Csci 5980 Spring 2020

LevelDB Introduction

An Key-Value Store Example

Projects Using LevelDB

Google chrome

Google BigTable

riak

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LevelDB

- “LevelDB is an open source on-disk key-value store written by Google fellows Jeffrey Dean and Sanjay Ghemawat.” – Wikipedia
- “LevelDB is a light-weight, single-purpose library for persistence with bindings to many platforms.” – leveldb.org

API

- Get, Put, Delete, Iterator (Range Query).

Key-Value Data Structures

- Hash table, Binary Tree, B^+-Tree

"when writes are slow, defer them and do them in batches” *

*Dennis G. Severance and Guy M. Lohman. 1976.

Log-structured Merge (LSM) Tree

O’Neil, P., Cheng, E., Gawlick, D., & O’Neil, E. (1996).

Two Component LSM-Tree

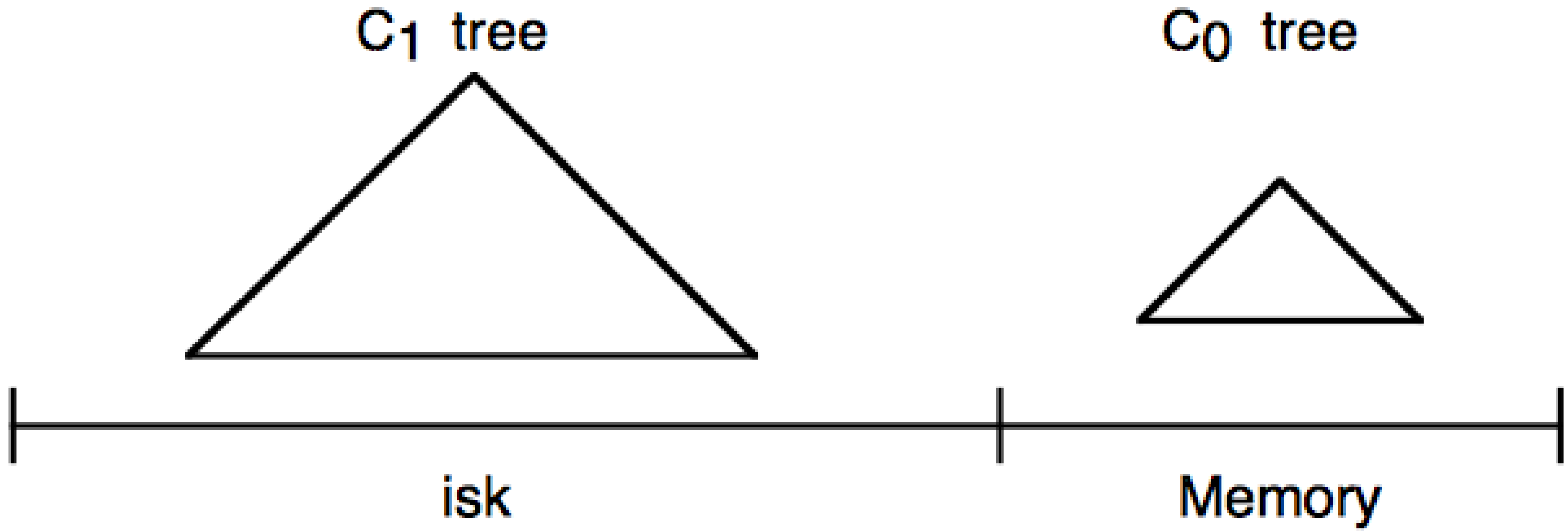


Figure 2.1. Schematic picture of an LSM-tree of two components

K+1 Components LSM-Tree

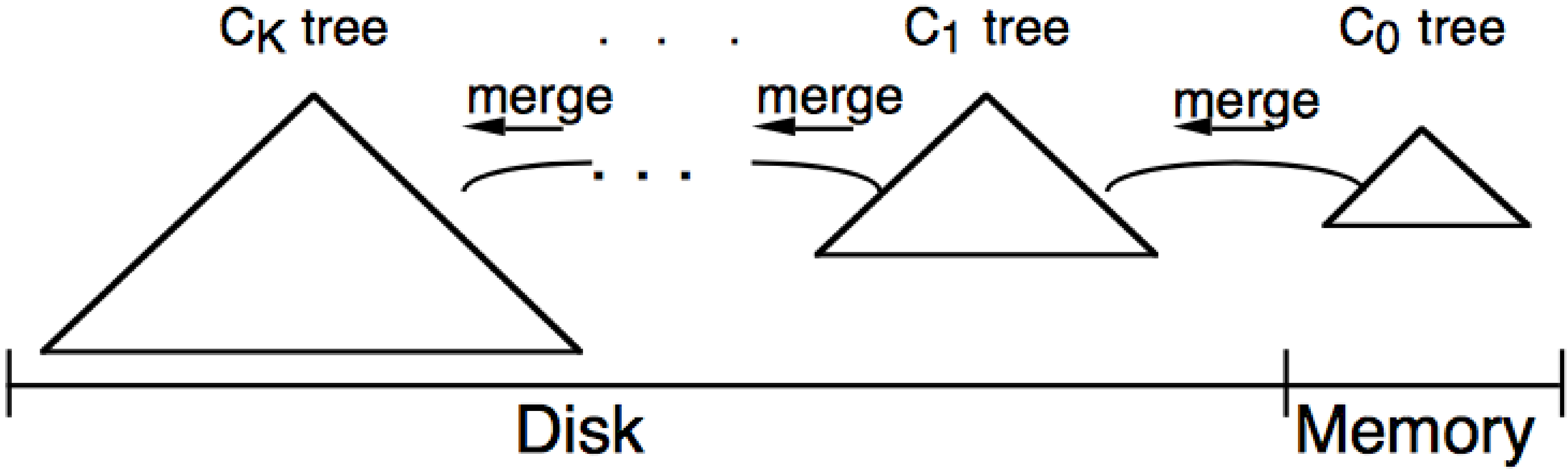


Figure 3.1. An LSM-tree of K+1 components

Rolling Merge

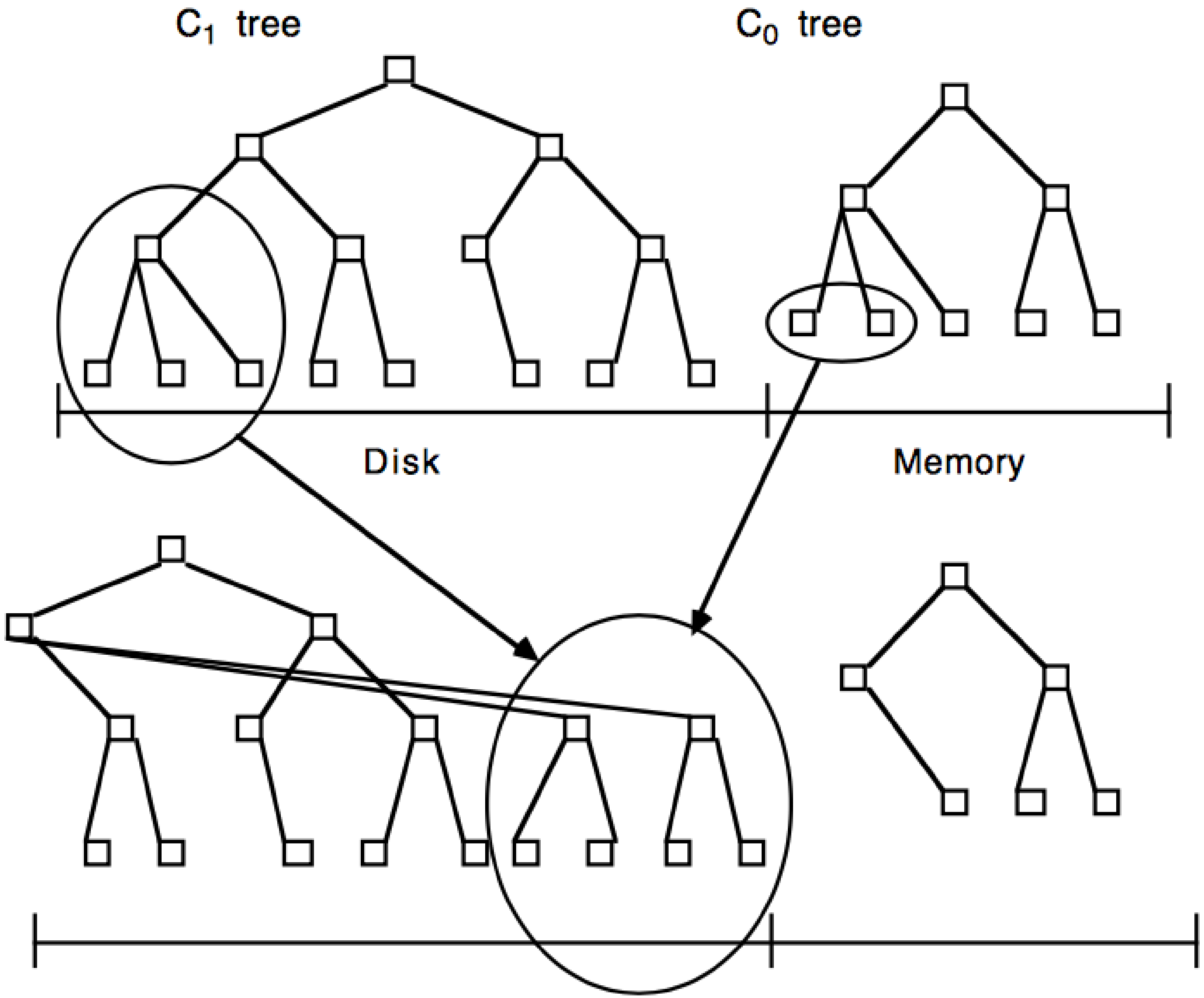
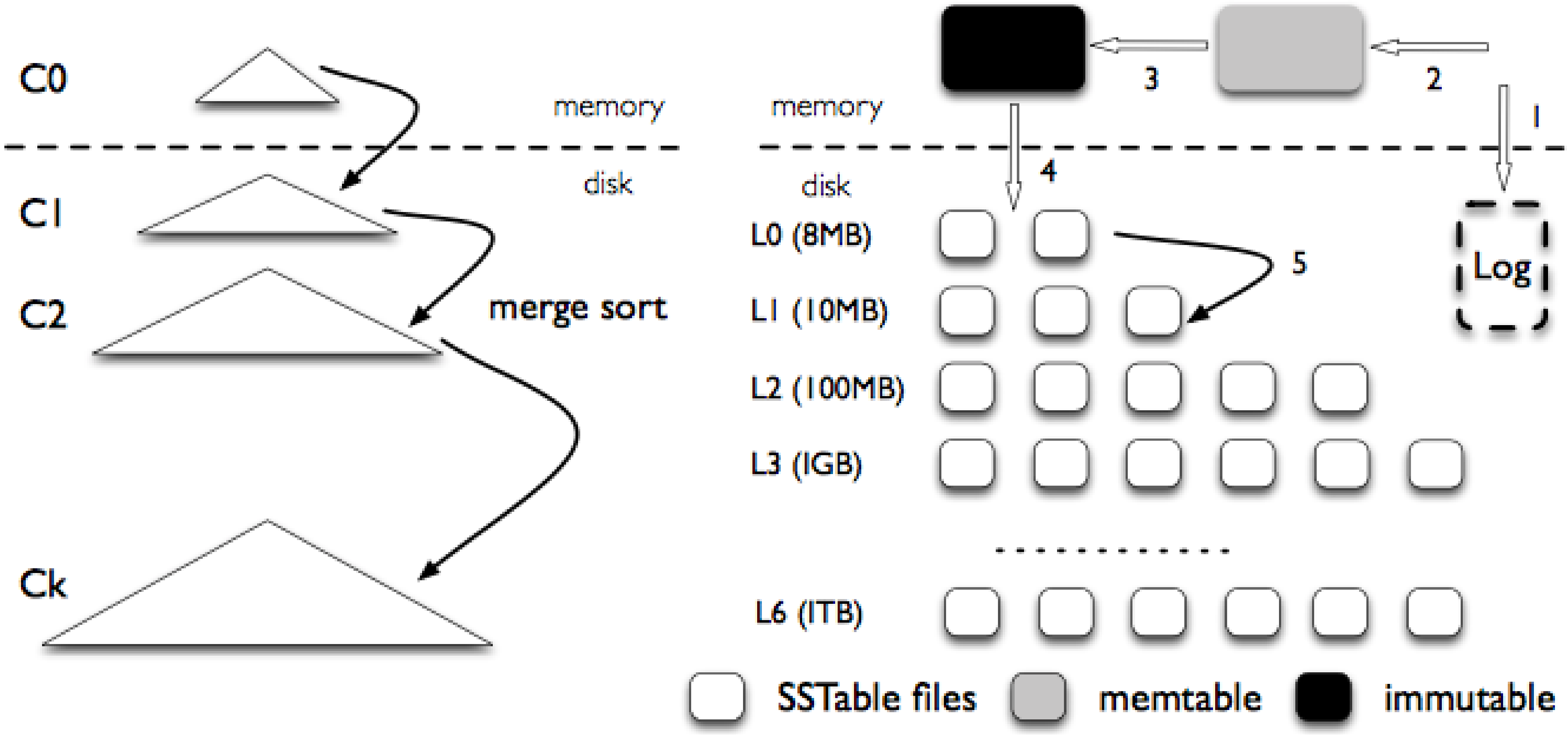


