Project 4

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Overview

Build on top of project 2 or project 3

- Up to 5% extra credit if you enable VM
- Edit 'filesys/Make.vars' to enable VM

Remove the severe limitations of the basic file system

- No internal synchronization
- File size is fixed at creation time
- File data is allocated on contiguous range of disk sectors
- No subdirectory

Scope of the work

```
Makefile.build       |    5
devices/timer.c      |   42 ++
filesys/Make.vars    |    6
filesys/cache.c      |  473 +++++++++++++++++++++++++
filesys/cache.h      |   23 +
filesys/directory.c  |   99 ++++-
filesys/directory.h  |    3
filesys/file.c       |    4
filesys/filesys.c    |  194 +++++++++-
filesys/filesys.h    |    5
filesys/free-map.c   |   45 +-
filesys/free-map.h   |    4
filesys/fsutil.c     |    8
filesys/inode.c      |  444 ++++++++++++++++++-----
filesys/inode.h      |   11
threads/init.c       |    5
threads/interrupt.c  |    2
threads/thread.c     |   32 +
threads/thread.h     |   38 +-
userprog/exception.c |   12
userprog/pagedir.c   |   10
userprog/process.c   |  332 +++++++++++++----
userprog/syscall.c   |  582 ++++++++++++++++++++++++++++++-
userprog/syscall.h   |    1
vm/frame.c           |  161 ++++++++
vm/frame.h           |   23 +
vm/page.c            |  297 +++++++++++++++
vm/page.h            |   50 ++
vm/swap.c            |   85 ++++
vm/swap.h            |   11
30 files changed, 2721 insertions(+), 286 deletions(-)
```

Requirements

- Buffer Cache
- Indexed and Extensible Files
- Subdirectories
- Synchronization

Buffer Cache

Modify the file system to keep a cache of file blocks

- Reduce expensive disk I/O
- No more than 64 sectors (including inode and file data)!
  64 x 512 bytes = 4 Kb = 1 page

Get rid of the "bounce buffer" in `inode_{read,write}_at()`

- Used to implement read/write in byte-granularity
- Interact with the buffer cache instead

Cache replacement algorithm

- Must be at least as good as the "clock" algorithm
- Maybe give higher priorities to metadata (i.e., inode) over file data?

