UNIVERZITET U NOVOM SADU
FAKULTET TEHNIČKIH NAUKA
KATEDRA ZA PRIMENJENE RAČUNARSKE NAUKE

Paralelni i distribuirani algoritmi i strukture podataka

prof. dr Dušan Gajić

Zimski semestar 2023/2024.

Studijski program: Računarstvo i automatika

Modul: Računarstvo visokih performansi

O predmetu

Pregled

- Predavači
- Cilj i sadržaj predmeta
- Organizacija ispita
- Tehnologije
  - Programski jezik Go
  - Blokčejn tehnologije

Literatura i resursi

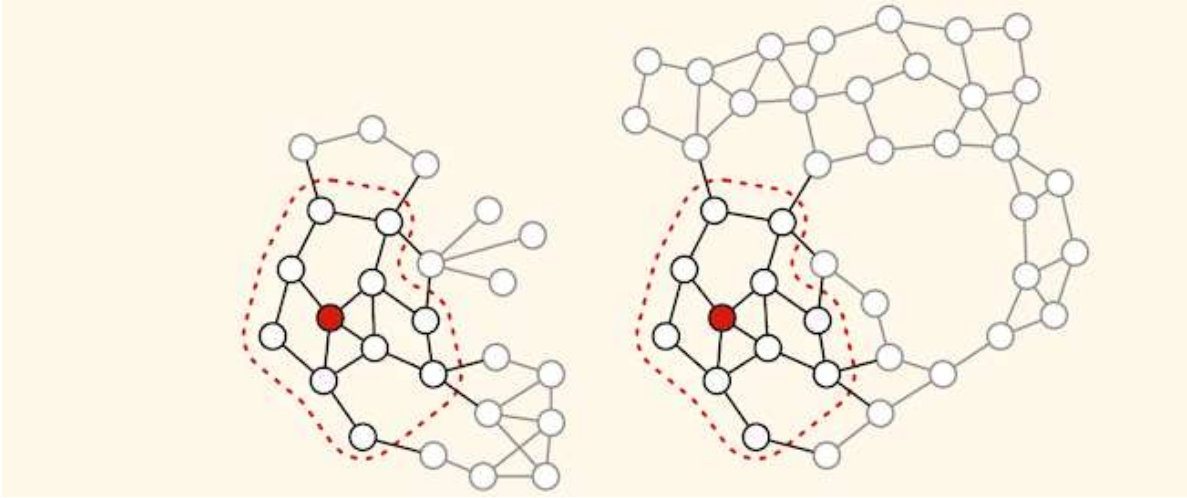
Predavači

Nastavnik:
prof. dr Dušan Gajić
E-mail: dusan.gajic@uns.ac.rs
Kancelarija: NTP-330
Konsultacije: dogovor putem mejla

Asistent:
Nebojša Horvat
E-mail: horva.n@uns.ac.rs
Kancelarija: NTP-328
Konsultacije: dogovor putem mejla

Cilj predmeta

Ovladavanje tehnikama izbora, analize, implementacije i primene paralelnih i distribuiranih algoritama i struktura podataka, sa posebnim fokusom na blokčejn tehnologije



Sadržaj predmeta

- **Uvod u paralelne i distribuirane sisteme**
- **Algoritmi za deljenu memoriju** (engl. *shared memory*)
- **Algoritmi sa prenosom poruka** (engl. *message passing*)
- **Arhitektura softvera u distribuiranim sistemima**
- **Procesi, komunikacija i imenovanje u distribuiranim sistemima**
- **Koordinacija, konzistentnost i replikacija u distribuiranim sistemima**
- **Otpornost na greške i bezbednost u distribuiranim sistemima**
  - **Konsenzus algoritmi** – Paxos, Raft, problem vizantijskih generala
- **Blokčejn** – osnovni pojmovi, koncepti i tehnike, kriptografija
- **Blokčejn tehnologije** – javni blokčejn sistemi: Bitcoin, Ethereum, …
- **Blokčejn tehnologija Hyperledger Fabric** – privatni blokčejn sistemi, koncepti i arhitektura, mehanizam transakcija, ostali Hyperledger projekti

Organizacija ispita

- Nastava: 3+3 (predavanja i računarske vežbe)
- Polaganje: **predispitne** (**70%**) i **ispitne** (**30%**) **obaveze**

1. **Predispitne obaveze – ukupno 70 bodova**
    1. **Zadatak** (Go) – 20 bodova
    2. **Projekat** – 40 bodova
    3. **Seminarski rad** – 10 bodova
2. **Ispit – ukupno 30 bodova**
    1. Teorijske osnove paralelnih i distribuiranih sistema sa fokusom na blokčejn
    2. Uslov za izlazak na ispit je osvojenih 36 bodova sa predispitnih obaveza

Sajt predmeta

- Sajt predmeta na: www.acs.uns.ac.rs
- [*Paralelni i distribuirani algoritmi i strukture podataka*]

Tehnologije

Go (Golang)

