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Design and Implementation of a Collaborative Board Using the
Local-First Approach

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Abstract

Design and Implementation of a Collaborative Board Using the Local-First Approach

The purpose of this thesis is to design and implement a collaborative board using the local-first approach. The solution uses distributed conflict free replicated data types (CRDTs) and real-time communication via WebRTC protocol to bring effortless collaboration with other users.

Final result of the effort done is an desktop application that enables drawing and erasing on the whiteboard with mutiple users simultaneously. This paper covers description of solution, but also thouches broader topic of local-first application design architectures.

Key words: rust language, local-first, CRDT, WebRTC, distributed system, star topology, multithread real time communication

Streszczenie

Projekt i wdrożenie kolaboratywnej tablicy z wykorzystaniem podejścia „local-first”

Celem pracy inżynierskiej jest zaprojektowanie i implementacja kolaboratywnej tablicy z wykorzystaniem podejścia "local-first". Wypracowane rozwiązanie uzywa rozproszzonego bezkonfliktowego typy danych (CRDTs) oraz komunikacji w czasie rzeczywistym przez protokół WebRTC by umożliwić bezproblemową kolaborację z innymi użytkownikami. Ostatecznym wynikiem jest aplikacja desktop-owa umożliwiająca rysowanie oraz zmazywanie poprzednich pociągnięć na białej tablicy z wieloma użytkownikami jednocześnie. Praca pokrywa opis rozwiązania ale również porusza bardziej obszerny temat architektury typu local-first w aplikacjach kolaboratywnych.

Słowa kluczowe: język rust, local-first, CRDT, WebRTC, system rozproszony, topologia gwiazdy, wielowątkowa komunikacja w czasie rzeczywistym

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1. Introduction

1.1. Analysis and description of collaborative local-first applications

Collaborative applications have not always been so popular as they are these days. You might not even know that some of applications that we use every day are collaborative. In everyday life of a software developer almost all of modern IDEs have collaborative work options, almost all project management software are also collaborative. These are examples close to software engineers, but these applications do not limit themselves to software development. Google Docs, Microsoft 365, Figma, Miro and many more are examples of collaborative applications that are used by millions of people every day. These applications are not only used for work, but also for education and entertainment.

It hasn't always been like this. The steep rise of collaborative applications began as the remote work became more popular but also it owes its rise of popularity to universality of fast global network and increase of computing power of everyday devices.

Current collaborative apps couldn't exist 20 years ago. They haven't been simply invented yet. Typical application of early days of online applications had a simple architecture. It was a client-server application. The server was responsible for storing data and processing it, while the client was responsible for presenting the data to the user and sending user input to the server. This architecture had its advantages and disadvantages. It was simple and easy to implement, but it had a single point of failure. If the server went down, the entire application went down. It also had scalability issues, as the server had to handle all the requests from the clients.

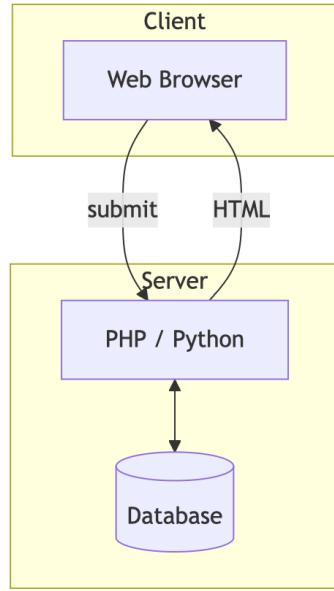


Figure 1.1: Simple client-server architecture of early internet era applications

These kind of application belong to “cloud-first” family. There was no need for “local-first” architectures yet and this term has not been popularized. Before even the discussion on topic of “local-first architectures” the “cloud-first” approach had its own more than one decade of fast development. From simple client server architectures the system rose to more difficult forms of large size client-side application with lots of layers and microservices. Picture below shows architectures that emerged on the market with rise of popularity of mobile and web apps from 2010.

