
    for (ii=0; ii < 3; ii++) {
        sleep(1);
        printf("x ");
    }
    printf("\n");
}
Sleeping 3s with fflush(): x x x
Sleeping with no fflush(): x x x
```

05-fork

```
#include <stdio.h>
#include <unistd.h>
#include <sys/types.h>
#include <sys/wait.h>

void main(void) {
    printf("Start:          PID[%d] PPID[%d]\n", getpid(), getppid());
    fflush(NULL);
    if (fork() == 0) {
        /* START BLOCK
           END   BLOCK */
        execlp("./00-fork", "00-fork", NULL);
        printf("Child:          ");
    } else {
        wait(NULL);
        printf("Parent:          ");
    }
    printf("          PID[%d] PPID[%d] <<< <<< <<<\n", getpid(), getppid());
}
```

```
execlp =====
Start:          PID[6007] PPID[1350]
[[[ This is 00-fork: PID[6008] PPID[6007] ]]]
Parent:          PID[6007] PPID[1350] <<< <<< <<<
```

```
no execlp =====
Start:          PID[6040] PPID[1350]
Child:          PID[6041] PPID[6040] <<< <<< <<<
Parent:          PID[6040] PPID[1350] <<< <<< <<<
```

06-fork

```
#include <sys/types.h>
#include <sys/wait.h>
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>

/***** main ***/
void main(void) {
    pid_t val1, val2, val3;
    val3 = val2 = val1 = 1000;
    printf("PID==%4d ==== \n", getpid());
    fflush(NULL);
    val1 = fork();
    wait(NULL);
    val2 = fork();
    wait(NULL);
    val3 = fork();
    wait(NULL);

    /* ***** START BLOCK *
       ***** END** BLOCK */
    printf("VAL1=%4d VAL2=%4d VAL3=%4d\n", val1, val2, val3);
}

=====
PID==6072 ==== \n
VAL1=  0 VAL2=  0 VAL3=  0
VAL1=  0 VAL2=  0 VAL3=6075
VAL1=  0 VAL2=6074 VAL3=  0
VAL1=  0 VAL2=6074 VAL3=6076
VAL1=6073 VAL2=  0 VAL3=  0
VAL1=6073 VAL2=  0 VAL3=6078
VAL1=6073 VAL2=6077 VAL3=  0
VAL1=6073 VAL2=6077 VAL3=6079
```

07-fork

```
>>>> $ cat 07-fork.c
/*
 * (c) 2005-2017 Rahmat M. Samik-Ibrahim
 * https://rahmatm.samik-ibrahim.vlsm.org/
 * This is free software.
 * REV05 Mon Oct 30 10:57:02 WIB 2017
 * REV02 Mon Oct 24 10:43:00 WIB 2016
 * REV01 Sun Feb 27 08:31:46 WIB 2011
 * START 2005
 */

#include <sys/types.h>
#include <sys/wait.h>
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#define DISPLAY1 "START * PARENT *** ** PID (%4d) ** *****\n"
#define DISPLAY2 "RANDOM: val1(%4d) -- val2(%4d) -- val3(%4d)\n"
/***** main ** */
void main(void) {
    pid_t val1, val2, val3;
    printf(DISPLAY1, getpid());
    val1 = fork();
    val2 = fork();
    val3 = fork();
    printf(DISPLAY2, val1, val2, val3);
    wait(NULL);
    wait(NULL);
    wait(NULL);
    /* ***** START BLOCK ***
     ***** END * BLOCK *** */
}
```


07-fork (2)