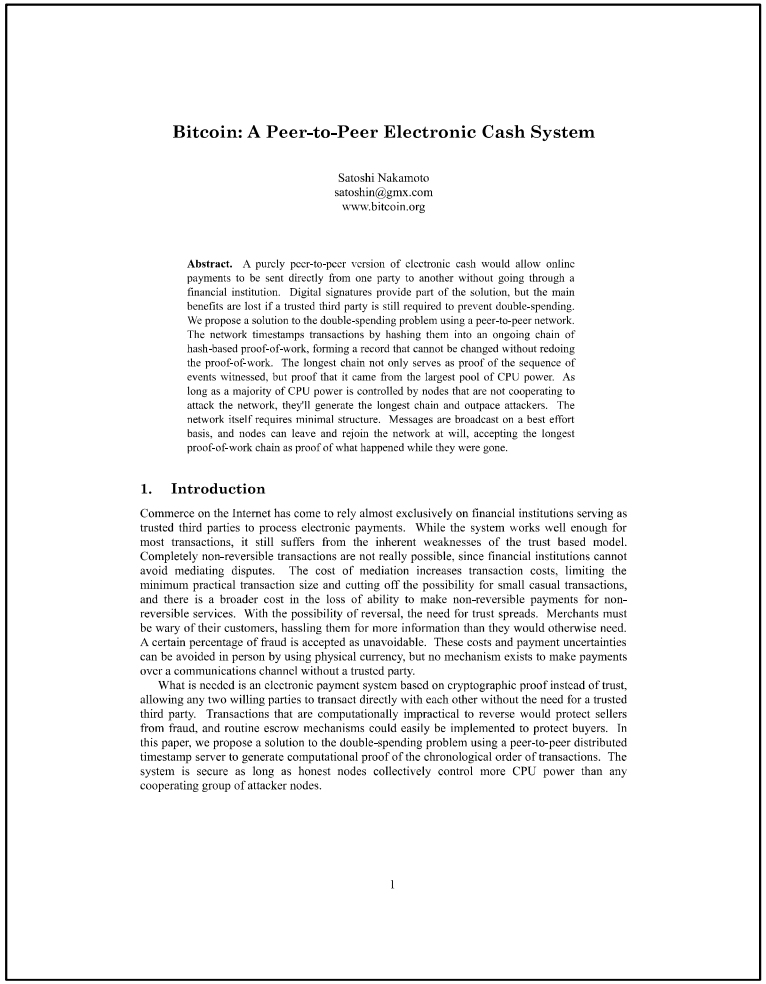
- **Kompajliran programski jezik sa statičkim tipovima**, efikasnost C++, čitljivost i upotrebljivost Python-a ili JS-a, i visoke performanse kod multiprocesiranja i mrežnog rada
- Prvu verziju Google je predstavio 2009
- Poznat i kao **"C za XXI vek"**, ali sa **bezbednim radom sa memorijom**, **sakupljanjem smeća** i **konkurentnom obradom** (CSP, gorutine i kanali)
- Podržava **imperativnu (strukturiranu)** i **konkurentu paradigmu**, implementira **CSP** (Communicating Sequential Processes) – formalni jezik Tony Hoare-a za opis interakcije u konkurentnim sistemima
- **Bogata biblioteka paketa**, dve implementacije – Google i gccgo
- **Go je korišćen za razvoj:**
  - **Docker**
  - **Kubernetes**
  - **IPFS**
  - **Hyperledger Fabric**
  - **Netflix**
  - **Dropbox**

```
package main

import "fmt"

func main() {
        fmt.Println("Hello, World")
}
```

Bitcoin



Bitcoin: A Peer-to-Peer Electronic Cash System

Satoshi Nakamoto
satoshin@gmx.com
www.bitcoin.org

Abstract. A purely peer-to-peer version of electronic cash would allow online payments to be sent directly from one party to another without going through a financial institution. Digital signatures provide part of the solution, but the main benefits are lost if a trusted third party is still required to prevent double-spending. We propose a solution to the double-spending problem using a peer-to-peer network. The network timestamps transactions by hashing them into an ongoing chain of hash-based proof-of-work, forming a record that cannot be changed without redoing the proof-of-work. The longest chain not only serves as proof of the sequence of events witnessed, but proof that it came from the largest pool of CPU power. As long as a majority of CPU power is controlled by nodes that are not cooperating to attack the network, they'll generate the longest chain and outpace attackers. The network itself requires minimal structure. Messages are broadcast on a best effort basis, and nodes can leave and rejoin the network at will, accepting the longest proof-of-work chain as proof of what happened while they were gone.

1. Introduction

Commerce on the Internet has come to rely almost exclusively on financial institutions serving as trusted third parties to process electronic payments. While the system works well enough for most transactions, it still suffers from the inherent weaknesses of the trust based model. Completely non-reversible transactions are not really possible, since financial institutions cannot avoid mediating disputes. The cost of mediation increases transaction costs, limiting the minimum practical transaction size and cutting off the possibility for small casual transactions, and there is a broader cost in the loss of ability to make non-reversible payments for non-reversible services. With the possibility of reversal, the need for trust spreads. Merchants must be wary of their customers, hassling them for more information than they would otherwise need. A certain percentage of fraud is accepted as unavoidable. These costs and payment uncertainties can be avoided in person by using physical currency, but no mechanism exists to make payments over a communications channel without a trusted party.

What is needed is an electronic payment system based on cryptographic proof instead of trust, allowing any two willing parties to transact directly with each other without the need for a trusted third party. Transactions that are computationally impractical to reverse would protect sellers from fraud, and routine escrow mechanisms could easily be implemented to protect buyers. In this paper, we propose a solution to the double-spending problem using a peer-to-peer distributed timestamp server to generate computational proof of the chronological order of transactions. The system is secure as long as honest nodes collectively control more CPU power than any cooperating group of attacker nodes.