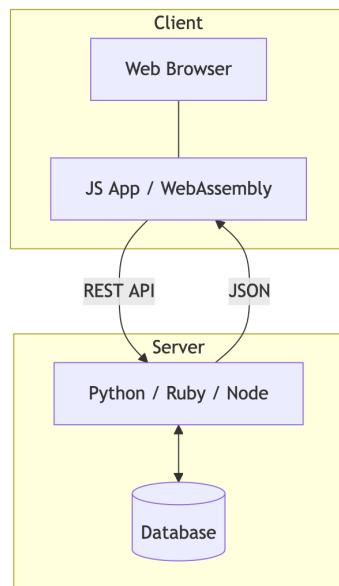


Figure 1.2: More complicated architecture of modern mobile/web applications

1.1. ANALYSIS AND DESCRIPTION OF COLLABORATIVE LOCAL-FIRST APPLICATIONS

How far are these architectures from being good fit for collaborative applications? Lets have a look on typical modules that take part in standard user interface interaction. Picture below shows typical modules of modern web/mobile/desktop cloud-application.

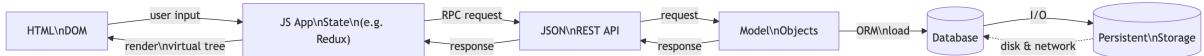


Figure 1.3: Typical modules of modern cloud-based applications

As we can see the level of complication is very high. Simple user interaction with a system triggers multiple functions from multiple modules from multiple services. This level of sophistication simply cannot be used for collaborative applications, because orchestration of synchronization of state shown in simultaneous users would be extremely difficult.

For one, it would require too many asynchronous time-consuming remote calls to different services. Total synchronization nightmare. For some time though there has been efforts to implement collaboration this way. This approach was known as OT - operational transformation (still used in Google Docs). Although Google Docs is a good example of usage of cloud-first approach, in this thesis I decided to focus on local-first architectures as they have proved to be more broadly used in the industry and it offers way more possibilities of different kind of applications.

There are also many other reasons to avoid cloud-first architectures when designing collaborative applications. Lets take a look at simple sequence of user interaction with the system. Below we can see general asynchronous interaction of a user with normal cloud-based application.

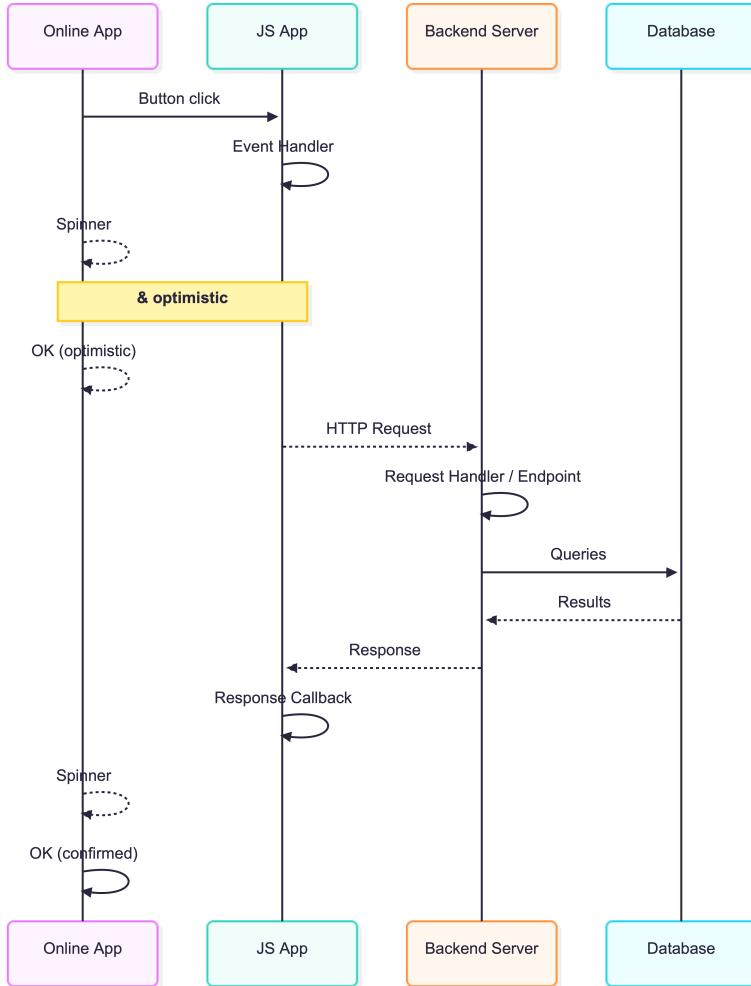


Figure 1.4: Typical sequence of interaction with a user in a modern cloud-based applications

