

Lecture III - Caching

Programming: Everyday Decision-Making Algorithms

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Learning Objectives

By the end of this lecture, you will be able to:

- Explain the fundamental concepts of caching and its importance
- Compare different cache replacement strategies
- Identify caching principles in everyday life
- Apply caching concepts to personal productivity
- Understand the relationship between caching and attention management

Introduction

A Quick Question First

Question: How many of you have a messy desktop right now?

Raise your hand!

Today's lecture will explain why that matters more than you think...

Let's approach the topic using an everyday decision

- We have a problem: Our cupboard.
- It's time to put things in order.



Question: What could we do?

- Better organization
- Clearing out things we no longer need
- Now we have two problems:
 - Storing?
 - Clearing out?



Two Approaches to Storage Problems

- Better Organization:
 - Subdivide storage
 - Efficient sorting
- More Space:
 - Increase capacity
- Question: Which approach is better?



Even best organization has limits

- Organization helps, but takes time.
- More space helps, but has limits.
- Every storage has a finite capacity.



Question: What do we do, when the storage is full?



We could increase the capacity

But...

- Increasing capacity = costly
- Trade-off: Size vs. Speed
- Larger = slower to search
- Sooner or later: Still fills up



Question: What else faces this problem?

- Cupboards
- Computers
- Email inbox
- Smartphones
- Warehouses
- Our brain?!

Question: Impact of full storage?

- Access speed drops
- Processing time up
- Performance down



Clearing out

Why Clearing Out Matters

- True for cupboards, computers, brains...
- But what stays and what goes?

Learning from Computer Science

The evolution of computer memory

- 1950s: Computer science faced the same problem
- Processors got faster (Moore's Law)
- Memory demands grew
- But memory speed couldn't keep up

→ The Memory Wall

The Bottleneck

- Modern CPUs: Billions of ops/second
- Problem: Data isn't available fast enough
- Question: What's the point of a fast CPU if it has to wait for slow memory?

→ Von Neumann Bottleneck

Cache

Cache: The Solution

A hierarchical memory system

- L1 Cache: Tiny but ultra-fast (64-256 KB)
- L2/L3 Cache: Larger, still fast (MB range)
- RAM: Main workspace (8-32 GB)
- Storage: Huge but slow (256 GB - 2 TB)

Like a library...

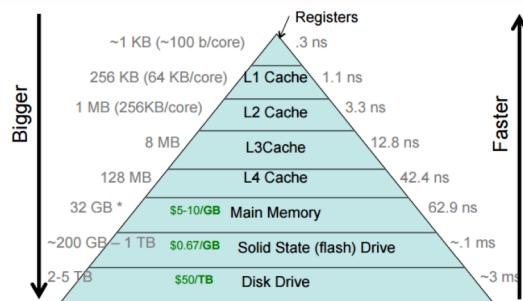
The Library Principle

- Library storage (5 million books, Mass Storage)
- Subject locations (100K books, RAM)
- Your desk (5 borrowed books, L2)
- Short-term memory (current page, L1)

Closer = Faster = Smaller



The Trade-off: Size and Speed



Registers are 10 million times faster than the hard drive!

Why can't we just make everything as fast as L1 cache?

Why the Trade-off?

Why not make everything ultra-fast?

- Physical limits: Larger caches sit further from CPU, signals take longer to travel, and dense fast memory generates extreme heat that must be dissipated
- Economic limits: SRAM costs \$50,000/GB vs. HDDs at \$0.02/GB

- Solution: Multiple cache levels, each optimized for different needs

The necessity of clearing out

- L1 and L2 cache only contain most necessary data.
- The same should apply to your desk.
- Therefore, both must be cleared regularly.



Clearing out Strategies

Question: Eviction Strategies?

- Random
- First-In, First-Out (FIFO)
- Least Frequently Used (LFU)
- Least Recently Used (LRU)

How to clear up?

- Optimal: Clairvoyance
 - Keep what you'll need
 - Remove what you won't
- Question: What's the problem?

→ Requires knowledge of the future!

Realistic Strategies

- Least Recently Used (LRU) is the dominant strategy.
- Evicts the least recently accessed item from the cache when space is needed.
- Leads to much better performance on average than, for example, random eviction.
- Question: Why do you think least recently used is the better strategy?

Why LRU Works: The Principle of Temporal Locality

- Temporal Locality: Recent use → Likely need again soon
- Examples:
 - Books on your desk
 - Apps opened today
 - People texted this morning
- Performance: 80-90% hit rate (vs. 50-60% random)

Recent past predicts near future

Managerial and personal insights:

- Let go of unused things → LRU principle
- Keep things where used → Spatial locality
- Result: Significant productivity increase

Marie Kondo = LRU for physical objects!