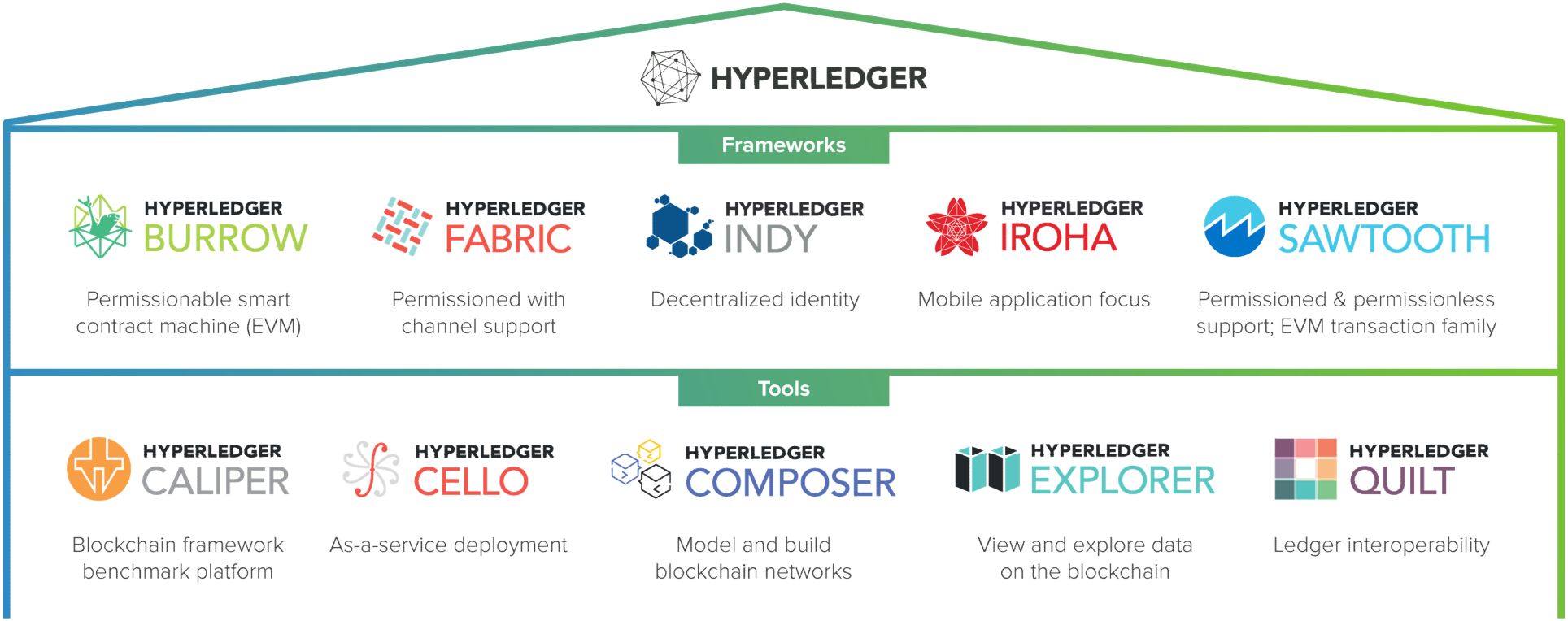
1

https://bitcoin.org/bitcoin.pdf

- Zamišljen kao "**The World Computer**"
- Koristi virtuelnu mašinu kao okruženje za izvršavanje (engl. runtime environment) programa napisanih u **Tjuring-kompletnom programskom jeziku** – **Ethereum Virtual Machine** (EVM), bajtkod u jeziku niskog nivoa zasnovan na radu sa stekom
- **Tjuring-kompletan programski jezik za opis transakcija**
  - Solidity, LLC, Serpent
  - u suštini namenski jezici (engl. domain specific languages – DSL)
- Koncept **pametnih ugovora** (engl. smart contracts)
  - **programski kod** koji **dovodi do promene stanja sistema** kada se **određeni uslovi ispune**
- Koncepti **inicijalne ponude novčića** – **initial coin offering** (**ICO**), **NFT** (**non-fungible tokens**)
  - pametni ugovori koji se izvršavaju na Ethereum blokčejnu
- **Decentralizovane aplikacije** (**Dapps**) i **DAO** (decentralizovane autonomne organizacije)
  - Primeri: CryptoKitties, EtherTweet, Etheria, domaći LemonMail

Hyperledger

- Open source kolaborativna inicijativa koju void Linux fondacija, pokrenuta decembra 2015.



HYPERLEDGER FABRIC

- **Hyperledger Fabric** je platforma za rešenja sa distribuiranom glavnom knjigom (engl. ledger)
  - **Mreža sa kontrolom pristupa bez nativne kriptovalute**
  - **Elastična i proširiva arhitektura** koja može da podrži kompleksnosti i specifičnosti koje postoje u ekonomskom ekosistemu
- IBM i Digital Asset donirali značajan deo koda

  https://github.com/hyperledger/fabric
- Osobine:
  - **Modularnost**
  - **Poverljivost**
  - **Otpornost** (resiliency)
  - **Fleksibilnost**
  - **Skalabilnost** i **visoke performanse**