As we can see on this diagram, the system relies heavily on connectivity with the database. The big question that comes to mind is - what happens to the system if there is no internet? Answer is simple. It would not work. Therefore, one could even say, that whole application is just a asynchronous graphical database wrapper, and it wouldn't be far from truth. This brings us the question - What is the definition of cloud-first and local first applications?

In simplest words the definition of cloud-approach is "If the interaction of the user with the system haven't been saved to database, it never happened". On other hand local-first is "What's important the most is local persistency - cloud brings only connectivity".

Therefore let's have a look on how would typical sequence of user interaction with local-first system look. The diagram below shows typical sequence in such system.

1.2. LOCAL-FIRST VS CLOUD-FIRST

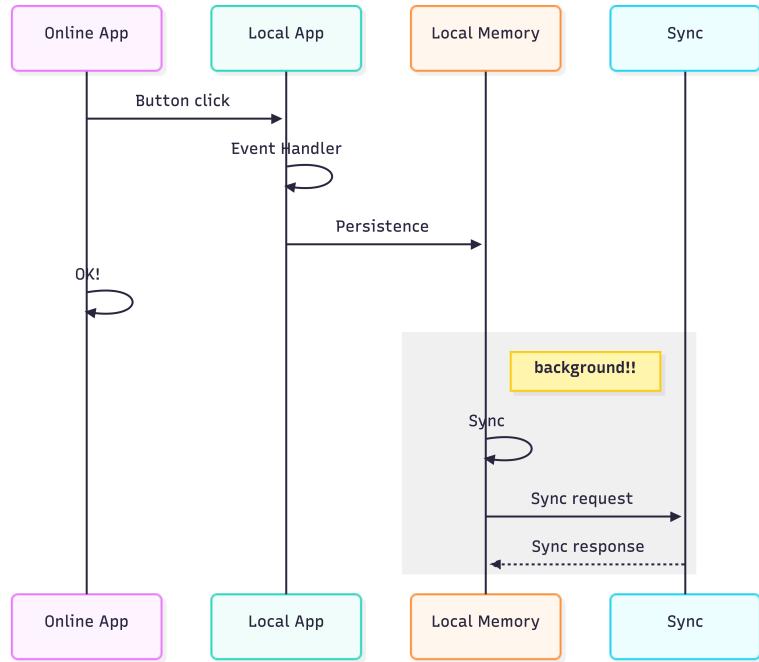


Figure 1.5: Typical sequence of interaction with a user in a local-first applications

The distinction is clear. In local-first approach the user interaction with the system is not dependent on connectivity with the database. Connectivity brings only messaging with other peers. Whole synchronization of replicas of data between users happens on local machine. This is the reason why we can call this system distributed. We can also notice that this approach requires much less modules across different services. Later, in the thesis, we will clearly how this concept allows us to bring true real time collaboration to the users.

1.2. Local-first vs Cloud-first

Lets have a look on the main differences between local-first and cloud-first approaches. The table below shows the main differences between these two approaches when it comes to designing collaborative application.