Figure 2.2. Conceptual picture of rolling merge steps, with result written back to disk

From LSM-Tree to LevelDB



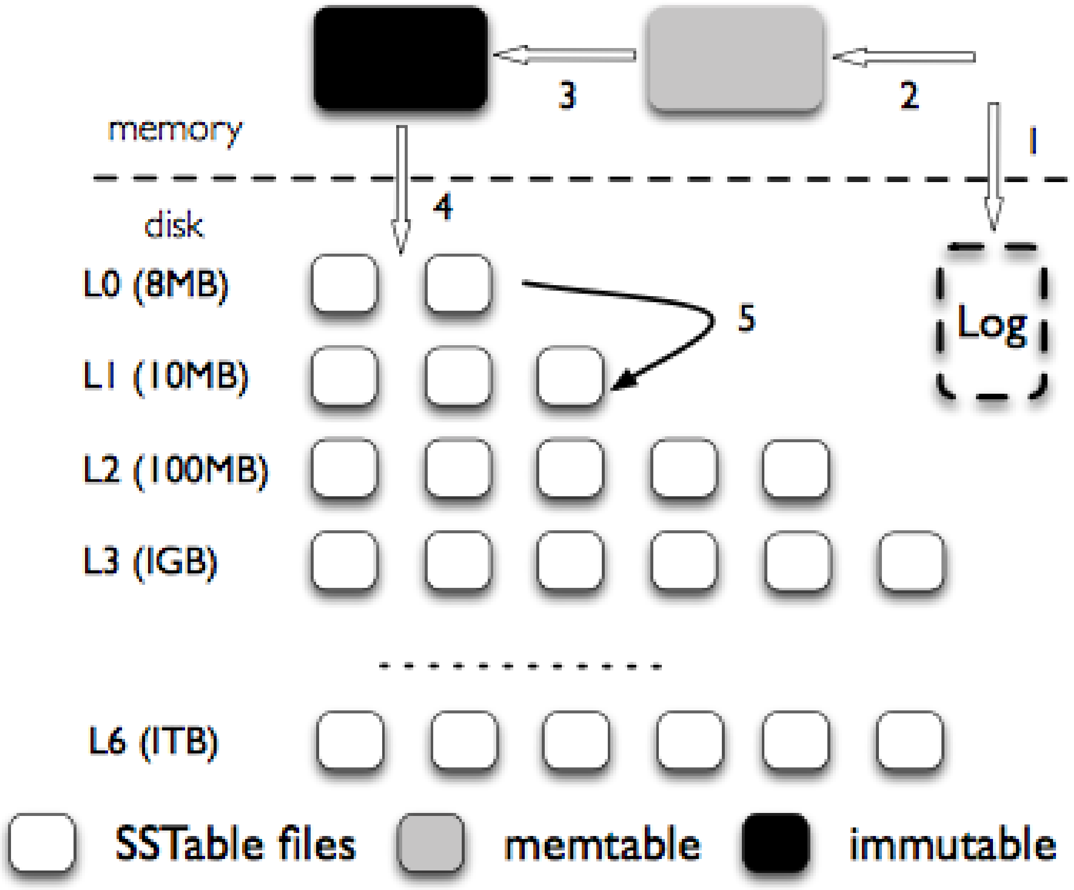
(a) LSM-tree

(b) LevelDB

Lu, L., Pillai, T. S., Arpaci-Dusseau, A. C., & Arpaci-Dusseau, R. H. (2016).

LevelDB Data Structures

- Log file
- Memtable
- Immutable Memtable
- SSTable (file)
- Manifest file



(b) LevelDB

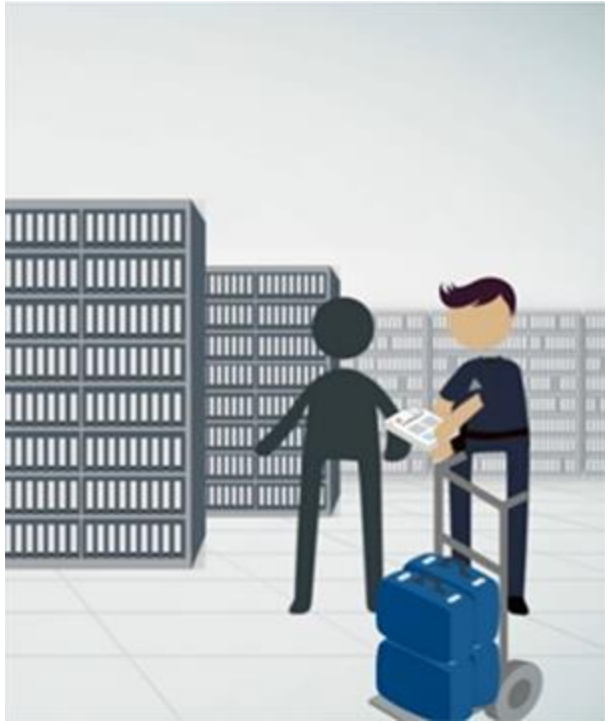
Archival Storage

Outline

- Archival Storage
  - archival
  - backup vs archival
- Long-term data retention
  - architecture and technologies
  - cloud for archival
  - Self-contained Information Retention Format

What is archival storage?

- In computers, archival storage is **<u>storage</u>** for data that may not be actively needed but is kept for possible **future use** or for **record-keeping** purposes.
- Archival storage is often provided using the same system as that used for backup storage. Typically, archival and backup storage can be retrieved using a restore process [1].



The Need for Digital Preservation

SNIA Global Education

Health Insurance Portability and Accountability Act

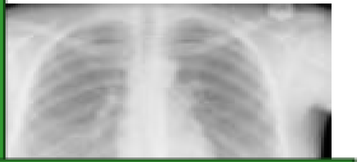
- Regulatory compliance and legal issues
  - Sarbanes-Oxley, HIPAA, FRCP, intellectual property litigation
- Emerging web services and applications
  - Email, photo sharing, web site archives, social networks, blogs
- Many other fixed-content repositories
  - Scientific data, intelligence, libraries, movies, music

Scientific and Cultural

Satellite data is kept for ever

We would like to keep digital art for ever

Healthcare



X-rays are often stored for periods of 75 years

Records of minors are needed until 20 to 43 years of age

M&E

Film Masters, Out takes. Related artifacts (e.g., games). 100 Years or more

An Archival Storage System

- A high-end computing environment includes a **132-petabyte tape storage system** that allows science and engineering users to archive and retrieve important results quickly, reliably, and securely (NASA)
- **44 PB** current unique data stored
- SGI

Backups and Archives

- Backups are for recovery
- Archives are for discovery and preservation

Storage Perspective: archival application

- Data archiving is the process of moving data that is no longer actively used to a separate data storage device for long-term retention.