Buffer Cache

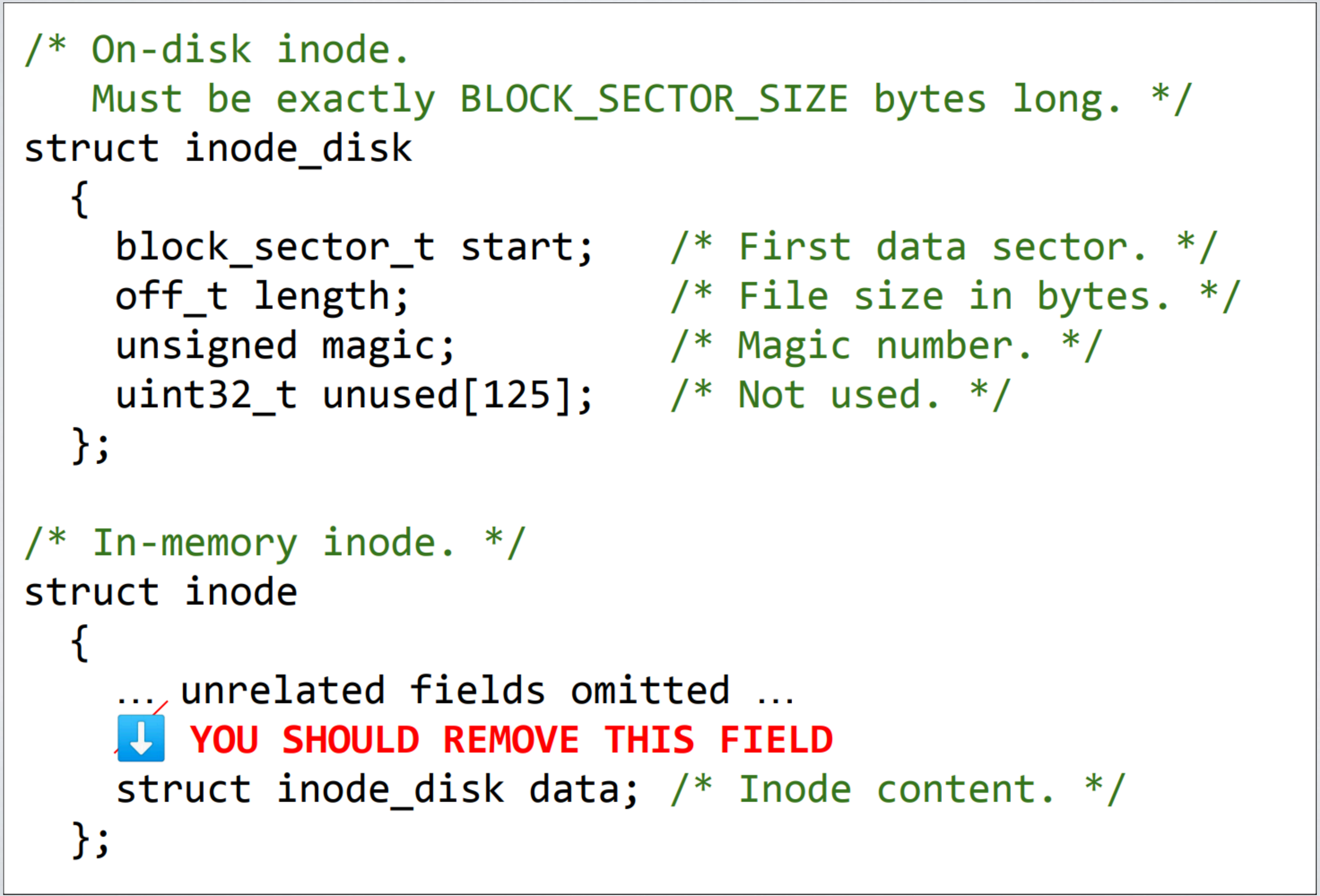
Your cache should be write-behind

- Keep dirty blocks in cache
- Write to disk on cache eviction or file closing
- Periodically (30 sec) flush dirty blocks back to disk
- Don't forget to flush when Pintos halts (in `filesys_done()`)

Your cache should also be read-ahead

- Prefetch the next block of a file when one block of file is read
- Only meaningful when done asynchronously, in the background

Remove inode_disk from inode



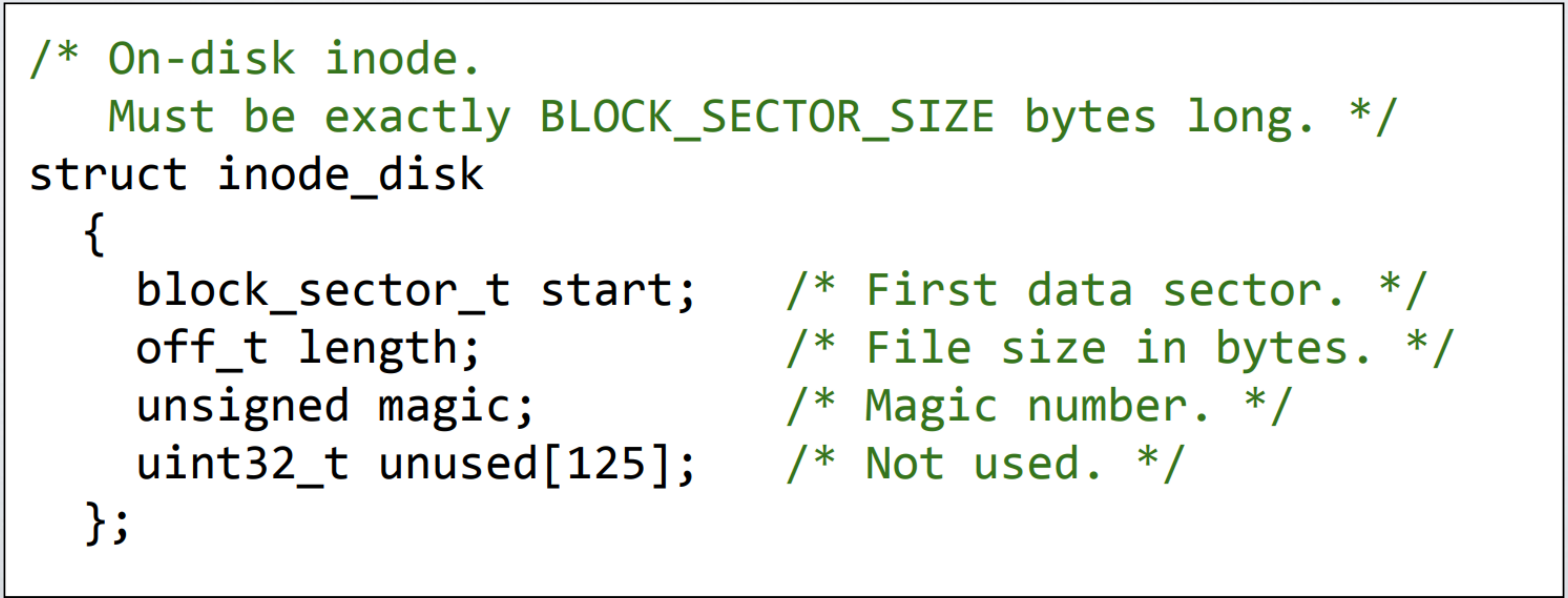
```
/* On-disk inode.
   Must be exactly BLOCK_SECTOR_SIZE bytes long. */
struct inode_disk
  {
    block_sector_t start;    /* First data sector. */
    off_t length;            /* File size in bytes. */
    unsigned magic;          /* Magic number. */
    uint32_t unused[125];    /* Not used. */
  };

/* In-memory inode. */
struct inode
  {
    ... unrelated fields omitted ...
    ⬇️ YOU SHOULD REMOVE THIS FIELD
    struct inode_disk data; /* Inode content. */
  };
```