Spatial Locality

Question: Can you think of examples where spatial locality is applied in your daily life?



Mathematically optimal

Productivity

Our Brains are Caches

- We've learned how computers manage limited cache space
- But why does this matter for humans?
- Your brain works remarkably similar to a computer cache:
 - Limited capacity for active information
 - Fast access to recently used information
 - Must constantly decide what to keep and what to forget

Cache Vulnerabilities

- Denial-of-Service (DoS) attacks exploit cache limitations:
 - Cache Flooding: Overload with excessive requests
 - Cache Poisoning: Insert malicious data to evict important information
- These attacks overload a system with excessive requests or data.
- Causing it to slow down or crash.
- The system is forced to evict important data.

Productivity Killers

- Overload (too much information, cache capacity exceeded)
- Exhaustion (too long without “cache clearing”)
- Context switching (interruption of “flow”, ~23 minutes to get back on track)
- Distraction (Cache Flooding: constant notifications, social media)
- Misinformation (Cache Poisoning: fake news, misleading information)

The Attention Crisis

- Technology & Social Media: Designed to capture attention (Cache Flooding)
- Constant Interruptions: Notifications = Forced cache evictions
- Result: Reduced creativity, critical thinking, and productivity

Reflection: How many times did you check your phone during this lecture?

The Solution: Manage Your Mental Cache

- Limit screen time and practice “monotasking” (Reduce cache thrashing).
- Prioritize sleep, nutrition, and mindful habits (Maintain cache performance).
- Create protected time for deep work (Prevent cache flooding).
- Be selective about what enters your attention (Smart cache management).

Mitigation

Mitigation

- Distraction can hardly be avoided in today’s world but can be mitigated.
- This is particularly important for managers.
- This lecture is designed to raise your awareness of what you can do to keep your brain working efficiently.
- Want to dive deeper? Read “Stolen Focus” by Johann Hari

Awareness: Three Levels of Attention

- Spotlight – Immediate goals – Focus (Your L1 Cache: What are you working on RIGHT NOW?)
- Starlight – Medium-term goals – Wishes (Your L2 Cache: What matters this week/month?)
- Daylight – Long-term goals – Values (Your Storage: What defines your life direction?)

Practical Strategies

- Prioritization: What deserves to be in your mental cache?
- Structure (Schedule): Time-boxing prevents cache overflow
- Breaks: Regular “cache clearing” prevents exhaustion
- Enable flow: Dedicated workspace, manage notifications, clear communication
- Meditation & exercise: Maintenance routines for optimal cache performance

Cache Hierarchy for Workspace

- Hot Cache (On your desk): Only items for current tasks (today)
- Warm Cache (Nearby shelf/drawer): This week’s projects (this week)
- Cold Storage (Archive/closet): Everything else

→ The key principle: If you haven’t used it recently, move it away!

Self-Assessment

Question: Right now:

1. How many browser tabs do you have open? ____

2. How many notifications did you receive in the last hour? ____
3. How many unread emails in your inbox? ____

Do you see any risks of cache flooding?

Key Takeaways

Key Takeaways: The Concepts

- Caching is universal: It applies to computers, organizations, and human cognition
- The fundamental trade-off: Fast storage is small, large storage is slow
- LRU works because of temporal locality: Recent past predicts near future

Key Takeaways: Your Life

- Your brain is a cache: Limited capacity, vulnerable to flooding and poisoning
- Protect your attention: It's your scarcest and most valuable resource
- Apply caching principles to life: Keep what you use, remove what you don't

Literature

Interesting literature to start

- Christian, B., & Griffiths, T. (2016). Algorithms to live by: the computer science of human decisions. First international edition. New York, Henry Holt and Company.¹
- Ferguson, T.S. (1989) 'Who solved the secretary problem?', Statistical Science, 4(3). doi:10.1214/ss/1177012493.

Books on Programming

- Downey, A. B. (2024). Think Python: How to think like a computer scientist (Third edition). O'Reilly. [Here](#)
- Elter, S. (2021). Schrödinger programmiert Python: Das etwas andere Fachbuch (1. Auflage). Rheinwerk Verlag.

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Note

Think Python is a great book to start with. It's available online for free. Schrödinger Programmiert Python is a great alternative for German students, as it is a very playful introduction to programming with lots of examples.

More Literature

For more interesting literature, take a look at the [literature list](#) of this course.

¹The main inspiration for this lecture. Nils and I have read it and discussed it in depth, always wanting to translate it into a course.