- Most are write once, but if needed, it is crucial

Backup and archiving at a glance

Issue	Backup	Archiving
What is it?	Protection for system and data "live state"	Records of inactive document "steady state"
Why use it?	Recovery" restore business operations after data loss, interruption, or disaster	Discovery: produce evidence to meet legal, regulatory, and policy obligations
Who wants it?	Business stakeholders—CEO, shareholders, your boss	Public stakeholders—courts, regulators
What's in it?	Images in full operational context	Individual objects, especially email
How many are there?	Many: original left in place plus multiple point-in-time copies	One: single global instance – originals replaced by links, or removed altogether from primary storage

Backup and disaster recovery requirements

- High media capacity
- High-performance read/write streaming
- Low storage cost per GB

Archive requirements

- Data authenticity
- Extended media longevity
- High-performance random read access
- Low total cost of ownership

Long Term Data Retention – 5 Key Considerations

1. Business and Regulatory Requirements Demand a Long-term Plan

2. Manage and Contain Your Total Cost of Ownership (TCO)

3. Encrypt Your Data for Secure Long-term Retention

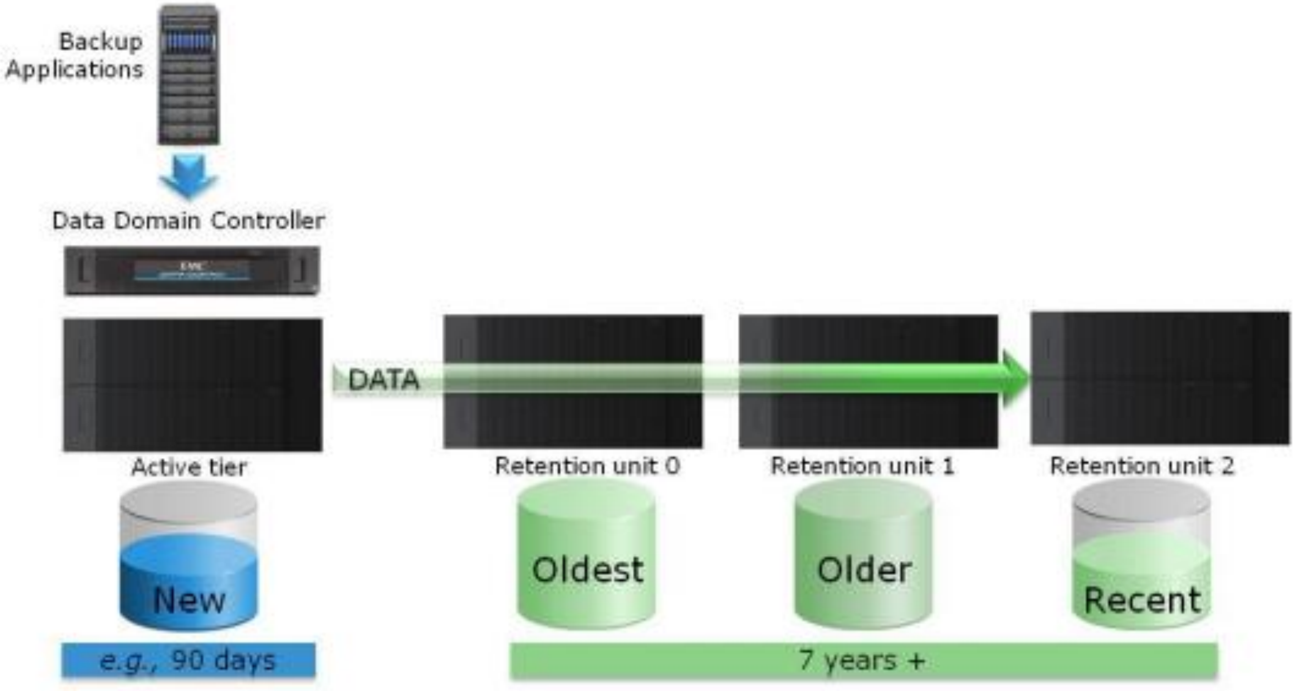
4. Weigh the Environmental Impacts and Minimize Power and Cooling Costs

5. Simplify Management of the Entire Solution

Disk scrubbing

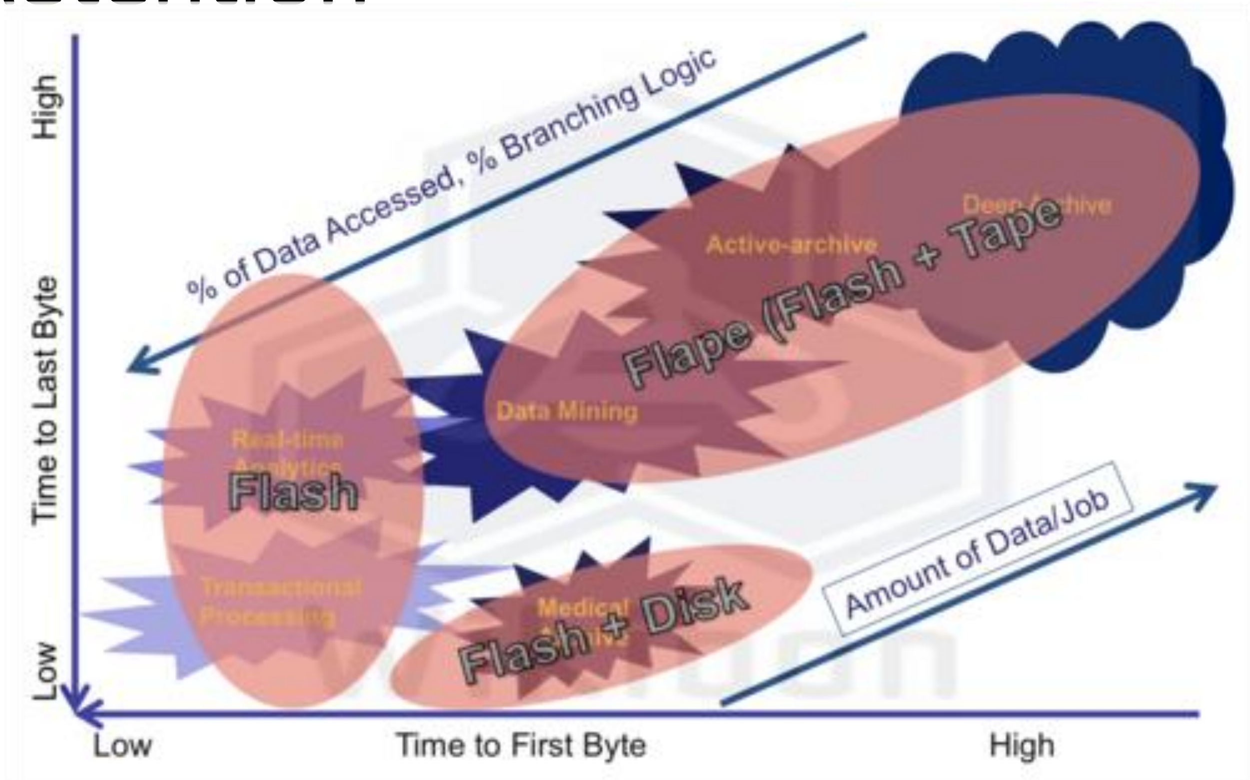
- Drives are periodically accessed to detect drive failure. By scrubbing all of the data stored on all of the disks, we can detect block failures and compensate for them by rebuilding the affected blocks.

The two-tiered data retention



The two-tiered architecture enables administrators to deploy a short-term active tier for fast ingest of backup data, and a retention tier for cost-effective long-term backup retention [7] (Data Domain).

The Emergence of a New Architecture for Long-term Data Retention



- By taking advantage of the tape layer, use cases like archiving, long-term retention and tiered storage (where 70+% of the data is stale) can live on a low-cost storage medium like tape.
- By leveraging Flash/SSD, each use case doesn't suffer the typical tape performance barriers.

