AN EXPERIMENTAL OPERATING SYSTEM

An operating system project for junior year undergraduate computer science students.

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What is XOS?

- A platform for students to build a simple operating system.
- XOS is to be built from scratch by the students according to the specification provided.
- Runs on a simulated machine hardware called XSM (Experimental String Machine).
- The hard disk is simulated and uses a file system called XFS (Experimental File System)
- Package includes machine simulator, system and application programming language compilers, file system interface, specification of components and a roadmap.

Why XOS?

- **Simple and Easy-to-understand:** Only essential and important features for giving an elementary understanding and practical feel.
- **Conceptual Clarity:** The operating system kernel completely resides in the machine memory, unlike popular instructional operating systems like Nachos.
- **Complete Package:** A complete simulation environment, interfaces and programming language compilers are provided.
- **Well Documented:** Every component is documented in detail and an implementation roadmap is provided.

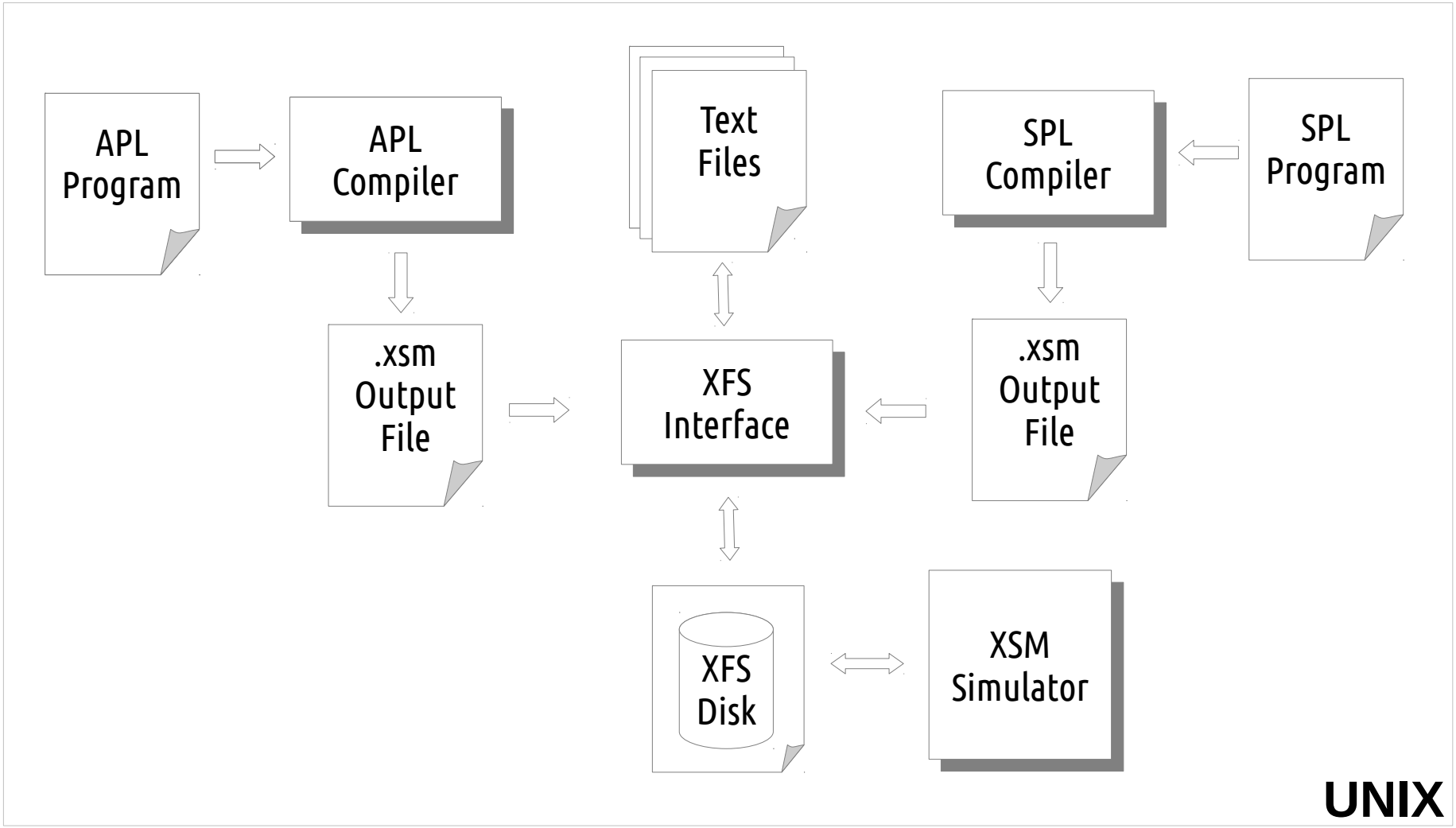
What is not there?