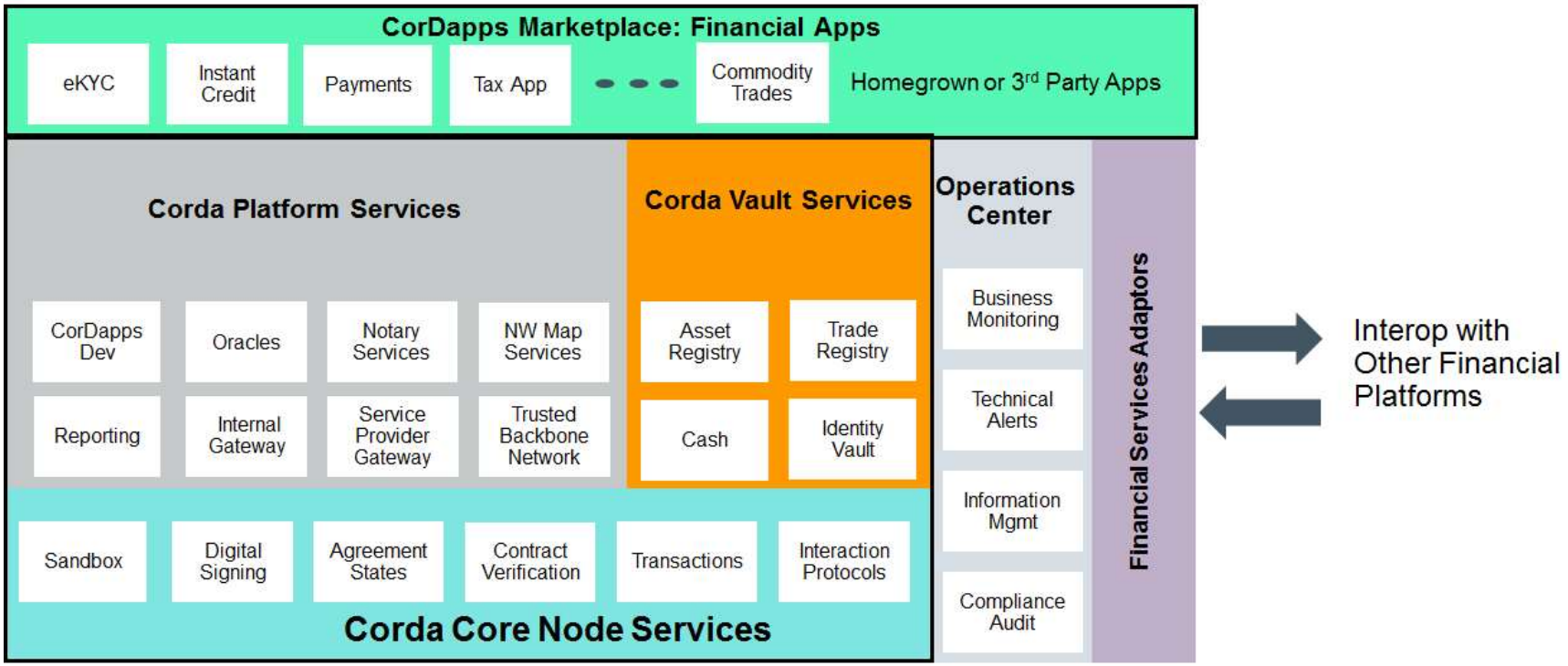
Izvor: https://www.youtube.com/watch?v=js3Zjxbo8TM

r3·c·rda

- **R3** nastao kao konzorcijum devet banaka (Bank of America, HSBC, UBS, Credit Suisse, ING, …)
- Primene u **poslovnom domenu** (bankarstvo, osiguranje, tržišta kapitala, međunardona trgovina),
- **Privatna mreže sa kontrolom pristupa**
- Koristi **JVM**, pametni ugovori u **Javi** ili **Kotlinu**
- **DLT** koji **nije blokčejn**, transakcije se ne organizuju u blokove, već se obrađuju na pojedinčanom nivou u realnom vremenu
- Osobine:
  - **privatnost**
  - **performanse**
  - **skalabilnost**
  - **open source**