File Systems

Files
Directories
File system implementation
Example file systems

Long-term Information Storage

1. Must store large amounts of data

2. Information stored must survive the termination of the process using it

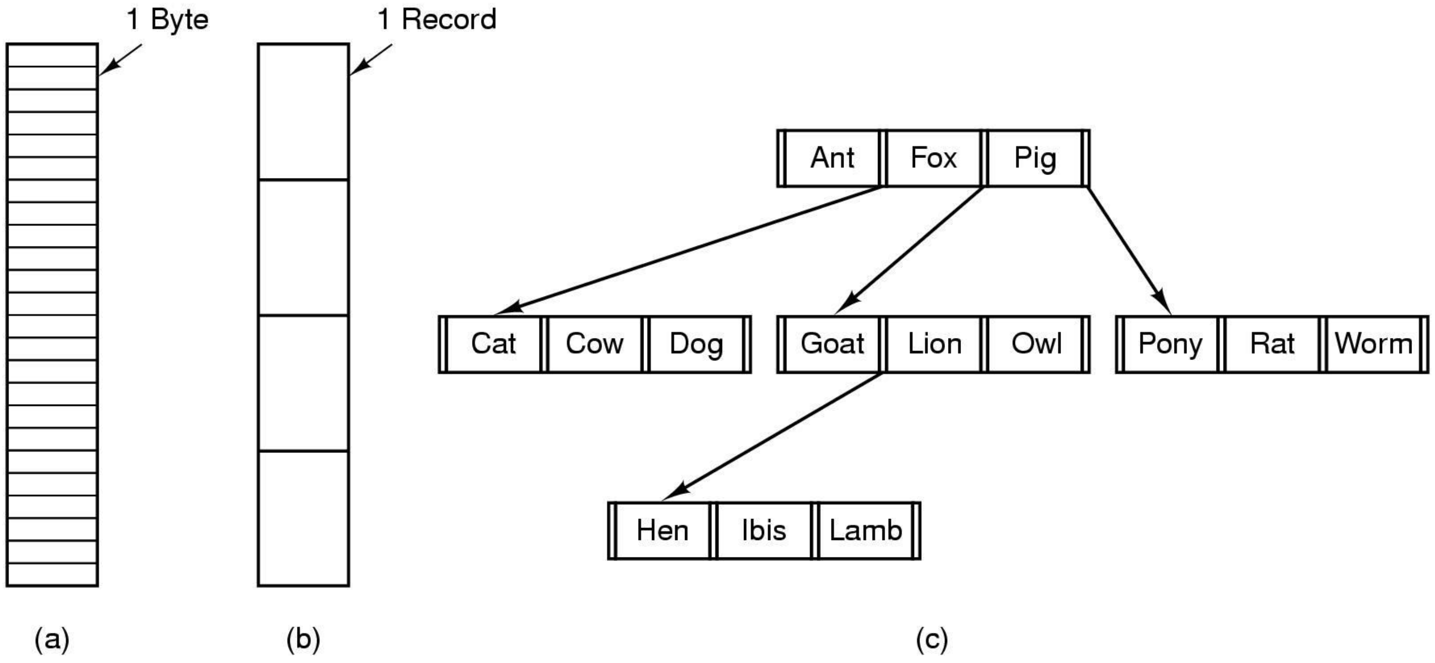
3. Multiple processes must be able to access the information concurrently

File Naming

Extension	Meaning
file.bak	Backup file
file.c	C source program
file.gif	Compuserve Graphical Interchange Format image
file.hlp	Help file
file.html	World Wide Web HyperText Markup Language document
file.jpg	Still picture encoded with the JPEG standard
file.mp3	Music encoded in MPEG layer 3 audio format
file.mpg	Movie encoded with the MPEG standard
file.o	Object file (compiler output, not yet linked)
file.pdf	Portable Document Format file
file.ps	PostScript file
file.tex	Input for the TEX formatting program
file.txt	General text file
file.zip	Compressed archive

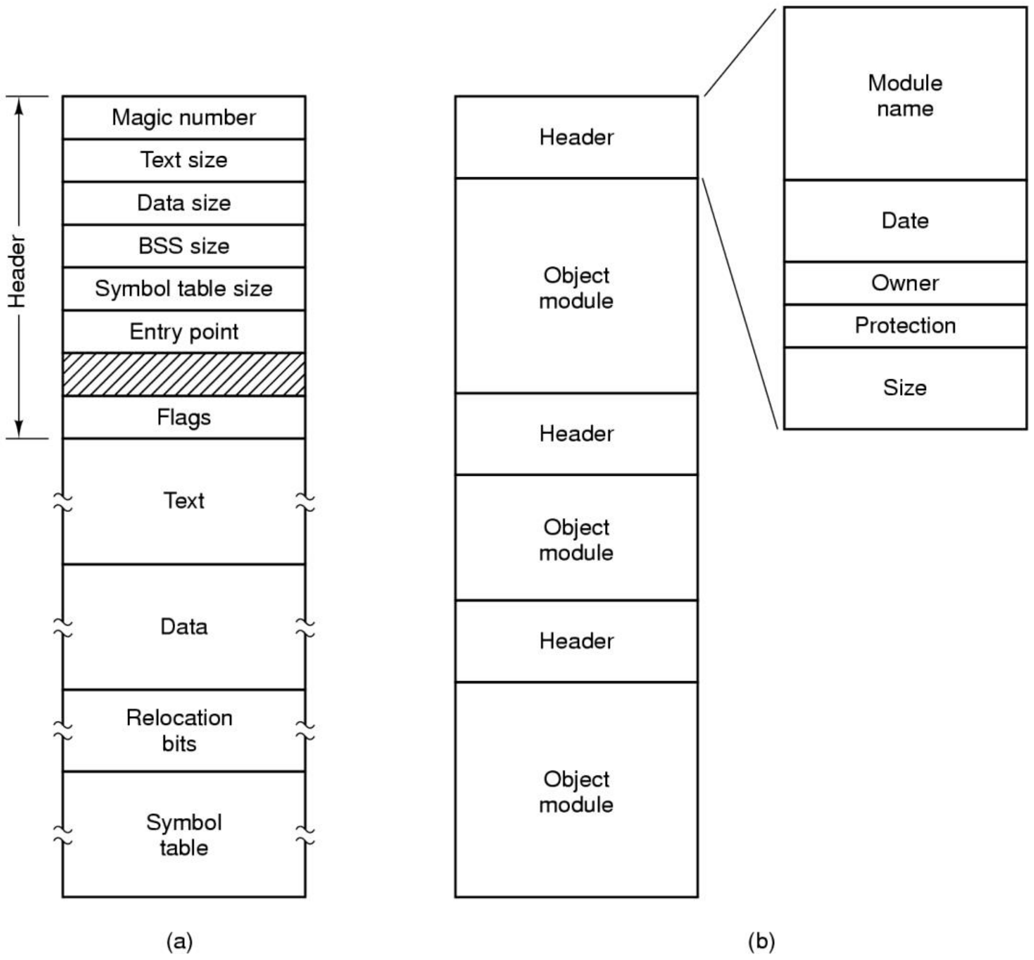
Typical file extensions.

File Structure



- Three kinds of files
  - byte sequence
  - record sequence
  - tree

File Types



(a) An executable file (b) An archive

File Access

- Sequential access
  - read all bytes/records from the beginning
  - cannot jump around, could rewind or back up
  - convenient when medium was mag tape
- Random access
  - bytes/records read in any order
  - essential for data base systems
  - read can be …
    - move file marker (seek), then read or …
    - read and then move file marker

File Attributes

Attribute	Meaning
Protection	Who can access the file and in what way
Password	Password needed to access the file
Creator	ID of the person who created the file
Owner	Current owner
Read-only flag	0 for read/write; 1 for read only
Hidden flag	0 for normal; 1 for do not display in listings
System flag	0 for normal files; 1 for system file
Archive flag	0 for has been backed up; 1 for needs to be backed up
ASCII/binary flag	0 for ASCII file; 1 for binary file
Random access flag	0 for sequential access only; 1 for random access
Temporary flag	0 for normal; 1 for delete file on process exit
Lock flags	0 for unlocked; nonzero for locked
Record length	Number of bytes in a record
Key position	Offset of the key within each record
Key length	Number of bytes in the key field
Creation time	Date and time the file was created
Time of last access	Date and time the file was last accessed
Time of last change	Date and time the file has last changed
Current size	Number of bytes in the file
Maximum size	Number of bytes the file may grow to

Possible file attributes

File Operations

1. Create
2. Delete
3. Open
4. Close
5. Read
6. Write
7. Append
8. Seek
9. Get attributes
10. Set Attributes
11. Rename

An Example Program Using File System Calls (1/2)

```
/* File copy program. Error checking and reporting is minimal. */

#include <sys/types.h>                    /* include necessary header files */
#include <fcntl.h>
#include <stdlib.h>
#include <unistd.h>

int main(int argc, char *argv[]);         /* ANSI prototype */

#define BUF_SIZE 4096                     /* use a buffer size of 4096 bytes */
#define OUTPUT_MODE 0700                  /* protection bits for output file */

int main(int argc, char *argv[])
{
     int in_fd, out_fd, rd_count, wt_count;
     char buffer[BUF_SIZE];

     if (argc != 3) exit(1);              /* syntax error if argc is not 3 */
```

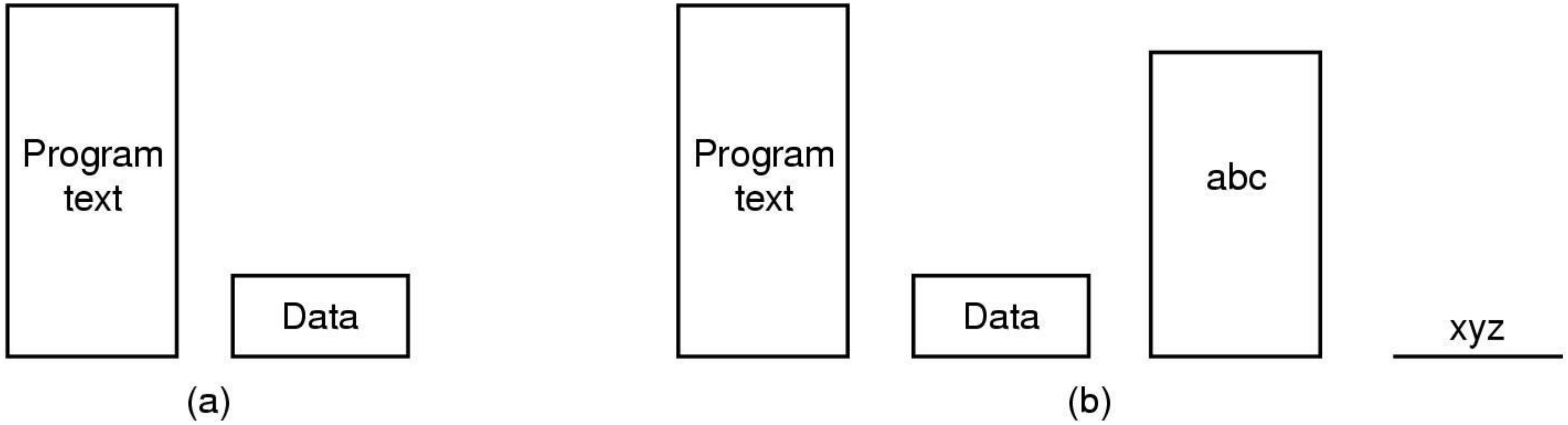
An Example Program Using File System Calls (2/2)

```
/* Open the input file and create the output file */
in_fd = open(argv[1], O_RDONLY);     /* open the source file */
if (in_fd < 0) exit(2);                            /* if it cannot be opened, exit */
out_fd = creat(argv[2], OUTPUT_MODE);  /* create the destination file */
if (out_fd < 0) exit(3);                           /* if it cannot be created, exit */

/* Copy loop */
while (TRUE) {
     rd_count = read(in_fd, buffer, BUF_SIZE); /* read a block of data */
if (rd_count <= 0) break;                          /* if end of file or error, exit loop */
     wt_count = write(out_fd, buffer, rd_count); /* write data */
     if (wt_count <= 0) exit(4);                   /* wt_count <= 0 is an error */
}

/* Close the files */
close(in_fd);
close(out_fd);
if (rd_count == 0)                                 /* no error on last read */
     exit(0);
else
     exit(5);                                      /* error on last read */
}
```