- Device Management or asynchronous devices
- Interprocess Communication
- File Caching and File Permissions
- Limited support of process synchronization has been suggested as enhancements to XOS. This includes process sytem calls like Wait, Signal, Getpid and Getppid.

Components

- Experimental String Machine (XSM) Simulator
- Experimental File System (XFS) Interface
- System Programmer's Language (SPL) Cross Compiler
- Application Programmer's Language (APL) Cross Compiler
- Experimental Operating System Specification and Roadmap

How they interact?



Experimental String Machine (XSM)

- XOS runs on a simulated machine hardware called XSM.
- Smallest addressable unit is a word which is string of 16 characters.
- Native 2-address instruction set architecture.
- Components include timer, registers, memory and disk.

Experimental String Machine (XSM)

- **Timer** in XSM occurs in fixed number of instructions.
- **Registers** in XSM include
  - Program Registers (R0 – R7) to be used by application programs
  - Kernel Registers (S0 – S15) to be used by system routines
  - Temporary Registers (T0 – T4) for compiling system programs
  - Special Purpose Registers, BP, IP, SP, PTBR, PTLR and EFR.
  - IP cannot be modified other than through IRET and jump / branching instructions
- **Memory** of XSM has 64 pages, with page size 512 words.
- **Disk** is simulated using a UNIX file.

Experimental String Machine (XSM)

- Operation is simplified by using **LOAD** and **STORE** instructions and not using a DMA controller.
- Machine supports multiprogramming and virtual memory.
- Exceptions occur during page fault, invalid instructions or arguments, and invalid operations.
- Upon encountering an exception, control is transferred to Exception Handler Routine.
- Machine has two privilege modes, USER and KERNEL modes.

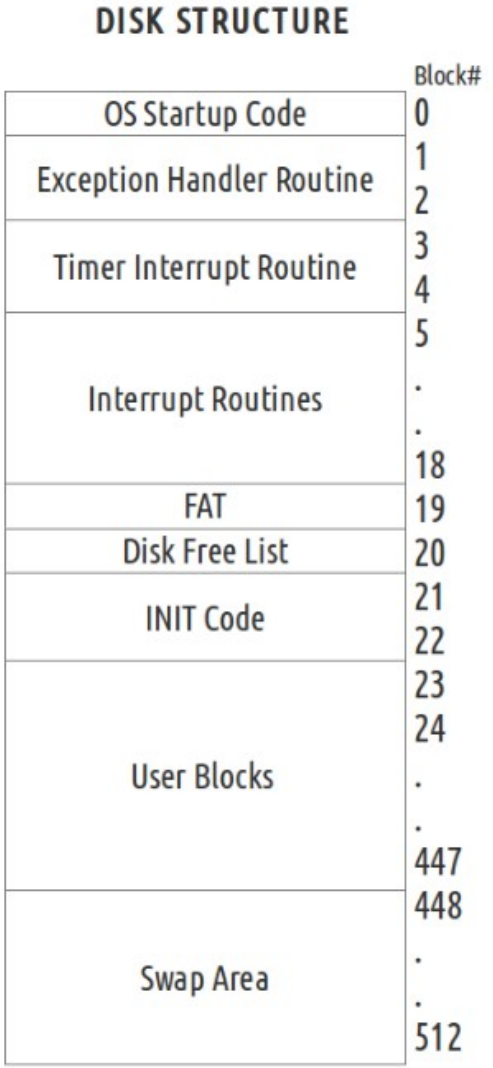
Experimental String Machine (XSM)

- Privilege Modes
  - Mode switching from USER to KERNEL occurs during interrupts and exceptions
  - Mode switching from KERNEL to USER occurs with **IRET** instruction
  - All addresses are physical or directly-mapped in KERNEL mode.
  - All addresses are logical in USER mode. Address translation from logical to physical is done using page tables following a basic and simple address translation scheme.
  - Privileged instructions can be invoked only in KERNEL mode.
  - Interrupts are disabled in KERNEL Mode. Machine halts on exceptions in KERNEL mode.