r3·c·rda

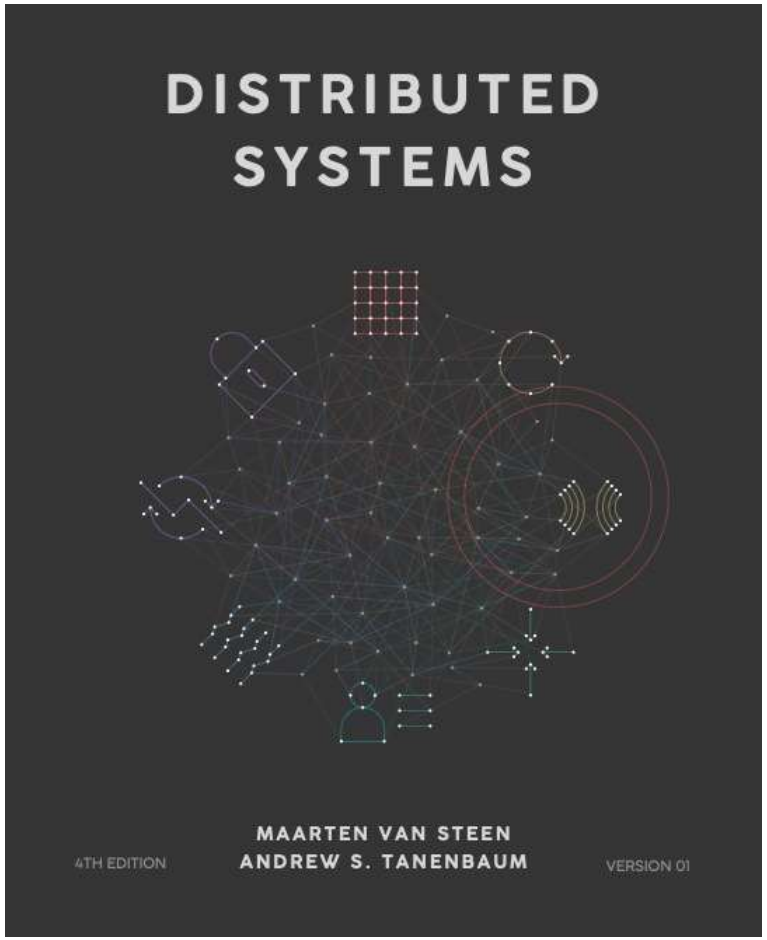
Corda Application Architecture

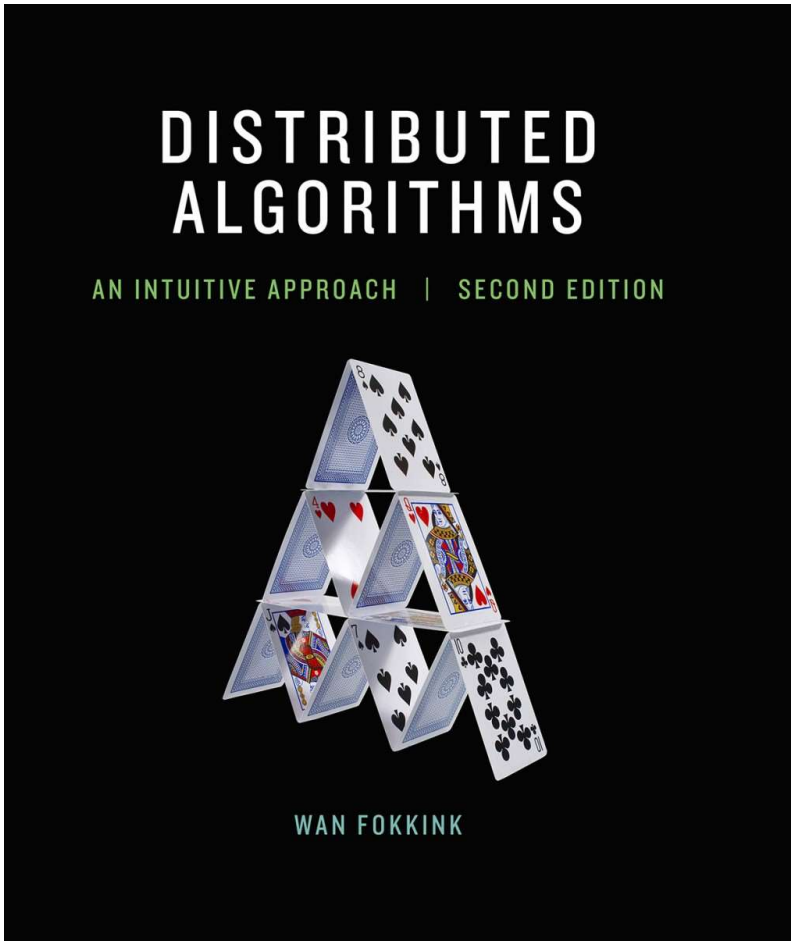


Izvor: http://arunkottolli.blogspot.com/2017/10/r3-corda-application-architecture.html