Memory-Mapped Files



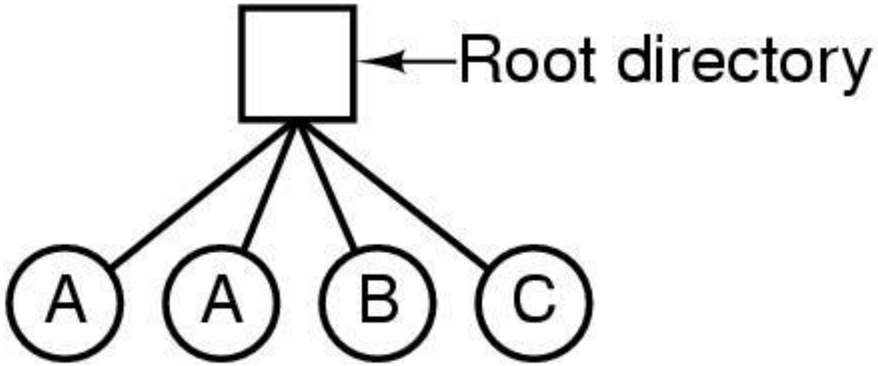
(a) Segmented process before mapping files into its address space

(b) Process after mapping

existing file *abc* into one segment

creating new segment for *xyz*

Directories
Single-Level Directory Systems

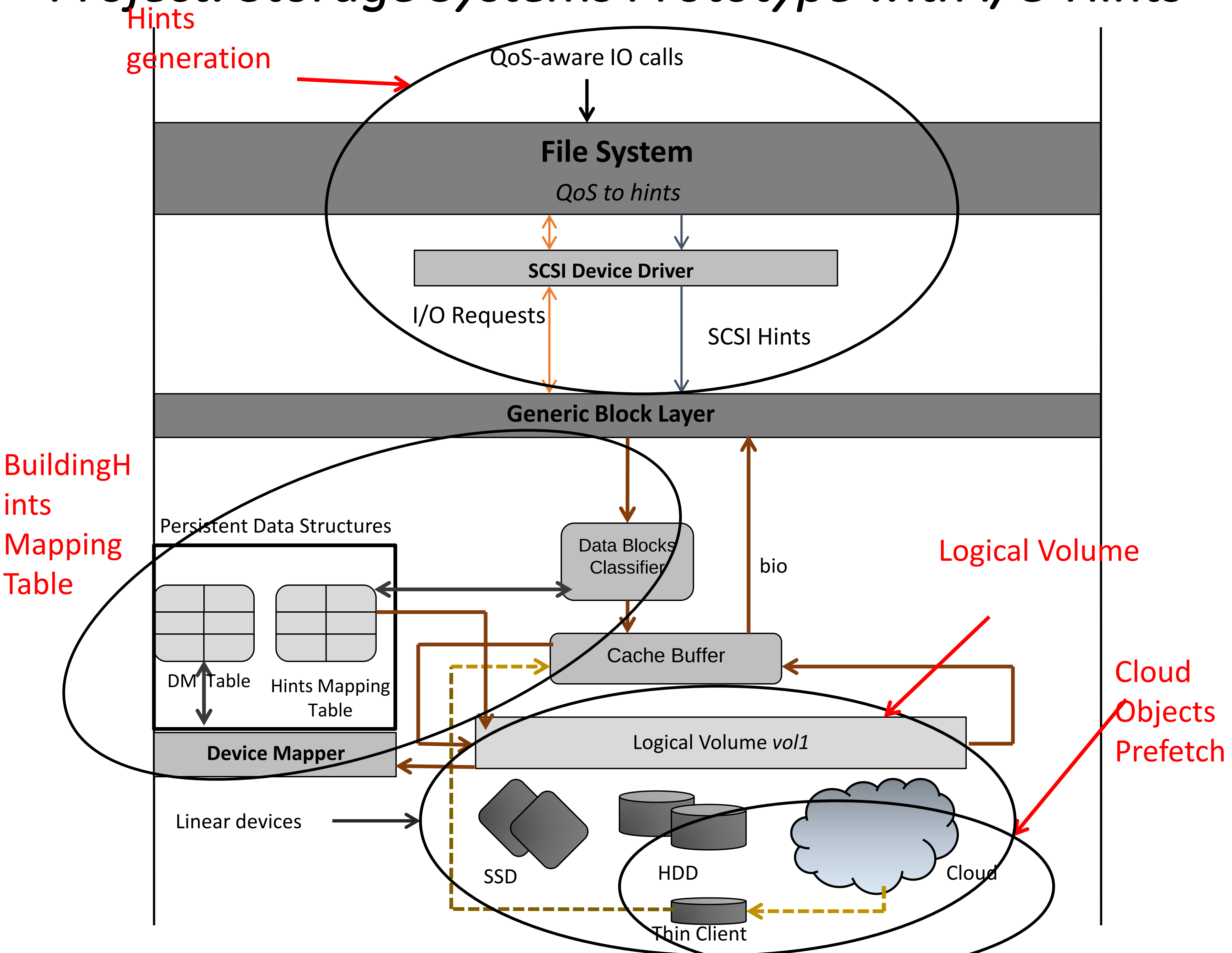


- A single level directory system
  - contains 4 files
  - owned by 3 different people, A, B, and C

Cloud Storage and Big Data

- OpenStack
- VM vs. Container
- Durability, Reliability and Availability
- Private vs. Public Cloud

Project: Storage Systems Prototype with I/O Hints



Parallel File Systems and IO Workload Characterization

Why Is This Important?

- **Workload Characterization**
  - Key to *performance analysis* of storage subsystems.
  - Key to the *implementation of simulators*, as captured/synthesized workloads are key inputs.
- **Key Issues**
  - Lack of *widely available tool sets* to capture file system level workloads for parallel file systems
  - Lack of *methods to characterize* parallel workloads (for parallel file systems)
  - Lack of *methods to synthesize* workloads accurately at all levels (Block, File , etc)
  - Understanding of how existing workloads *scale* in the exascale regime is lacking

Goals and Objectives

- *A detailed understanding and survey* of existing methods in file system tracing, trace replaying, visualization, synthetic workload generators at the file system input levels, and existing mathematical models

- *Tools , techniques and methods to analyze parallel file system input traces (require to know more about OS, meta-data server, and applications)*

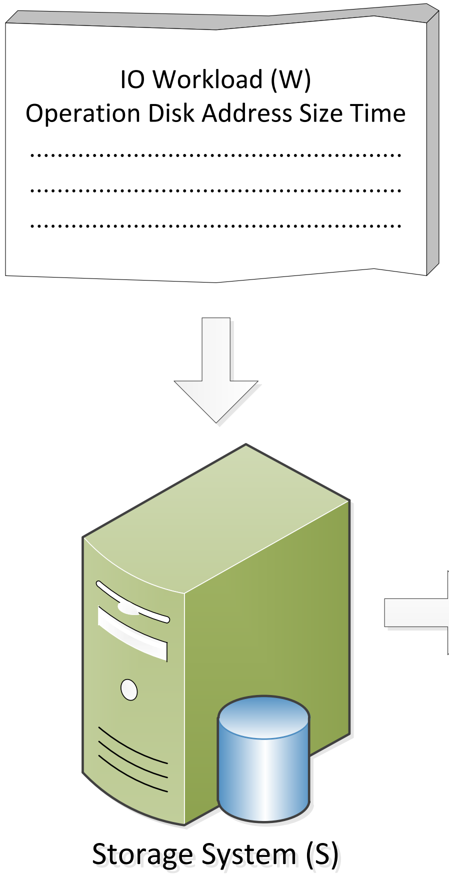
- Models to *characterize* the above workloads traces (Using statistical and analytical methods)

- *Synthetic workload generation* at the parallel file system input level – which will be used as inputs to the simulator.

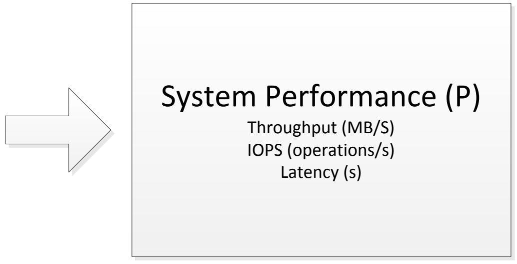
- *Understanding of the interactions of workloads* at the file system level and making the file system aware of the workloads

Block-Level Workload Characterization

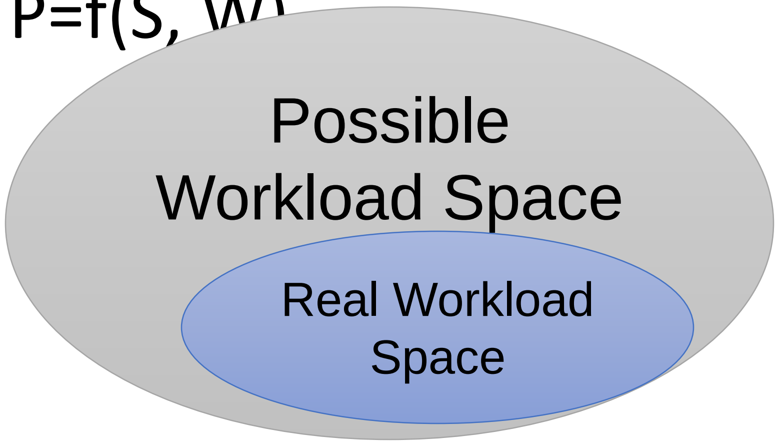
Storage system performance cannot be determined by the system alone.