XSM Simulator

- A C program simulates XSM
- The interval of timer can be varied in the simulator
- The simulator can be run in the **DEBUG** mode which invokes a GDB-like debugger
  - Pauses execution upon encountering a **BRKP** instruction
  - Memory and register contents can be viewed.
  - A register value can be watched whenever changes are made
  - Instructions can be single stepped or execution can be continued at breakpoints.

Experimental File System (XFS)

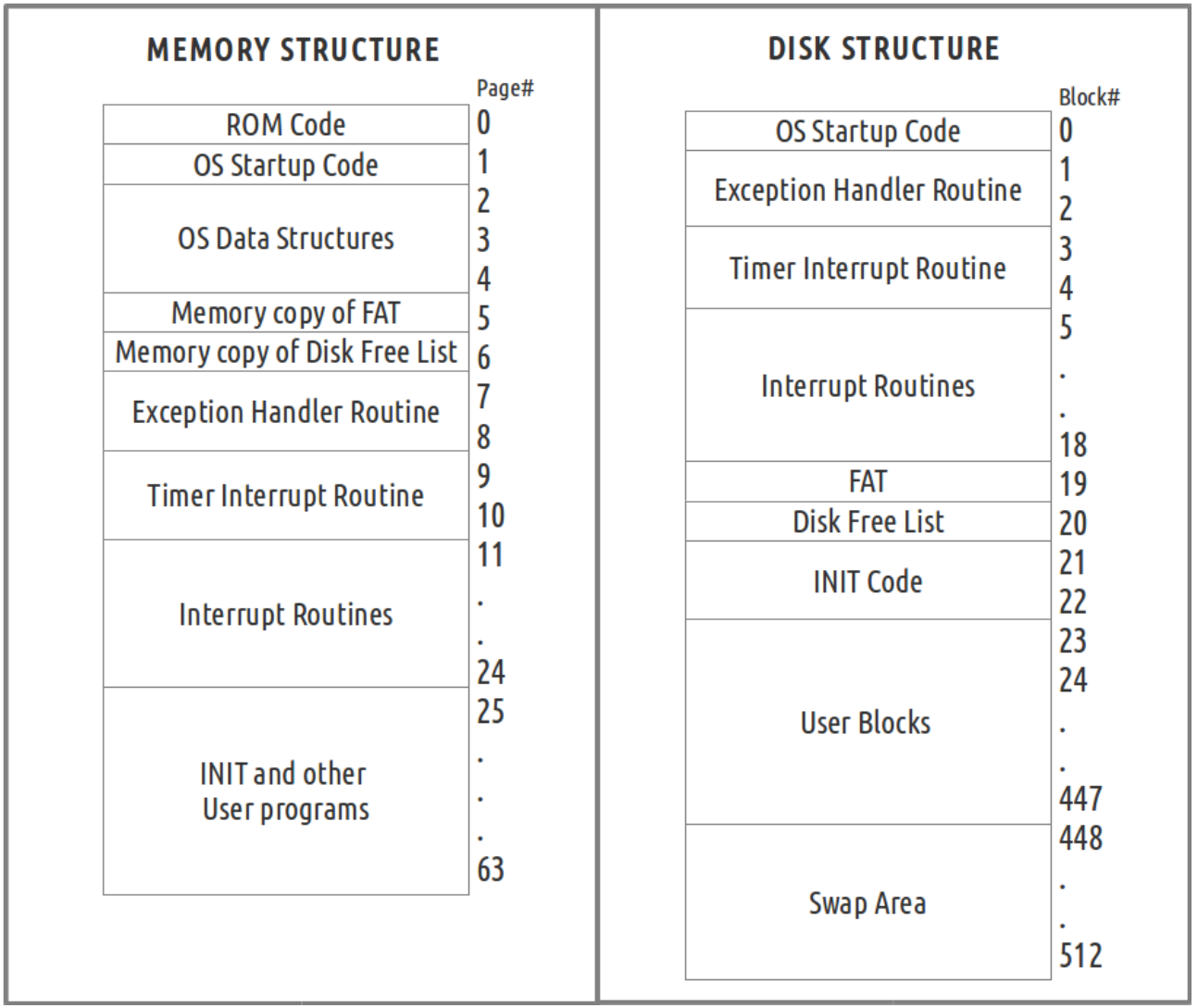


- XFS is a simple filesystem with no directory structure.
- Disk size is 512 blocks, with block size same as the page size in XSM (512 words).
- Every file contains a basic block and a data block.
- Two kinds of files, Executable and Data Files
- INIT Code has no FAT entry

XFS Interface

- XFS disk is simulated using a UNIX file, **disk.xfs**
- XFS interface is provided as part of the development tools
- XFS interface can be used to
  - Create and Format the XFS disk
  - Move files from UNIX machine to the XFS disk.
  - Copy range of blocks from XFS disk and put it in a UNIX file.
  - Commands like **ls** and **cat** are provided to display the list of files and the content of a particular file within the XFS disk.

Experimental Operating System (XOS)



Experimental Operating System (XOS)

- The various functionalities to be implemented in XOS are process management, file management and memory management.
- The functionalities are implemented as system calls, scheduler and page fault handler.
- XOS is capable of multiprogramming and demand paging.
- In this project, XOS routines like OS Startup Code, the various interrupt routines including timer interrupt routine and the exception handler routine is to be programmed.

XOS Data Structures

- **Per-process page tables**: used for address translation for each process in memory.
- **Memory Free List**: Indicates if a memory page is used or not.
- **System Wide Open File Table**: list of files opened by processes
- **Ready List of PCBs**: list of task structures (PCBs) of processes in memory