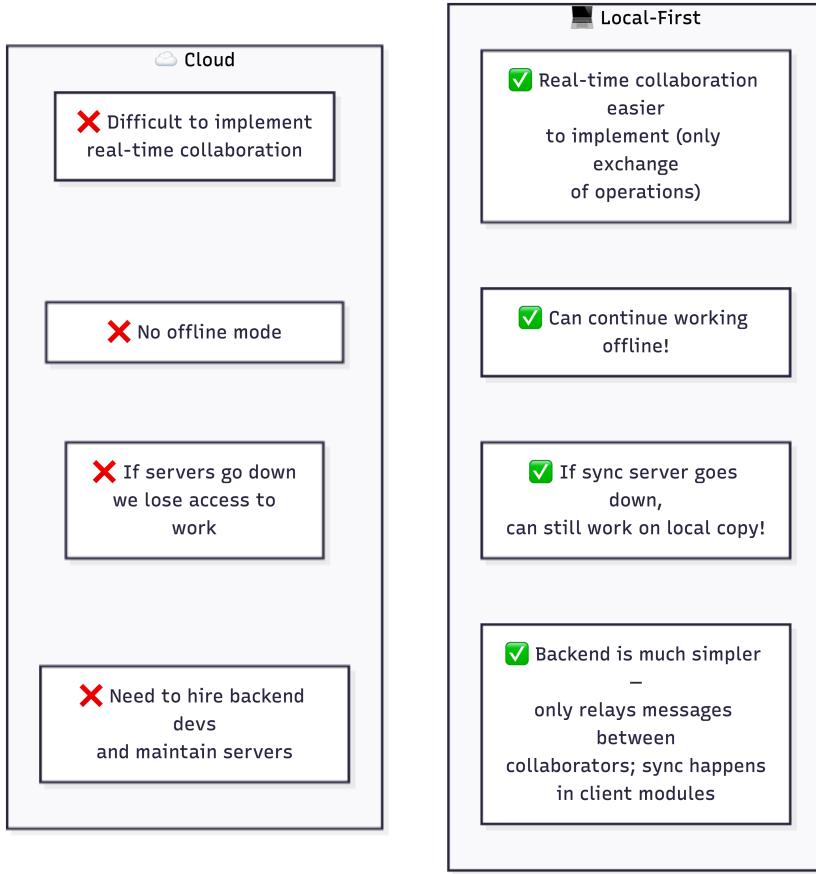


Figure 1.6: Cloud vs Local comparison

Clearly, the obvious choice for approach when designing collaborative application would be Local-first. Let's now try to distinguish, what are boundaries of such system - what use cases are not applicable with local-first approach. The table below shows use cases that are not good fit for local-first approach.

Table 1.1: Use cases: Suitable and Unsuitable for Local-First Approach

Suitable for	Unsuitable for
Real-time collaborative editing (documents, whiteboards)	Applications requiring strong centralized control
Offline-first mobile/desktop apps	Systems with strict regulatory or audit requirements
Peer-to-peer file sharing	Applications with massive global data aggregation
Personal productivity tools with sync	Centralized transactional systems (e.g., banking)
Small/medium team collaboration	Apps needing immediate global consistency

1.3. WHY WOULD ONE IMPLEMENT OWN COLLABORATIVE SYSTEM ?

1.3. Why would one implement own collaborative system ?

Creating collaborative whiteboard is just an introduction to the general topic of distributed conflict free real time data storage with editable operations. Design whiteboard is easy example for system that can be used to many use cases (distributed conflict free data) - it serves as a great introduction to this topic.

There are multiple use cases/possible usage of distributed systems. For example drone swarms - distributed replicas of formation among drones broadcasted between each other. Peer-to-peer file sharing - distributed replicas of files among users. Real time collaborative editing - distributed replicas of documents among users.

1.4. Examples from industry

Known examples of local-first applications are: Figma, Miro, Notion, Obsidian, Roam Research, Coda, Google Docs (although it is not pure local-first application). These applications are used by millions of people every day. They are used for work, education and entertainment.

1.5. Known architecture solutions for collaborative applications

1.6. Vision of the System

1. rust
2. start topology

1.7. OT vs CRDTs

1.8. Requirements Specification

1.8.1. Functional Requirements

1.8.2. Non-Functional Requirements

1.9. Business Cases

2. Example chapter

This T_EX file is to be compiled with pdfLaTeX (it's just quick build in TeXMaker).

2.1. Example section

Definition 2.1 (Definition). A *definition* is a statement of the meaning of a term (a word, phrase, or other set of symbols).

2.1.1. Example subsection

It's the deepest depth of sectioning allowed by rector.

Definition 2.2 (Equation). In mathematics, an *equation* is a statement of an equality containing one or more variables.

