# Distributed Systems
## Inter-Process Communication

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# Agenda

1. Processes
2. Communication
3. Parameter Handling

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1 Processes

2 Communication

3 Parameter Handling

# Programs and Processes

- A **Program** is an executable piece of software including a set of instructions
- A **Process** is a program currently executed by an operating system

## Program Classification

- Available in a hardware-specific binary format (and thus including the machine instructions) to be directly executable by the Operating System.
  Example: Windows `*.exe` and `*.com` files; UNIX `ELF` and `a.out` files
- Require an additional **Interpreter**, usually executing the statements sequentially.
  Example: Unix shell scripts, PERL, JAVA scripts
- Available in machine-independent binary format (Byte-code) to be executed within a certain environment: **Virtual Machine**.
  Example: JAVA `*.jar` files; Python script files

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# Processes, Threads and LWPs

- Processes:
  - A process possess a environment which is inherited from its parent
  - The OS manages processes
  - Each process contains a **Process Control Block PCB**) which maintains its attributes
- Threads:
  - Individual tasks within a process may be individual assigned to **threads**
  - A process can schedule several (concurrent) threads: multithreading
  - Unix Operating Systems supporting POSIX Pthreads

# Inter-Process Communication (IPC)

- In order to cooperatively work on a common task processes need to exchange information
- A process shares common resources (e.g., memory) $\Rightarrow$ threads may access these resources concurrently
- Processes on the same computer also share common resources (e.g., the file system), but in most cases they require support from the OS to exchange information
- Processes in a distributed system have to rely on message passing

**What type of information is exchanged?**

- Occurrence of events
- Program flow information
- Program data

# Agenda

# Types of Inter-Process Communication (IPC)

- **Files**
  An resource stored in the file system which can be accessed by multiple processes
- **Signals and Flags**
  Notify another process about the occurrence of an event
- **Pipes**
  An unidirectional channel between two processes (can be named or anonymous)
- **Shared Memory**
  A memory block that can be accessed by multiple processes
- **Message Queues**
  Processes use a queue for message exchange
- **(IP and Unix domain) Sockets**
  An inode or network based communication end point

# Files

- **Linux**
  - File descriptors represent file handles
  - Part of the POSIX API
  - Per default every process owns three file descriptors (`stdin`, `stdout`, and `stderr`)
  - File descriptors can be used for, e.g., reading, writing, seeking, or truncating a file
- **RIOT**
  - Virtual File System may be implemented by various backends
  - Not all IoT devices provide persistent memory
  - If available, persistent memory is often realized on flash memory $\rightarrow$ wear leveling is required

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# Signals and Flags

- **Linux**
  - POSIX signals
  - Standardized messages to trigger a certain behaviour
  - The receiver process gets interrupted
  - If a signal is unhandled by the receiver, it will terminate
- **RIOT**
  - Thread flags
  - Optional kernel feature
  - Notify threads of conditions in a race-free and allocation-less way

# Pipes

- **Linux**
  - A simplex FIFO, i.e., a unidirectional data channel
  - One process accesses the write end, the other the read end of the pipe
  - It can be anonymous or named via an inode in the file system
- **RIOT**
  - No equivalent available

# Shared Memory

- **Linux**
  - POSIX shared memory objects
  - A shared memory object can be **mapped** into the process' memory space
  - Shared memory objects are accessed in a similar manner as files
- **RIOT**
  - Since most MCUs do not provide a MMU, all processes can typically access all memory regions ...

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# Message Queues

- Linux
  - POSIX and System V message queues
  - Queues are named and can be shared via this name between processes
  - Message have priorities
- RIOT
  - Kernel messages and mailboxes
  - Optional feature
  - Block and non-block API available
  - A thread may create a message buffer
  - Mailboxes can be accessed by multiple processes

# Sockets

- **Linux**
  - POSIX (or BSD) Sockets
  - Common API for Internet and Unix Domain sockets
  - A socket represents the endpoint of a communication endpoint
- **RIOT**
  - POSIX Sockets on top of the **sock** interface
  - sock is currently implemented for ...
    - TCP
    - UDP
    - Raw IP
    - DTLS
    - DNS
  - More lightweight and custom-tailored $\Rightarrow$ less generic

# Types of Inter-Process Communication (IPC)

Which type of IPC can be used for what?