- **PCB** of a process contains its Process Identifier (PID), STATE information, register values, details about files opened by the process.
- **File Allocation Table**: Disk data structure storing details of files on the disk. A memory copy is maintained by XOS.
- **Disk Free List:** Disk data structure that indicates if a disk block is used or not. A memory copy is maintained by XOS.

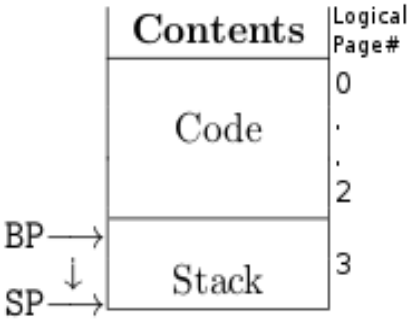
Process Structure

Code

- These are pages of the memory that contain the executable code loaded from the disk.

Stack

- This is the user stack used for program execution.
- The variables and data used during execution of program is stored in the stack.
- It grows in the direction of increasing word address.
- The location of the stack is fixed at the 4th page of the process.



OS Startup Code

- The OS Startup Code should be programmed to load and initialize data structures like Page Tables, Memory Free List and memory copy of Disk Free List.
- The OS Startup Code should also load the interrupt routines and exception handler routine from disk to the memory.
- It must load disk data structures like FAT and Disk Free List from disk to memory.
- It must setup the PCB and Page Tables of the INIT program, load it from disk to memory and start its execution.

Timer Interrupt Routine

- Timer interrupt routine is invoked when a timer interrupt occurs at specific intervals of instructions
- The scheduler is to be implemented within the timer interrupt routine.
- The scheduler of XOS follows a *round-robin* scheduling technique.

Interrupt Routines 1 - 7

- Implementation of various system call interfaces in XOS is to be done within software interrupt routines 1 – 7.
- These are invoked using INT instructions.
- The system calls to be handled by XOS include
  - File System Calls like Create, Delete, Open, Close, Read, Write, Seek
  - Process system calls like Fork, Exec and Exit
  - System calls like Wait, Signal, Getpid and Getppid are suggested as enhancements.