```
>>>> $ 07-fork
START * PARENT *** ** PID (6160) ** *****
RANDOM: val1(6161) -- val2(6162) -- val3(6163)
RANDOM: val1(6161) -- val2(6162) -- val3(  0)
RANDOM: val1(6161) -- val2(  0) -- val3(6165)
RANDOM: val1(6161) -- val2(  0) -- val3(  0)
RANDOM: val1(  0) -- val2(6164) -- val3(6166)
RANDOM: val1(  0) -- val2(6164) -- val3(  0)
RANDOM: val1(  0) -- val2(  0) -- val3(6167)
RANDOM: val1(  0) -- val2(  0) -- val3(  0)
>>>> $ 07-fork
START * PARENT *** ** PID (6168) ** *****
RANDOM: val1(6169) -- val2(6170) -- val3(6172)
RANDOM: val1(6169) -- val2(  0) -- val3(6173)
RANDOM: val1(6169) -- val2(6170) -- val3(  0)
RANDOM: val1(  0) -- val2(6171) -- val3(6174)
RANDOM: val1(6169) -- val2(  0) -- val3(  0)
RANDOM: val1(  0) -- val2(  0) -- val3(6175)
RANDOM: val1(  0) -- val2(  0) -- val3(  0)
RANDOM: val1(  0) -- val2(6171) -- val3(  0)
>>>> $ 07-fork
START * PARENT *** ** PID (6176) ** *****
RANDOM: val1(6177) -- val2(6178) -- val3(6181)
RANDOM: val1(  0) -- val2(6179) -- val3(6180)
RANDOM: val1(  0) -- val2(6179) -- val3(  0)
RANDOM: val1(  0) -- val2(  0) -- val3(6182)
RANDOM: val1(6177) -- val2(  0) -- val3(6183)
RANDOM: val1(6177) -- val2(  0) -- val3(  0)
RANDOM: val1(6177) -- val2(6178) -- val3(  0)
RANDOM: val1(  0) -- val2(  0) -- val3(  0)
>>>> $
```

08-fork

```
/* (c) 2005-2017 Rahmat M. Samik-Ibrahim
 * https://rahmatm.samik-ibrahim.vlsm.org/
 * This is free software.
 * REV02 Thu Oct 26 12:27:30 WIB 2017
 * START 2005
 */
#include <sys/types.h>
#include <sys/wait.h>
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
void main(void) {
    int ii=0;
    if (fork() == 0) ii++;
    wait(NULL);
    if (fork() == 0) ii++;
    wait(NULL);
    if (fork() == 0) ii++;
    wait(NULL);
    printf ("Result = %d \n",ii);
    exit(0);
}
=====
Result = 3
Result = 2
Result = 2
Result = 1
Result = 2
Result = 1
Result = 1
Result = 0
>>>>> $
```

```
/*
 * (c) 2015-2017 Rahmat M. Samik-Ibrahim
 * https://rahmatm.samik-ibrahim.vlsm.org/
 * REV03 Mon Oct 30 11:04:10 WIB 2017
 * REV00 Mon Oct 24 10:43:00 WIB 2016
 * START 2015
 */

#include <stdio.h>
#include <sys/types.h>
#include <sys/wait.h>
#include <unistd.h>

void main(void) {
    int value;

    value=fork();
    wait(NULL);
    printf("I am PID[%4d] -- The fork() return value is: %4d\n", getpid(), value);

    value=fork();
    wait(NULL);
    printf("I am PID[%4d] -- The fork() return value is: %4d\n", getpid(), value);
}

=====
I am PID[6225] -- The fork() return value is:    0)
I am PID[6226] -- The fork() return value is:    0)
I am PID[6225] -- The fork() return value is: 6226)
I am PID[6224] -- The fork() return value is: 6225)
I am PID[6227] -- The fork() return value is:    0)
I am PID[6224] -- The fork() return value is: 6227)
>>>>> $
```

10-fork

```
/* (c) 2016-2017 Rahmat M. Samik-Ibrahim
 * https://rahmatm.samik-ibrahim.vlsm.org/
 * This is free software.
 * REV02 Mon Oct 30 20:25:44 WIB 2017
 */

#include <stdio.h>
#include <sys/types.h>
#include <sys/wait.h>
#include <unistd.h>

void procStatus(int level) {
    printf("L%d: PID[%d] (PPID[%d])\n", level, getpid(), getppid());
    fflush(NULL);
}

int addLevelAndFork(int level) {
    if (fork() == 0) level++;
    wait(NULL);
    return level;
}

void main(void) {
    int level = 0;
    procStatus(level);
    level = addLevelAndFork(level);
    procStatus(level);
}

=====
L0: PID[7540] (PPID[1350])
L1: PID[7541] (PPID[7540])
L0: PID[7540] (PPID[1350])
```

11-fork

```
/* (c) 2016-2017 Rahmat M. Samik-Ibrahim
 * https://rahmatm.samik-ibrahim.vlsm.org/
 * This is free software.
 * REV02 Mon Oct 30 20:27:24 WIB 2017
 * START Mon Oct 24 09:42:05 WIB 2016
 */