Example 2.3. This is an example of an equation:

$$2 + 2 = 4. \quad (2.1)$$

Equation without a number:

$$2 + 2 = 4,$$

or:

$$2 + 2 = 4.$$

It is worthwhile to peruse other mathematical environments like *multiline*, *align* and their versions with a star (, i.e. without numeration). The description of their use can be found at <https://texdoc.org/serve/amsldoc.pdf/0> starting from the end of the third page.

Equation (2.2) is false. References (and some other things) work properly after compiling T_EX file twice.

$$\int_0^1 x \, dx = \frac{3}{2}. \quad (2.2)$$

Theorem 2.4 is a very interesting result.

Theorem 2.4 (Pythagoras' Theorem). Let c represent the length of the hypotenuse and a and b the lengths of the triangle's other two sides. Then:

$$a^2 + b^2 = c^2.$$

Proof. The proof has been presented in [1] and [2]. We can write then [1, 2]. \square

Corollary 2.5. The use of the term *corollary*, rather than *proposition* or *theorem*, is intrinsically subjective.

Remark 2.6. You can find a rather comprehensive list of available symbols at https://www3.nd.edu/~nmark/UsefulFacts/LaTeX_symbols.pdf.

If you want to find a symbol by its shape, you can use the following site: <https://detexify.kirelabs.org/classify.html>.

Lemma 2.7 (Someone's Lemma). Ten lemat jest nie na temat.

Proof. Dowód przez indukcję. \square

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2.2. Floats – tables and figures

Place labels after captions or you get the wrong labelling.

In Table 2.1 there are additional options for `table` and `figure` environments.

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Table 2.1: Additional options

symbol	effect
h	Place the float here, i.e., approximately at the same point it occurs in the source text (however, not exactly at the spot)
t	Position at the top of the page
b	Position at the bottom of the page
p	Put on a special page for floats only
!	Override internal parameters LaTeX uses for determining "good" float positions
H	Places the float at precisely the location in the L<small>A</small>T<small>E</small>X code. Requires the float package,[1] i.e., <code>\usepackage{float}</code> . This is somewhat equivalent to <code>!ht</code> .

Figure 2.1: Example figure – it has been drawn by **LATEX** default tools

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3. The next chapter

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3.1. Matrices

Simple matrix:

$$\begin{matrix} a & b & c & d \\ d & e & f & g \\ 1 & 1 & 1 & 1 \end{matrix}$$

Matrix with parentheses:

$$A = \begin{pmatrix} a & b & c & d \\ d & e & f & g \\ 1 & 1 & 1 & 1 \end{pmatrix}$$

Matrix with brackets:

$$\begin{bmatrix} a & b & c & d \\ d & e & f & g \\ 1 & 1 & 1 & 1 \end{bmatrix}$$

You can also use more general environment:

$$\begin{matrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{matrix}$$

Matrix with braces:

$$\left\{ \begin{array}{ccc} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{array} \right\}$$

Definition 3.1. Let $A \neq \emptyset$, $n \in \mathbb{N}$. Every function $f: A^n \rightarrow A$ is called an *n-ary operation* or *działaniem określonym na A*. 0-ary operations are constant functions.

Definition 3.2 (Algebra). The ordered pair (A, F) , where $A \neq \emptyset$ is a set and F is a family of operations defined on A , shall be called an *algebra* (or *F-algebra*). The set A is called *the set of elements, support or universe* of an algebra (A, F) and F is called *the set of elementary operations*.

Proposition 3.3. I state that, having passed to the limit, the only thing left me is to camp at said limit or return, or, maybe, search for a pass or an exit to other areas.

Bibliography

- [1] A. Author, *Title of a book*, Publisher, year, page–page.
- [2] J. Bobkowski, S. Dobkowski, Title of an article, *Magazine X, No. 7*, year, PAGE–PAGE.
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- [4] F. Burris, H. P. Sankappanavar, *A Course of Universal Algebra*, Springer-Verlag, New York, 1981.

List of symbols and abbreviations

nzw. nadzwyczajny

* star operator

~ tilde

If you don't need it, delete it.

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