Indexed and Extensible Files

The basic file system suffers from external fragmentation

- Always allocates files as a single extent
- Dictated by the current representation of an inode

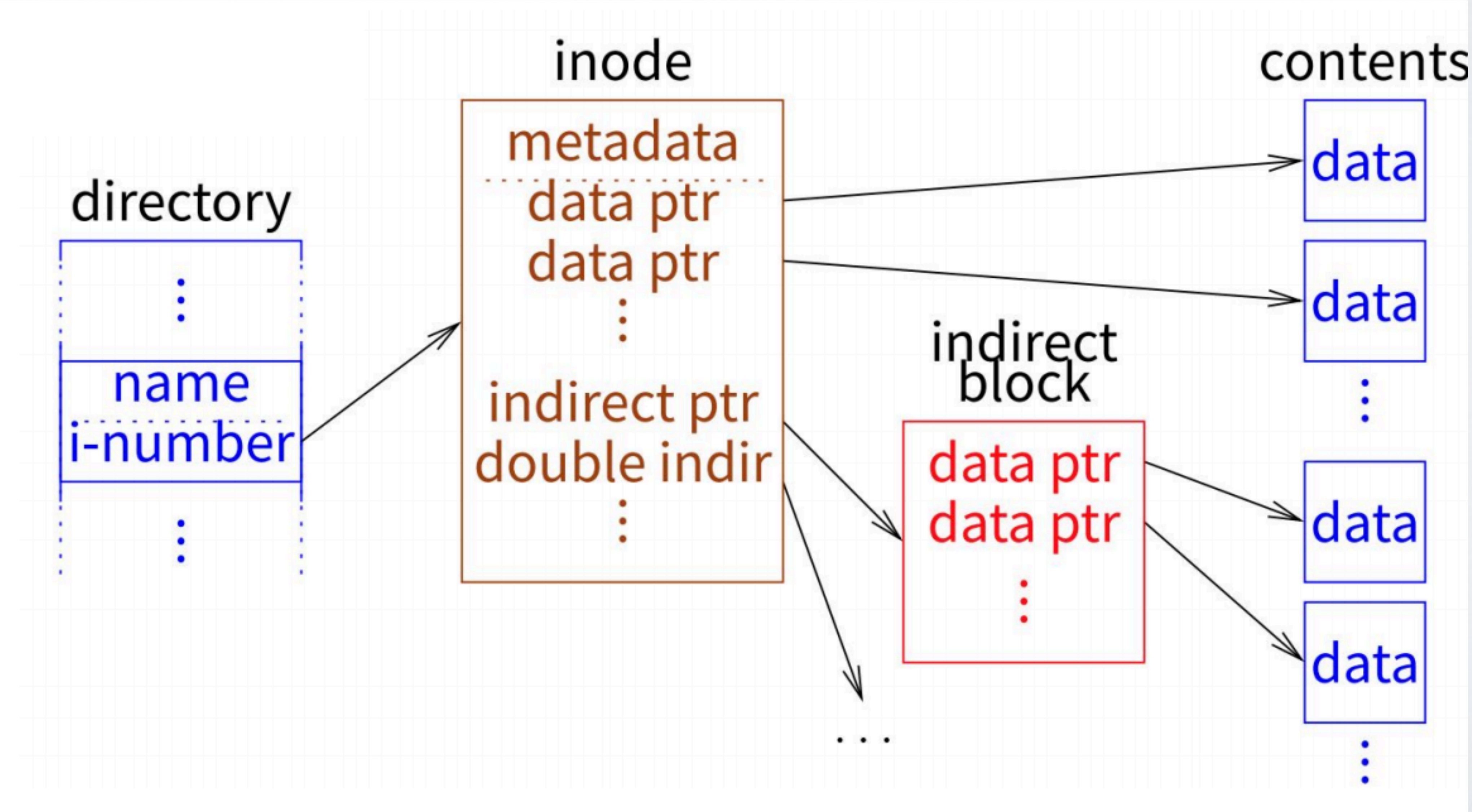


```
/* On-disk inode.
   Must be exactly BLOCK_SECTOR_SIZE bytes long. */
struct inode_disk
  {
    block_sector_t start;   /* First data sector. */
    off_t length;           /* File size in bytes. */
    unsigned magic;         /* Magic number. */
    uint32_t unused[125];   /* Not used. */
  };
```