P	System Performance
S	Storage System
W	IO Workload

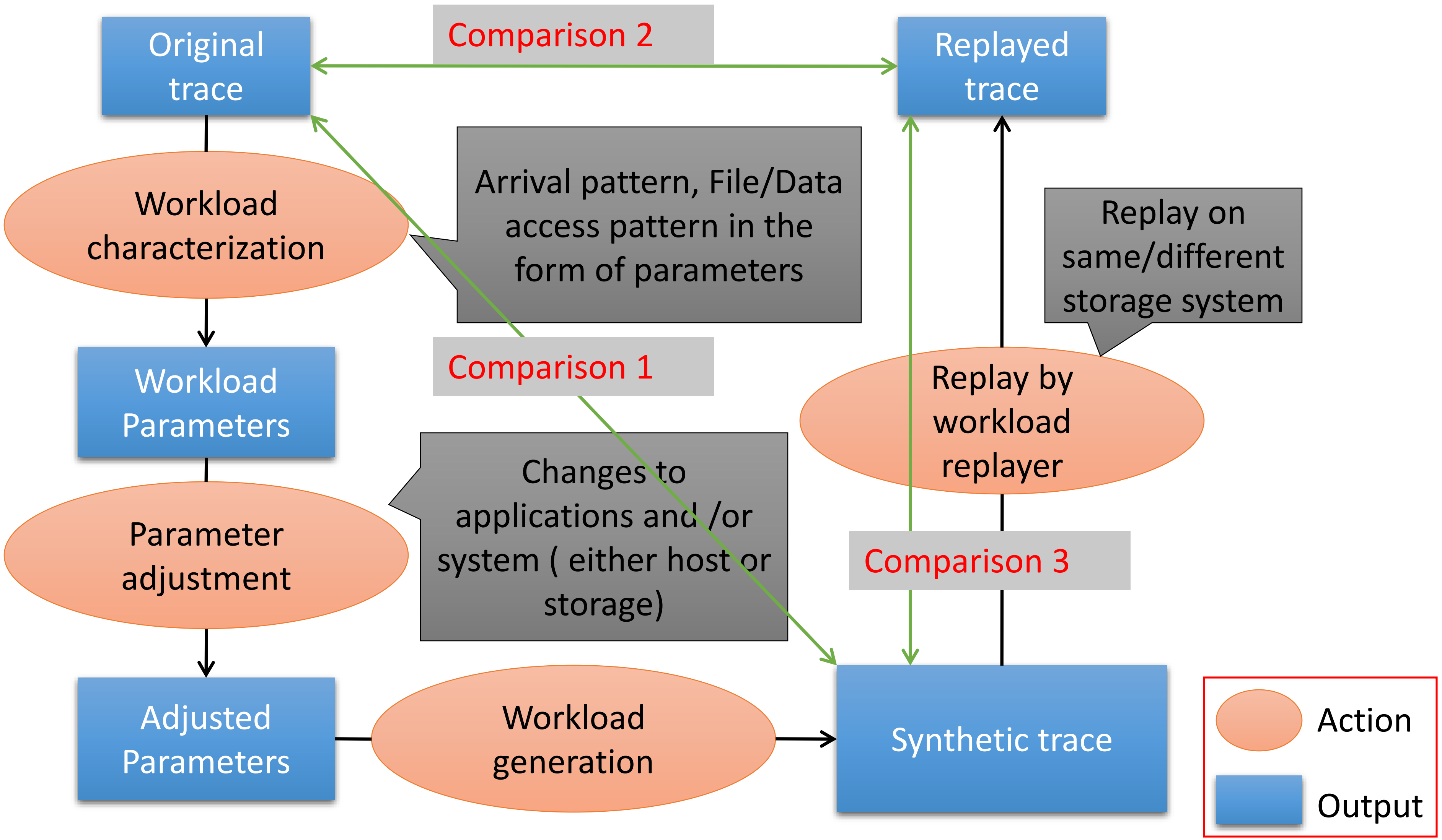


- P=f(S, W)

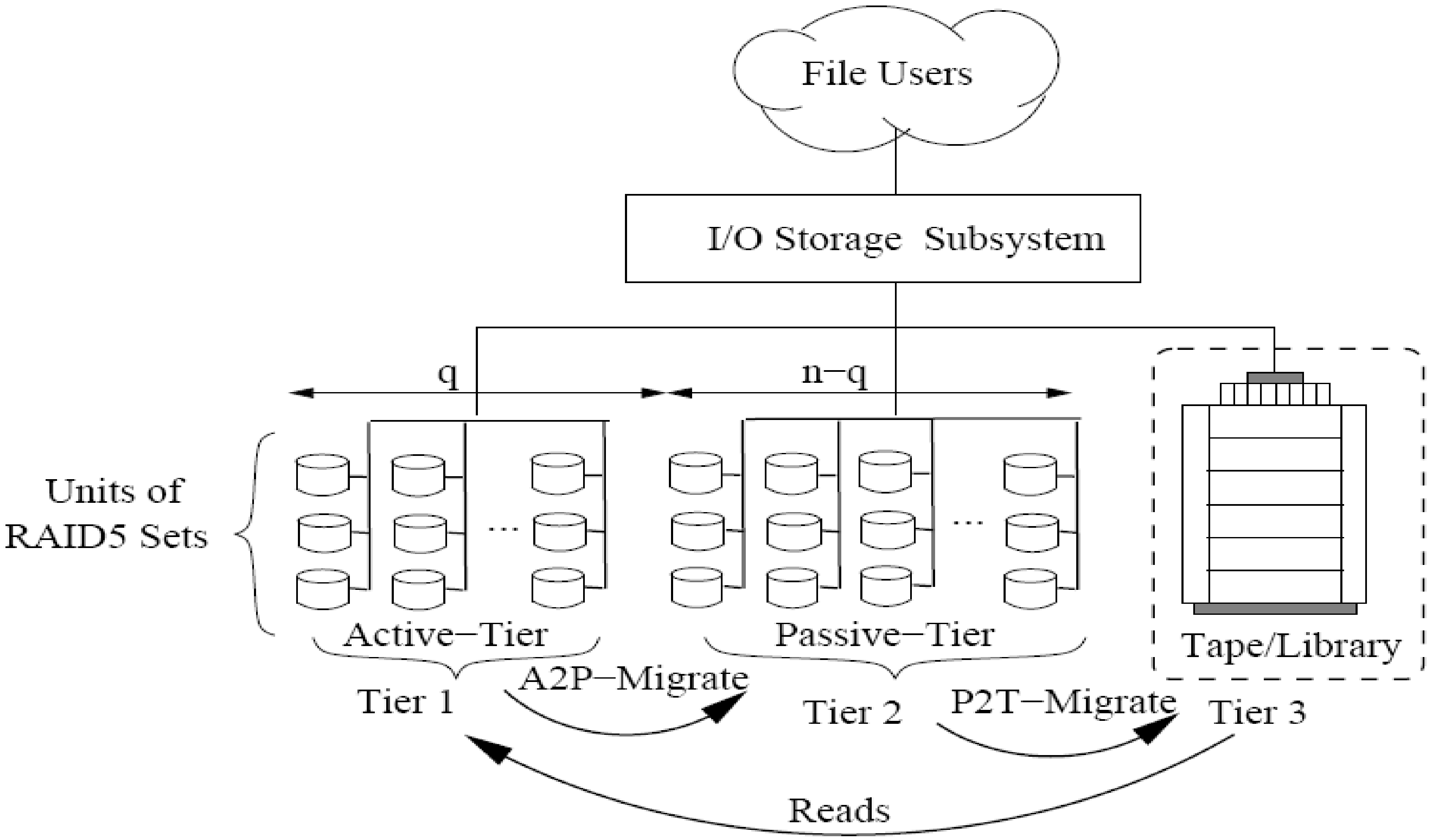


- Improving system for all possible workload space is difficult.
- If we know the real workload space we can improve performance more efficiently.