Reference

Literatura – Distribuirani sistemi i algoritmi





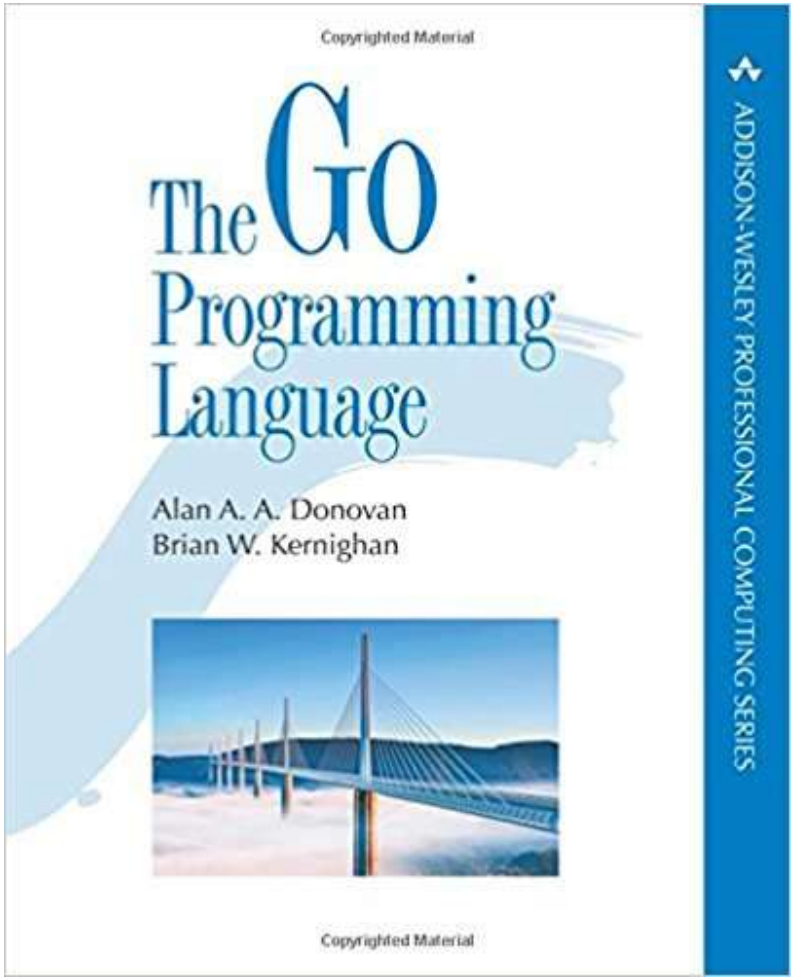
https://www.distributed-systems.net

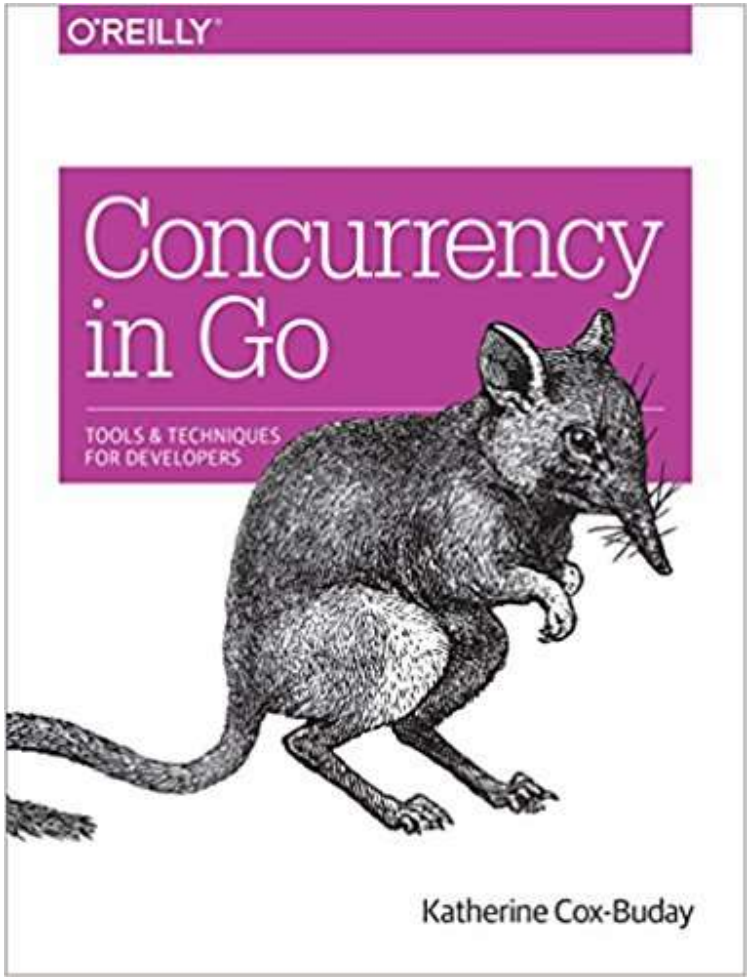
https://www.cs.vu.nl/~tcs/da/

Literatura – Konkurentni i distribuirani sistemi

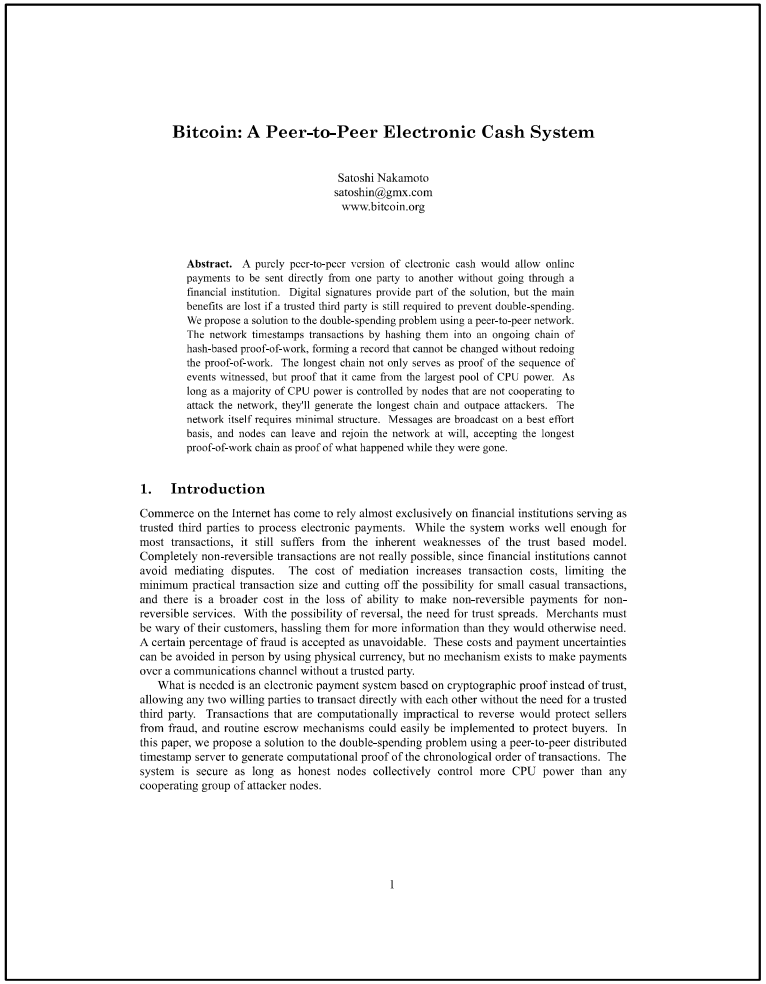
https://cet.rs/shop/java/konkurentni-i-distribuirani-sistemi/