#define LOOP 3
#include <stdio.h>
#include <sys/types.h>
#include <sys/wait.h>
#include <unistd.h>

void procStatus(int level) {
    printf("L%d: PID[%d] (PPID[%d])\n", level, getpid(), getppid());
    fflush(NULL);
}

int addLevelAndFork(int level) {
    if (fork() == 0) level++;
    wait(NULL);
    return level;
}

void main(void) {
    int ii, level = 0;
    procStatus(level);
    for (ii=0;ii<LOOP;ii++) {
        level = addLevelAndFork(level);
        procStatus(level);
    }
}
```

11-fork (2)

```
L0: PID[7548] (PPID[1350])
L1: PID[7549] (PPID[7548])
L2: PID[7550] (PPID[7549])
L3: PID[7551] (PPID[7550])
L2: PID[7550] (PPID[7549])
L1: PID[7549] (PPID[7548])
L2: PID[7552] (PPID[7549])
L1: PID[7549] (PPID[7548])
L0: PID[7548] (PPID[1350])
L1: PID[7553] (PPID[7548])
L2: PID[7554] (PPID[7553])
L1: PID[7553] (PPID[7548])
L0: PID[7548] (PPID[1350])
L1: PID[7555] (PPID[7548])
L0: PID[7548] (PPID[1350])
```

12-fork

```
#include <stdio.h>
#include <unistd.h>
#include <sys/types.h>
#include <sys/wait.h>

void waitAndPrintPID(void) {
    wait(NULL);
    printf("PID: %d\n", getpid());
    fflush(NULL);
}

void main(int argc, char *argv[]) {
    int rc, status;

    waitAndPrintPID();
    rc = fork();
    waitAndPrintPID();
    if (rc == 0) {
        fork();
        waitAndPrintPID();
        execlp("./00-fork", "00-fork", NULL);
    }
    waitAndPrintPID();
}

=====
PID: 7614
PID: 7615
PID: 7616
[[[ This is 00-fork: PID[7616] PPID[7615] ]]]
PID: 7615
[[[ This is 00-fork: PID[7615] PPID[7614] ]]]
PID: 7614
PID: 7614
>>>>> $
```

14-fork

```
#include <stdio.h>
#include <unistd.h>
#include <sys/types.h>
#include <sys/wait.h>
#include <stdlib.h>

void main(void) {
    int firstPID = (int) getpid();
    int RelPID;

    fork();
    wait(NULL);
    fork();
    wait(NULL);
    fork();
    wait(NULL);

    RelPID=(int)getpid()-firstPID+1000;
    printf("RelPID: %d\n", RelPID);
    fflush(NULL);
}

=====
RelPID: 1003
RelPID: 1002
RelPID: 1004
RelPID: 1001
RelPID: 1006
RelPID: 1005
RelPID: 1007
RelPID: 1000
>>>> $
```


15-fork

```
#include <stdio.h>
#include <sys/types.h>
#include <unistd.h>
#include <sys/wait.h>
#define NN 2

void main (void) {
    int ii, id1000=getpid()-1000;
    for (ii=1; ii<=NN; ii++) {
        fork();
        wait(NULL);
        int rPID = getpid()-id1000; // "relative"
        int rPPID=getppid()-id1000; // "relative"
        if (rPPID < 1 || rPID < rPPID) rPPID=999;
        printf("Loop [%d] - rPID[%d] - rPPID[%4d]\n", ii, rPID, rPPID);
        fflush(NULL);
    }
}

=====
Loop [1] - rPID[1001] - rPPID[1000]
Loop [2] - rPID[1002] - rPPID[1001]
Loop [2] - rPID[1001] - rPPID[1000]
Loop [1] - rPID[1000] - rPPID[ 999]
Loop [2] - rPID[1003] - rPPID[1000]
Loop [2] - rPID[1000] - rPPID[ 999]
>>>>> $
```

The End

- ☐ This is the end of the presentation.
- ☒ This is the end of the presentation.
 - This is the end of the presentation.