Framework of I/O Workload Characterization



Tiered Storage Research



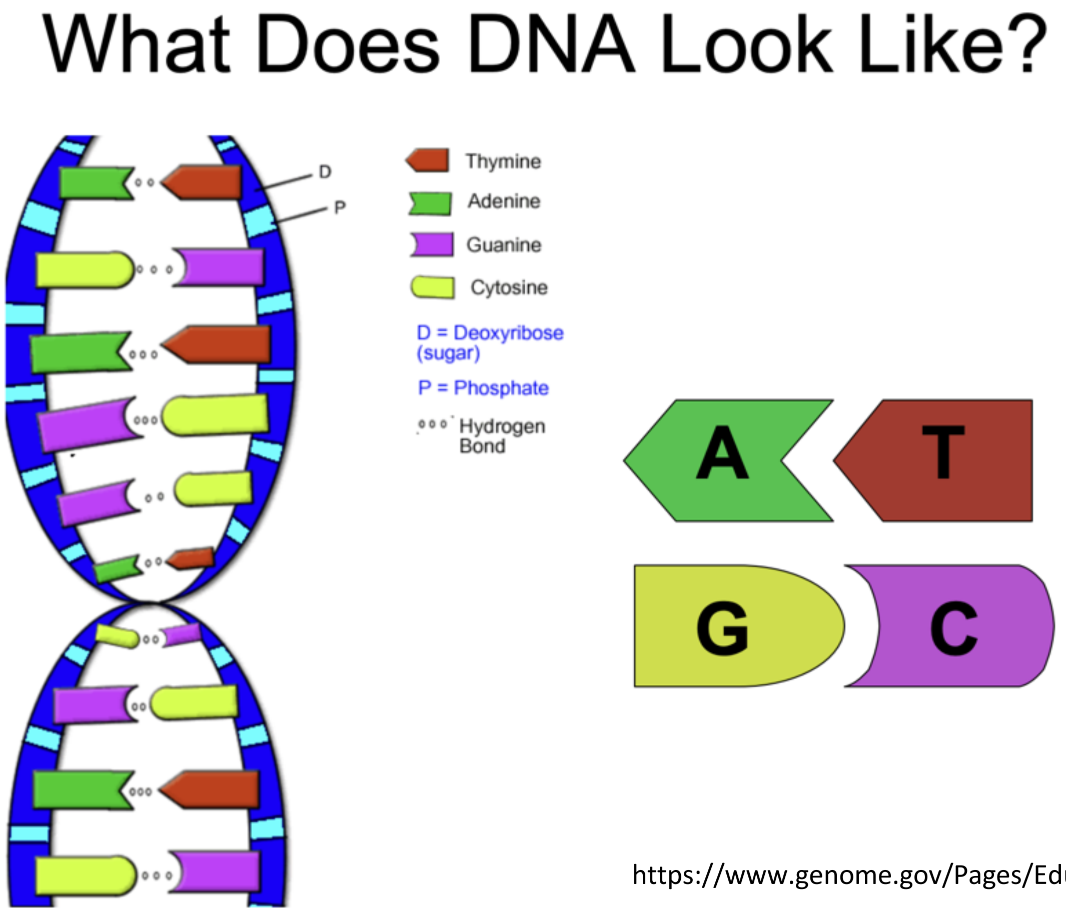
Data Migration, Duplication, and Deduplication

- Tiered Storage Management
- When a file is accessed, we may want to move related data level up to a faster storage provisioning potential near future access requests
- Duplication level optimal for a long-term storage
- Dedup algorithm and how to preserve it long-term (need to make sure we know how to get the data back)
- How to find the right balance between duplication and dedup? How do we validate that data is stored the we think it is?
- Imperfect dedup may be what we are looking for. However, what do we do if we want to have different levels of backup for different data.

DNA-Storage

Background

DNA Basics



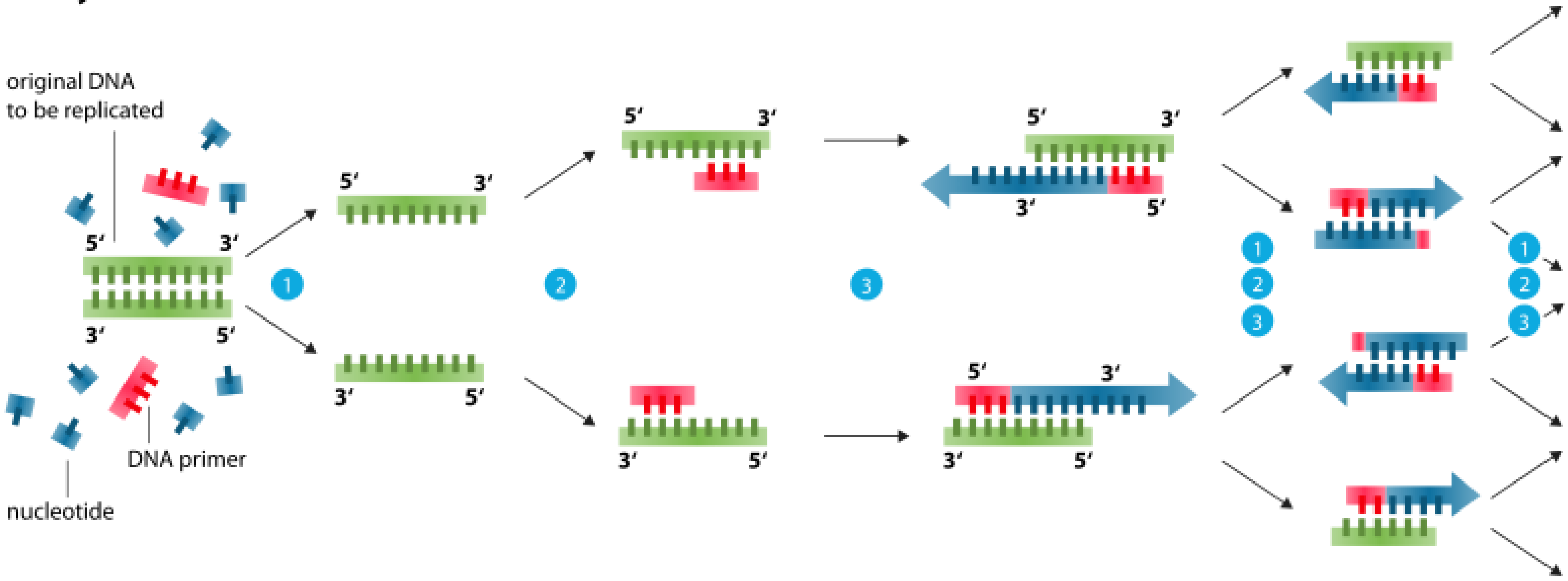
https://www.genome.gov/Pages/Education/Modules/BasicsPresentation.pdf

Background

PCR: polymerase chain reaction

- PCR: a method for exponentially amplifying the concentration of selected sequences of DNA within a pool.
- Primers: The DNA sequencing primers are short synthetic strands that define the beginning and end of the region to be amplified.

Polymerase chain reaction - PCR



1 **Denaturation** at 94-96°C

2 **Annealing** at ~68°C

3 **Elongation** at ca. 72 °C

https://en.wikipedia.org/wiki/Polymerase_chain_reaction

Background

DNA Synthesis

- Arbitrary single-strand DNA sequences can be synthesized chemically, nucleotide by nucleotide.
- Synthesizing error limits the size of the oligonucleotides (< 200 nucleotides).
  - truncated byproducts
- Parallel synthesize: 10^5 different oligonucleotides.

Background

DNA sequencing

- The DNA strand of interest serves as a template for PCR.
- Fluorescent nucleotides are used during this synthesis process.
- Read out the complement sequence optically.
  - Read error. (~1%)

A DNA Storage System

- Very **dense** and **durable** archival storage with access times of many hours to days.
- DNA synthesis and sequencing can be made arbitrarily **parallel**, making the necessary read and write **bandwidths** attainable.

Overview

- **basic unit**: DNA strand that is roughly 100-200 nucleotides long, capable of storing 50-100 bits total.
- **data object**: maps to a very large number of DNA strands.

- The DNA strands will be stored in **pools**
  - stochastic spatial organization
  - structured addressing: impossible
  - address: embedded into the data stored in a strand

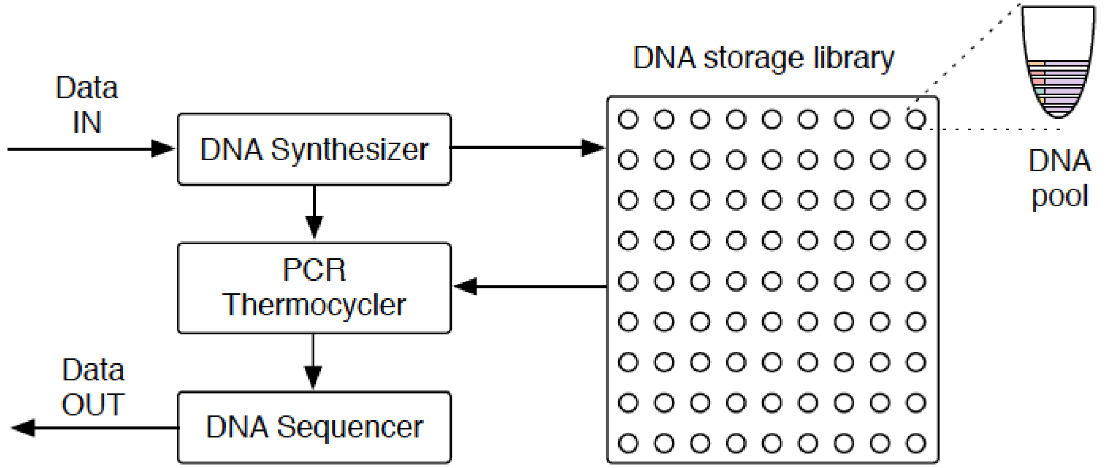
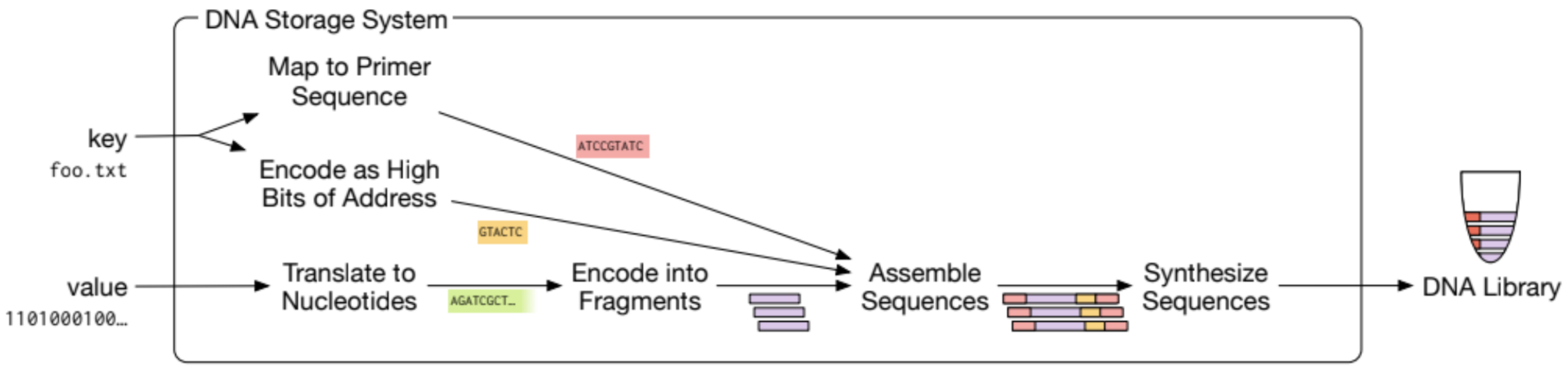


Figure 3. Overview of a DNA storage system.