Literatura – Go





Literatura – Blokčejn



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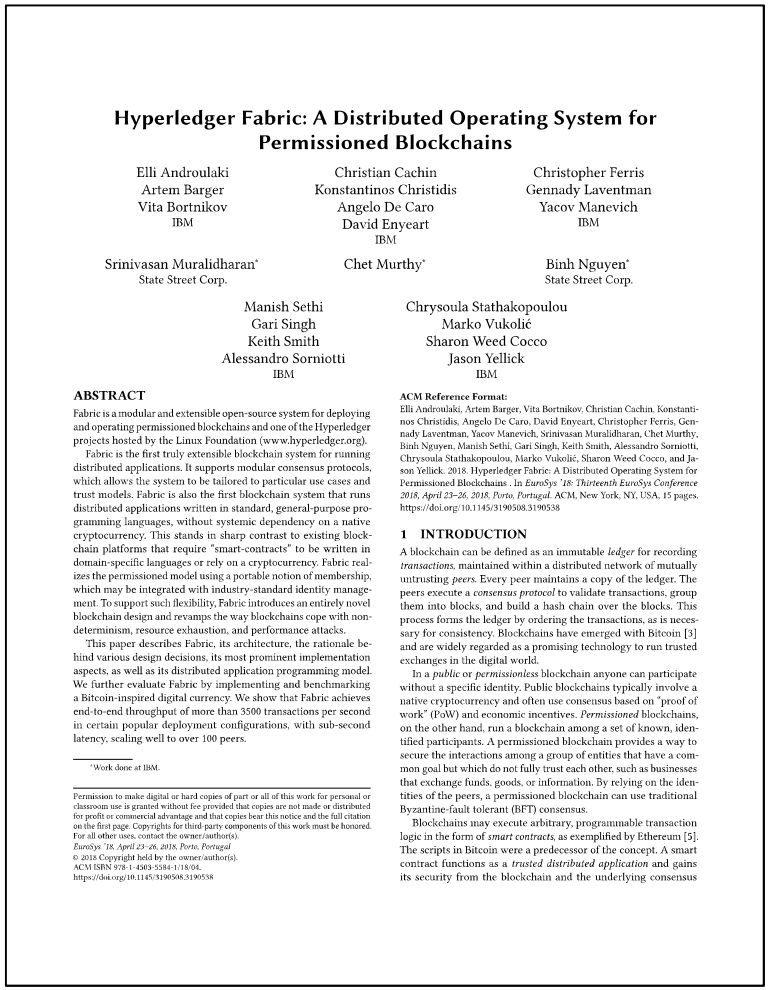


Hyperledger Fabric: A Distributed Operating System for Permissioned Blockchains

Elli Androulaki, Artem Barger, Vita Bortnikov — IBM
Christian Cachin, Konstantinos Christidis, Angelo De Caro, David Enyeart — IBM
Christopher Ferris, Gennady Laventman, Yacov Manevich — IBM
Srinivasan Muralidharan*, Chet Murthy*, Binh Nguyen* — State Street Corp.
Manish Sethi, Gari Singh, Keith Smith, Alessandro Sorniotti — IBM
Chrysoula Stathakopoulou, Marko Vukolić, Sharon Weed Cocco, Jason Yellick — IBM

ABSTRACT

Fabric is a modular and extensible open-source system for deploying and operating permissioned blockchains and one of the Hyperledger projects hosted by the Linux Foundation (www.hyperledger.org).

Fabric is the first truly extensible blockchain system for running distributed applications. It supports modular consensus protocols, which allows the system to be tailored to particular use cases and trust models. Fabric is also the first blockchain system that runs distributed applications written in standard, general-purpose programming languages, without systemic dependency on a native cryptocurrency. This stands in sharp contrast to existing blockchain platforms that require "smart-contracts" to be written in domain-specific languages or rely on a cryptocurrency. Fabric realizes the permissioned model using a portable notion of membership, which may be integrated with industry-standard identity management. To support such flexibility, Fabric introduces an entirely novel blockchain design and revamps the way blockchains cope with non-determinism, resource exhaustion, and performance attacks.

This paper describes Fabric, its architecture, the rationale behind various design decisions, its most prominent implementation aspects, as well as its distributed application programming model. We further evaluate Fabric by implementing and benchmarking a Bitcoin-inspired digital currency. We show that Fabric achieves end-to-end throughput of more than 3500 transactions per second in certain popular deployment configurations, with sub-second latency, scaling well to over 100 peers.

*Work done at IBM.

EuroSys '18, April 23–26, 2018, Porto, Portugal

ACM ISBN 978-1-4503-5584-1/18/04.
https://doi.org/10.1145/3190508.3190538

ACM Reference Format:
Elli Androulaki, Artem Barger, Vita Bortnikov, Christian Cachin, Konstantinos Christidis, Angelo De Caro, David Enyeart, Christopher Ferris, Gennady Laventman, Yacov Manevich, Srinivasan Muralidharan, Chet Murthy, Binh Nguyen, Manish Sethi, Gari Singh, Keith Smith, Alessandro Sorniotti, Chrysoula Stathakopoulou, Marko Vukolić, Sharon Weed Cocco, and Jason Yellick. 2018. Hyperledger Fabric: A Distributed Operating System for Permissioned Blockchains . In *EuroSys '18: Thirteenth EuroSys Conference 2018, April 23–26, 2018, Porto, Portugal.* ACM, New York, NY, USA, 15 pages. https://doi.org/10.1145/3190508.3190538