- Files
- Signals and Flags
- Pipes
- Shared Memory
- Message Queues
- (IP and Unix domain) Sockets

# Agenda

# Parameter Handling

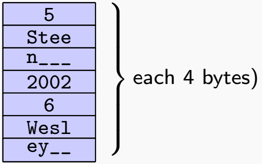
- Heterogeneity Problem
  - Different **encodings** (e.g., ASCII, UTF-8)
  - Endianness → little endian vs. big endian
  - Differing number formats
- Possible solutions
  - Mapping between local data representations
    - Sender uses its local representation, the receiver transforms it
    - ⇒ Requires $n \cdot n$ mappings
  - **Canonical network representation** for all types
    - Requires $2n$ mappings (for $n$ local representations)
    - Potentially unnecessary encoding

# Common Network Representations: XDR

- **External Data Representation**
  - Defined by Sun as part of SunRPC
  - Mostly Motorola 68000 data formats: ASCII; big endian, two complements; IEEE floating points, ...
  - Compound data types: arrays, structures, unions
  - No explicit data typing, i.e., no self-describing data
  - For RPC systems the parameter types are known for both sides during generation via the stub codes

## Example

```
struct {
    string author<>;
    int year;
    string publisher<>;
    }
```



# Common Network Representations: ASN.1 BER

- **ISO Abstract Syntax Notation Number 1, Basic Encoding Rules, ISO 8824, 8825, ITU X.409**
  - Explicit data types, i.e., the type information precedes all data fields
  - Commonly used: CANopen, LDAP, UMTS/LTE, VoIP, Encryption
  - Standard representation: (type, length, value)
  - Drawback: runtime costly (bit access)

## Example

```
count ::=INTEGER
```

| Byte | |
|---|---|
| 0 2 | } Type (Identifier) |
| 0 1 | } Length |
| 1 A | } Value($26_{10}$) |

each 1 byte (hex)

Type Identifier:

| 7 6 | 5 | 4 … 0 |
|---|---|---|
| Class | Type | Tag |

| | | |
|---|---|---|
| Tag: | 1 | Boolean |
| | 2 | Integer, ... |
| | 16 | Sequence |
| Type: | 0 | Primitive |
| | 1 | Constructed |
| Class: | 00 | Universal |
| | 01 | Application... |

# Common Network Representation: CDR

- **Common Data Representation**
  - Defintion in OMG CORBA 2.0
  - Use for CORBA IIOP protocol
  - Sender uses its own format, "‘Receiver makes it right"’
  - Simple types (`short, long, float, char, ...`)
  - Complex types (`sequence, string, union, struct, ...`)
  - Alignment/Padding according to the multiple of the element length
  - Big endian

## Example

```
1 struct <string, unsigned long>
```

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | | | | 'S' | 'T' | 'E' | 'E' | 'N' | | | | 2002 | | | |
| 05 | 00 | 00 | 00 | 53 | 54 | 45 | 45 | 4E | 00 | 00 | 00 | 00 | 00 | 07 | D2 |
| ← Länge → | | | | | | | | | ← Padding → | | | | | | |

# Common Network Representations: JSON

- JavaScript Object Notation Data Interchange Format
  - Lean, text based exchange format
  - Independent of programming languages
  - RFC 7159, derived from ECMAScript
  - Easy to parse, many parsers available
  - Simple types (string, number, boolean, null)
  - Complex types (object, array)
    - An object is an unordered list of name/value pairs
    - A name is a string and the values may be a simple type, an object, or an array
    - An array is an ordered sequence of values

## Example

```
{
    "AUTHOR" : "Steen",
    "YEAR" : 2002,
    "PUBLISHER" : "Wesley"
}
```

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# Problems

- Complex, compound parameter types
  - e.g., structs, arrays, require rules for serialization
- Addresses in parameters
  - No meaning at the destination's address space
  - Most simple solution: prohibit addresses, only allow call-by-value (e.g., SunRPC)
  - Use of a common, global address space if possible
  - Replace pointers by markers and reconstruct compound data structures at receiver side by pointers (e.g., DCE RPC)

Important takeaway messages of this chapter

- IPC is required to exchange information between processes (or threads)
- Various common concepts exist implemented differently for different operating systems
- If data is exchanged between hosts in the network a common interpretation of the data is required