Lecture III - Caching

Programming: Everyday Decision-Making Algorithms

Dr. Nils Roemer Kühne Logistics University Hamburg - Winter 2025

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

Caching: Making the most of limited resources

In the practical use of our intellect, forgetting is as important a function as remembering. – [William James]

- Today's lecture is on caching.
- The discussed topics are highly relevant for everything that has to do with computers and data.
- On top of that, caching is another very important concept for our everyday decision-making.

Let's approach the topic using an everyday decision-making situation

- 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?



Storing

How to bring order to storage?

- Subdivide storage
- Efficient sorting
- Increase capacity



Subdivide storage and efficient sorting outcome

- Time investment can improve storing.
- That is a difficult trade-off in itself.
- Nontheless: Each storage has a limited capacity.



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



We could increase the capacity

But...

- Increase capacity is costly.
- There is a trade-off between size and speed.
- Sooner or later, every storage will fill up if not cleared out.



Question: What types of storages can you imagine that are affected by this?

- Our cupboard
- Our computer (hard drive, RAM, cache, ...)
- Our brain?!

Question: What is the impact of a full storage?

- Access speed drops significantly
- Processing time increases
- Overall performance decreases



Clearing out

Now we see, why clearing out is so important

- And that goes for our cupboard as well as for computers and other storages...
- But what stays and what goes?

Question: What replacement/eviction policies can you imagine?

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

Once again, we can learn a lot from the computer sciences.

The evolution of computer memory

- In the 1950s, computer science faced the same question...
- ...and has faced it repeatedly since then.
- Processors have become faster and faster (Moore's Law).
- The demands on memory also grew.

CPU

- The processor (CPU, Central Processing Unit) is central to a computer and is often referred to as the "brain" of the system.
- It executes instructions and performs calculations, to process data and run programs.

Problem: Access Time

Problem: No matter how much faster the processor gets, if input data isn't available fast enough or can't be stored quickly enough, the system won't become faster overall.

Question: What is the solution?

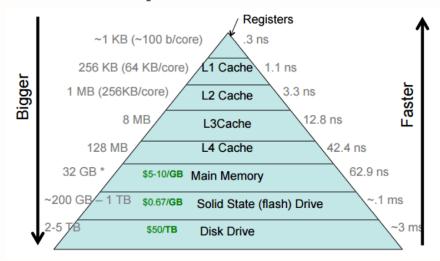
Cache

Cache

Hierarchical memory pyramid for efficient data management

- L1 Cache, directly on CPU, very fast access time.
- L2 Cache, between L1 and main memory.
- RAM memory.
- Mass Storage (hard drive).
- The whole memory system works like a library.
- Find an explanation here.

Cache - Size and Speed trade-off



Registers are 10 million times faster than the hard drive!

Library Principle

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



Library Principle

- 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

How to clear up?

- Optimal: Clairvoyance
 - Store everything in the cache that will be needed
 - Delete everything from the cache that won't be needed
- Question: What is the problem with this strategy?
- Optimal strategy not achievable in reality

Realisable strategies?

- Least recently used 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?

Managerial and personal insights:

- Let go of things you haven't used in ages
- · Keep things where they are used
- Both have been proven to contribute to a significant increase in productivity

Keeping things where they are used...



Might be optimal, in a mathematical sense

Productivity

The strong limitations of caches make them a "security risk".

- Denial-of-Service Attacks (DoS) attacks.
 - Cache Flooding
 - Cache Poisoning
- Overload a system with excessive requests or data.
- Causing it to slow down or crash.
- The system is forced to evict important data.

Question: Why are the findings about cache so important for humans? Your Brain is a Cache, Not a Database -[Joe Chrysler]

Our brain has similar weaknesses

Productivity and creativity are negatively affected by:

- Overload (too much)
- Exhaustion (too long)
- Context switching (interruption of "flow", 23 minutes to get back on track)
- Distraction (Cache Flooding)
- Fake News (Cache Poisoning)

This can lead to burnout.

Question: What do you think should we do about it?

Stolen Focus: Why You Can't Pay Attention - Key Insights I Main Idea:

- Modern life is eroding our ability to concentrate and engage deeply, with societal factors affecting personal focus.
- The reason for that has much to do with the way our brain works and how we interact with technology.

Stolen Focus: Why You Can't Pay Attention - Key Insights II Key Causes of Attention Loss:

- Technology & Social Media: Designed to capture and keep attention, leading to fragmented focus.
- Constant Interruptions: Notifications and multitasking disrupt deep work and concentration.
- Environmental & Lifestyle Factors: Poor sleep, stress, and diet impact cognitive function.

Stolen Focus: Why You Can't Pay Attention - Key Insights III Consequences:

- Reduced ability to think critically and creatively.
- Difficulty sustaining attention on meaningful tasks.

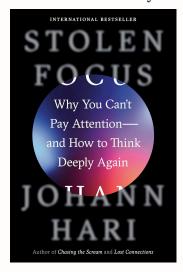
Stolen Focus: Why You Can't Pay Attention - Key Insights IV Solutions Suggested:

- Limit screen time and practice "monotasking."
- Prioritize sleep, nutrition, and mindful habits.

Stolen Focus: Why You Can't Pay Attention - Key Insights V https://www.youtube.com/watch?v=DqlywBxYELw

But even better: read the book!

Stolen Focus: Why You Can't Pay Attention - Book



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.

Awareness I

Train awareness

- Spotlight immediate goals Focus
- Starlight medium-term goals Wishes
- Daylight long-term goals Values

Awareness II

Prioritization

- Prioritization
- Structure (Schedule)
- Breaks

- Enable flow (dedicated workspace, manage notifications, clear communication)
- Meditation & exercise

Key Takeaways

Key Takeaways

- Caching is a universal concept that applies to computers, organizations, and human cognition
- Efficient cache management requires strategic decisions about what to keep and what to remove
- LRU (Least Recently Used) is often the most practical replacement strategy
- Our brain's limitations are similar to computer caches
- Managing our attention and focus requires understanding these limitations

Summary Quiz

Question: Take a moment to reflect:

- 1. What are the three main types of cache replacement strategies?
- 2. How does the library principle relate to computer memory hierarchy?
- 3. What are two ways you can apply caching principles to improve your productivity?
- 4. How can understanding cache flooding help protect against information overload?

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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i 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.

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.

More Literature

For more interesting literature, take a look at the literature list of this course.