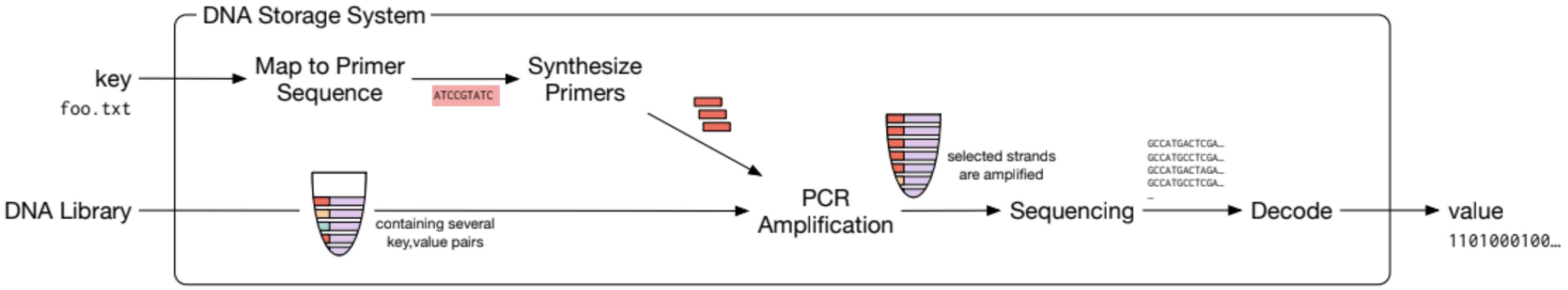
Interface and Addressing

- Object Store: Put(key, value) / Get(key).
- Random access: mapping a key to a pair of PCR primers.
  - write: primers are added to the strands
  - read: those same primers are used in PCR to amplify only the strands with the desired keys.
- Separating the DNA strands into a collection of pools:
  - primers reacts.
  - the chances of the sample contains all the desired data.

System Operation



(a) The write process performs `put(key, value)`, generating a DNA library.

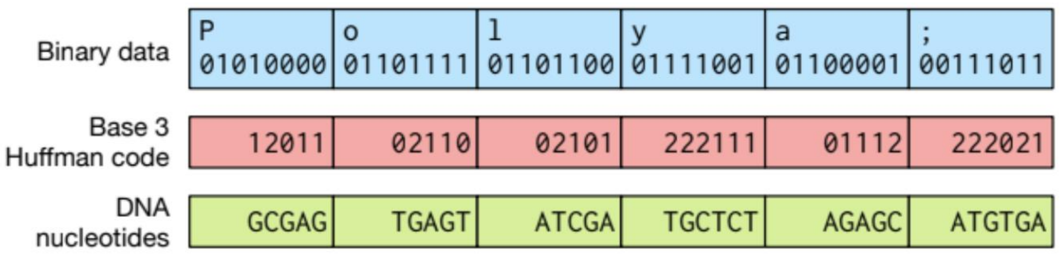


(b) The read process performs `get(key)` on a DNA library, returning the value.

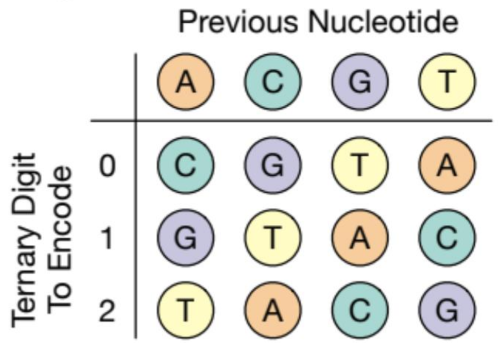
Figure 4. Overview of a DNA storage system operation as a key-value store.

Encoding

- Base 4 encoding: 00, 01, 10, 11 => A, T, G, C.
  - Error prone: synthesis, PCR, sequencing (substitutions, insertions, and deletions of nucleotides)
- Base 3 + Huffman code + rotation code



(a) Translating binary data to DNA nucleotides via a Huffman code.



(b) A rotating encoding to nucleotides avoids homopolymers (repetitions of the same nucleotide), which are error-prone.

Data Format

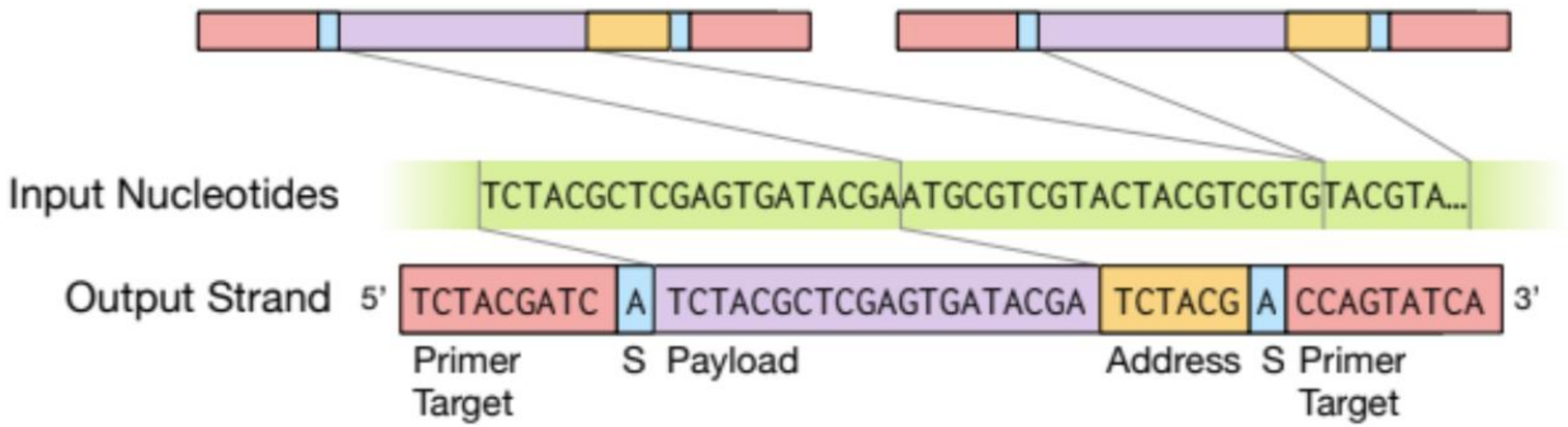


Figure 6. An overview of the DNA data encoding format. After translating to nucleotides, the stream is divided into strands. Each strand contains a payload from the stream, together with addressing information to identify the strand and primer targets necessary for PCR and sequencing.

Adding Redundancy

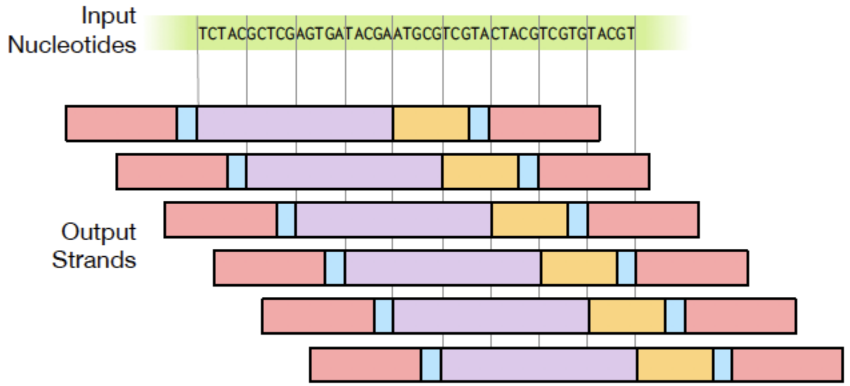


Figure 7. An encoding proposed by Goldman et al. [10]. The payloads of each strand are overlapping segments of the input stream, such that each block in the stream appears in four distinct strands.

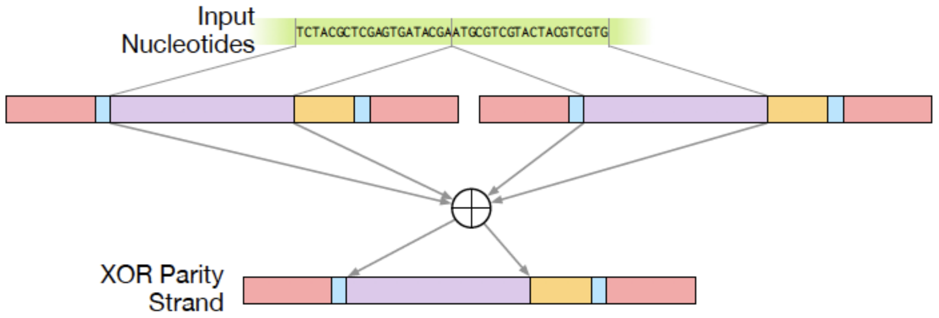


Figure 8. Our proposed encoding incorporates redundancy by taking the exclusive-or of two payloads to form a third. Recovering any two of the three strands is sufficient to recover the third.

Goldman Encoding

XOR Encoding