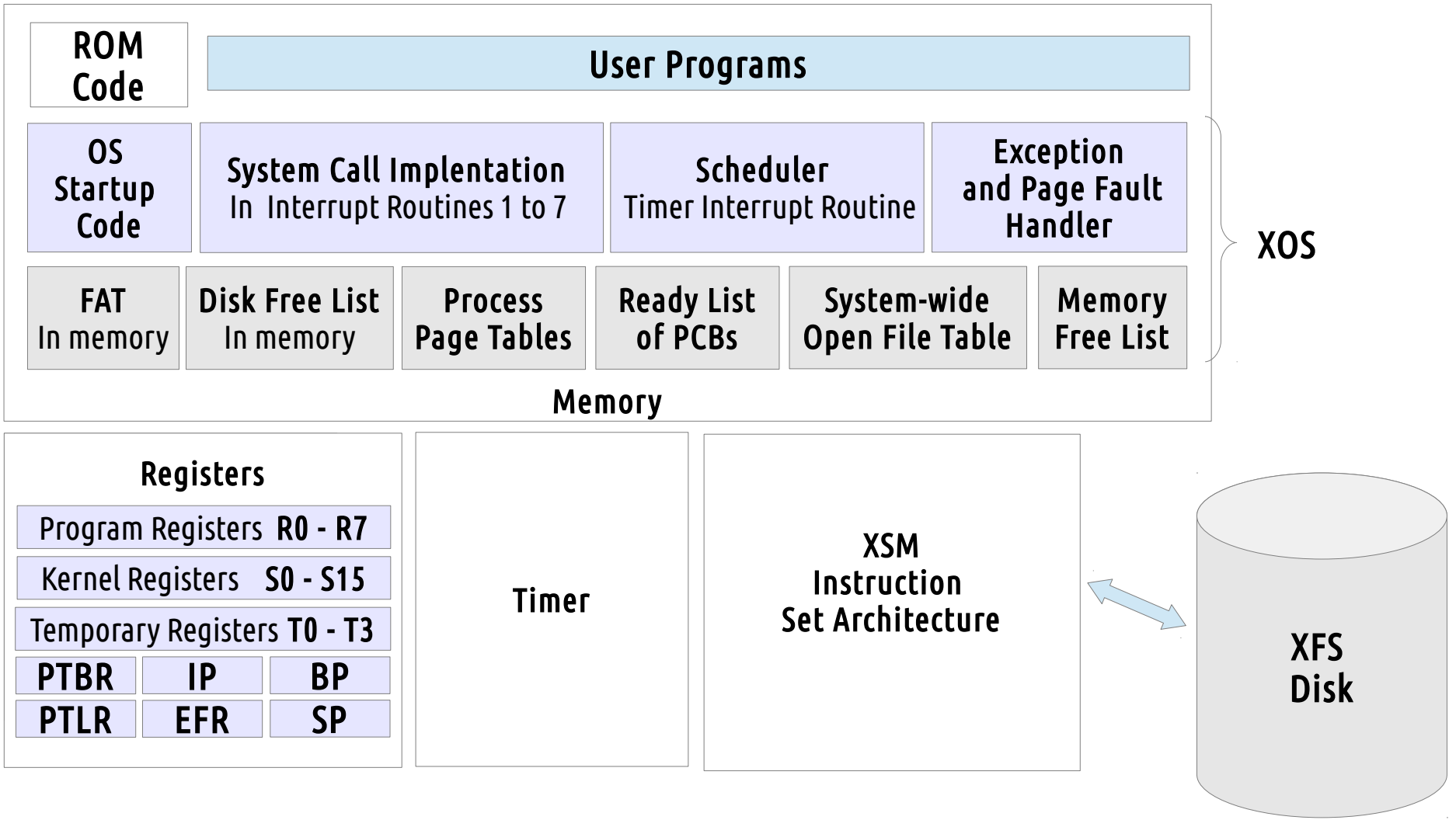
Exception Handler Routine

- The Exception handler routine must be programmed to exit the process on all exceptions except the page fault exception
- Page Fault exception occurs when translation is attempted on an invalid logical page.
- Upon a page fault exception, if its an accessible page, the page must be loaded from disk to memory.

Virtual Memory and Demand Paging

- If memory for loading a page from disk to memory is not available, page replacement must be done to make space.
- A page is swapped from the memory to the swap area of the disk and the required page is loaded.
- For simplicity, XOS avoids swapping out the stack page and code pages shared by more than one process.
- Page replacement is done using reference bits, by following the *Second Chance Algorithm*.