Indexed and Extensible Files

Modify struct inode_disk to use an index structure

- Use a combination of direct, indirect, and doubly indirect blocks
- Support file size up to 8MB



Indexed and Extensible Files

Support file growth

- There should be no predetermined limit on the size of a file
- File size starts as 0; expanded every time user writes beyond EOF
- ✓ Details in Section 5.3.2

Directory can grow too

- remove the 16-file limit in the root directory
- `dir_create(ROOT_DIR_SECTOR, 16)` in `filesys.c:do_format(void)`

Use the "free map" (`free-map.c`) to keep track of free disk sectors

- Hard-coded to be kept at disk sector 0 (i.e., `#define FREE_MAP_SECTOR 0`)
- You can keep a cached copy permanently in memory

Subdirectories

Implement a hierarchical name space

- e.g. `/foo/bar/../baz/./a`
- Directory entries (i.e. `struct dir_entry`) can point to files or other directories

Each process has its own current directory

- Set to the root directory at startup
- Inherited by the child process started by the exec system call

Implement path resolution

- Update existing syscalls to take path names (absolute or relative) as inputs
- Support special file names `.` and `..`

Subdirectories

Update existing system calls

- Update open to open directories
- Update remove to delete empty directories
- …

✓ Many more details in Section 5.3.3

More system calls

- Implement `chdir`, `mkdir`, `readdir`, `isdir`, and `inumber`
- User programs `ls`, `mkdir`, and `pwd` should work now

Synchronization

No more global file system lock

- Operations on different buffer cache blocks must be independent
- e.g. process A can read cache block 3 while process B is replacing block 7

Multiple processes must be able to access the same file concurrently

- When the file size is fixed - read can see partial change; writes can interleave
- But extending a file and writing data into the new section must be atomic

Operations on the same directory must be serialized

- Operations on different directories are independent

✓ Recall the readers/writers problems from lecture 4 "Concurrency Problems"

Getting Started

New code to work with

- `directory.c` performs directory operations using inodes
- `inode.c` data structures representing the layout of a file's data on disk
- `file.c` translates file reads and writes to disk sector reads and writes

✓ Details in Section 5.1.1

Testing file system persistence

- Invoke Pintos a second time to copy files out of the Pintos file system
- Grading scripts check if the contents of the file meet expectation
- Won't pass the extended file system tests until you support tar

✓ Details in Section 5.1.2

Suggested Order of Implementation

➡ Think about synchronization from the beginning

1. Buffer cache
   - All tests from project 2 (or project 3) should still pass
2. Extensible files
   - Pass the file growth tests
3. Subdirectories
   - Pass the directory tests

✓ #2 and #3 can be done more or less in parallel

Acknowledgments

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