Structure


ROM Code
User Programs
OS Startup Code
System Call Implentation
In Interrupt Routines 1 to 7
Scheduler
Timer Interrupt Routine
Exception and Page Fault Handler
XOS
FAT
In memory
Disk Free List
In memory
Process Page Tables
Ready List of PCBs
System-wide Open File Table
Memory Free List
Memory
Registers
Program Registers R0 - R7
Kernel Registers S0 - S15
Temporary Registers T0 - T3
PTBR
IP
BP
PTLR
EFR
SP
Timer
XSM Instruction Set Architecture
XFS Disk

System Programmer's Langauge (SPL)

- The System Programmer's Language is a programming language to write the operating system routines inorder to build XOS.
- It is very closely related to XSM instruction set, and has statements to access machine registers and memory directly.
- It is provided for convenience of the system programmer instead of directly using the machine instructions.
- Registers can be aliased using meaningful identifiers.
- Allows defining constants and has predefined constants for XOS.
- SPL cross compiler is provided as part of development tools to generate .xsm output files. These files are loaded as system routines to the XFS disk.

Application Programmer's Langauge (APL)

- The Application Programmer's Language is a high level language used to write user programs to be run on top of XOS.
- It supports both string and integer data types.
- It has system call interfaces corresponding to the various system calls available in XOS.
- APL cross compiler is provided as part of development tools
- Programs written in APL is compiled using the cross-compiler to XSM machine instructions.

ROADMAP

- The roadmap helps to build XOS from scratch sequentially by carefully understanding every concept.
- The roadmap is divided into stages including a stage to implement a few enhancements on XOS.
- The roadmap contains theory points and explanations at every stage of implementation including links to other documents.
- Its a source of obtaining elementary understanding to operating system concepts, by parallely building the operating system.

ROADMAP

- STAGE 1: Setting up the system
  - Helps set up and test the development tools.
  - Elementary understanding of the various components of the project.
- STAGE 2: Understanding the filesystem
  - Introduces the XFS filesystem including disk data structures.
  - Teaches how to use the XFS interface.
- STAGE 3: Starting the machine
  - Start the machine in kernel mode
  - Run a kernel program to print odd numbers and run it as OS Startup Code.

ROADMAP

- STAGE 4: Running a user program
  - A user program to print primes is to be written in APL, compiled and loaded to disk.
  - The OS Startup code is to be programmed to set up the INIT process and load the newly written program as the INIT program.
  - The OS now runs in a single process mode.
- STAGE 5:Interrupt Routines
  - Introduces the concept of interrupts.
  - A sample implementation of a software interrupt routine and timer interrupt routine is done.

ROADMAP

- STAGE 6: Getting started with multiprogramming
  - OS is made to run two programs concurrently.
  - The scheduler is implemented in the timer interrupt routine to switch between the two programs.
- STAGE 7: Creating Files
  - The first system call 'Create' is to be implemented in the stage.
  - System Calls and corresponding stack operations are explained in detail in this stage.
- STAGE 8: Playing with Files
  - This stage includes the implementation of the remaining file system calls.
  - Test cases are provided for checking if the system calls are working properly.

ROADMAP

- STAGE 9: Process System Calls
  - Process system calls which includes Fork, Exec and Exit are to be implemented in this stage.
- STAGE 10: Exception Handling and Demand Paging
  - Virtual Memory managment is implemented in this stage
  - Page replacement is also done in this stage.
  - The process system calls are modified to incorporate demand paging and page replacement.
- STAGE 11: Enhancements to XOS
  - This stage includes implementing Wait, Signal, Getpid and Getppid system calls
  - This stage also includes making a shell for XOS

Conclusions

- The project is easier to implement compared to the existing instructional operating systems.
- Simple system which is buildable from first principles
- It will help to
  - better comprehend the textbooks on operating systems
  - get a practical feel of operating systems
  - move on to more complex platforms later.
- Limited set of features to be implemented in a 14 – 16 week semester.
- Not intended to be scaled to implement complex features. Real platforms are suggested for advanced understanding of operating systems.

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Resources

- Website: http://xosnitc.github.com
- Mailing lists:
  - Users' Mailing List: xos-users@googlegroups.com
  - Developers' Mailing List: xos-developers@googlegroups.com