1 INTRODUCTION

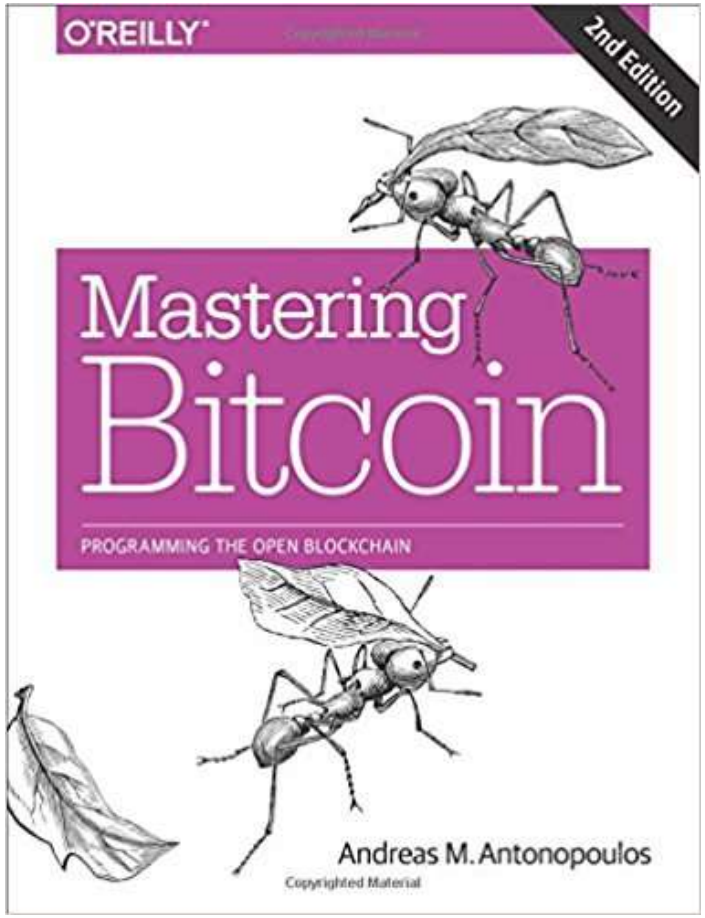
A blockchain can be defined as an immutable *ledger* for recording *transactions*, maintained within a distributed network of mutually untrusting *peers*. Every peer maintains a copy of the ledger. The peers execute a *consensus protocol* to validate transactions, group them into blocks, and build a hash chain over the blocks. This process forms the ledger by ordering the transactions, as is necessary for consistency. Blockchains have emerged with Bitcoin [3] and are widely regarded as a promising technology to run trusted exchanges in the digital world.

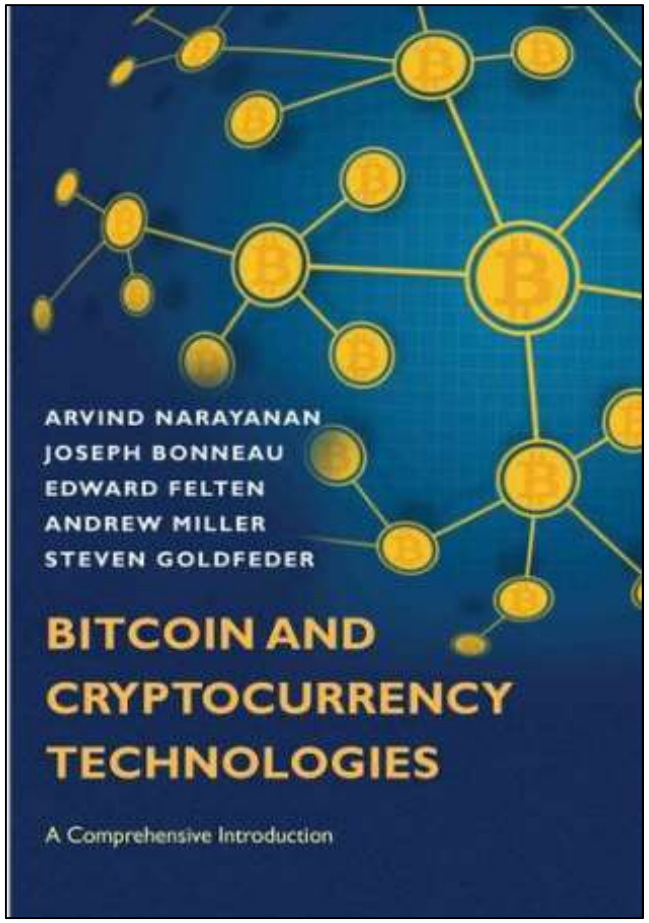
In a *public* or *permissionless* blockchain anyone can participate without a specific identity. Public blockchains typically involve a native cryptocurrency and often use consensus based on "proof of work" (PoW) and economic incentives. *Permissioned* blockchains, on the other hand, run a blockchain among a set of known, identified participants. A permissioned blockchain provides a way to secure the interactions among a group of entities that have a common goal but which do not fully trust each other, such as businesses that exchange funds, goods, or information. By relying on the identities of the peers, a permissioned blockchain can use traditional Byzantine-fault tolerant (BFT) consensus.

Blockchains may execute arbitrary, programmable transaction logic in the form of *smart contracts*, as exemplified by Ethereum [5]. The scripts in Bitcoin were a predecessor of the concept. A smart contract functions as a *trusted distributed application* and gains its security from the blockchain and the underlying consensus

https://arxiv.org/abs/1801.10228

Literatura – Blokčejn





https://github.com/bitcoinbook/bitcoinbook

http://bitcoinbook.cs.princeton.edu/

Online resursi – Hyperledger

- Hyperledger Whitepaper:

  http://www.the-blockchain.com/docs/Hyperledger%20Whitepaper.pdf

- Hyperledger Architecture Working Group, Paper 1:

  https://www.hyperledger.org/wp-content/uploads/2017/08/HyperLedger_Arch_WG_Paper_1_Consensus.pdf

- Official documentation:

  https://hyperledger-fabric.readthedocs.io/en/latest/

- Rocket Chat:

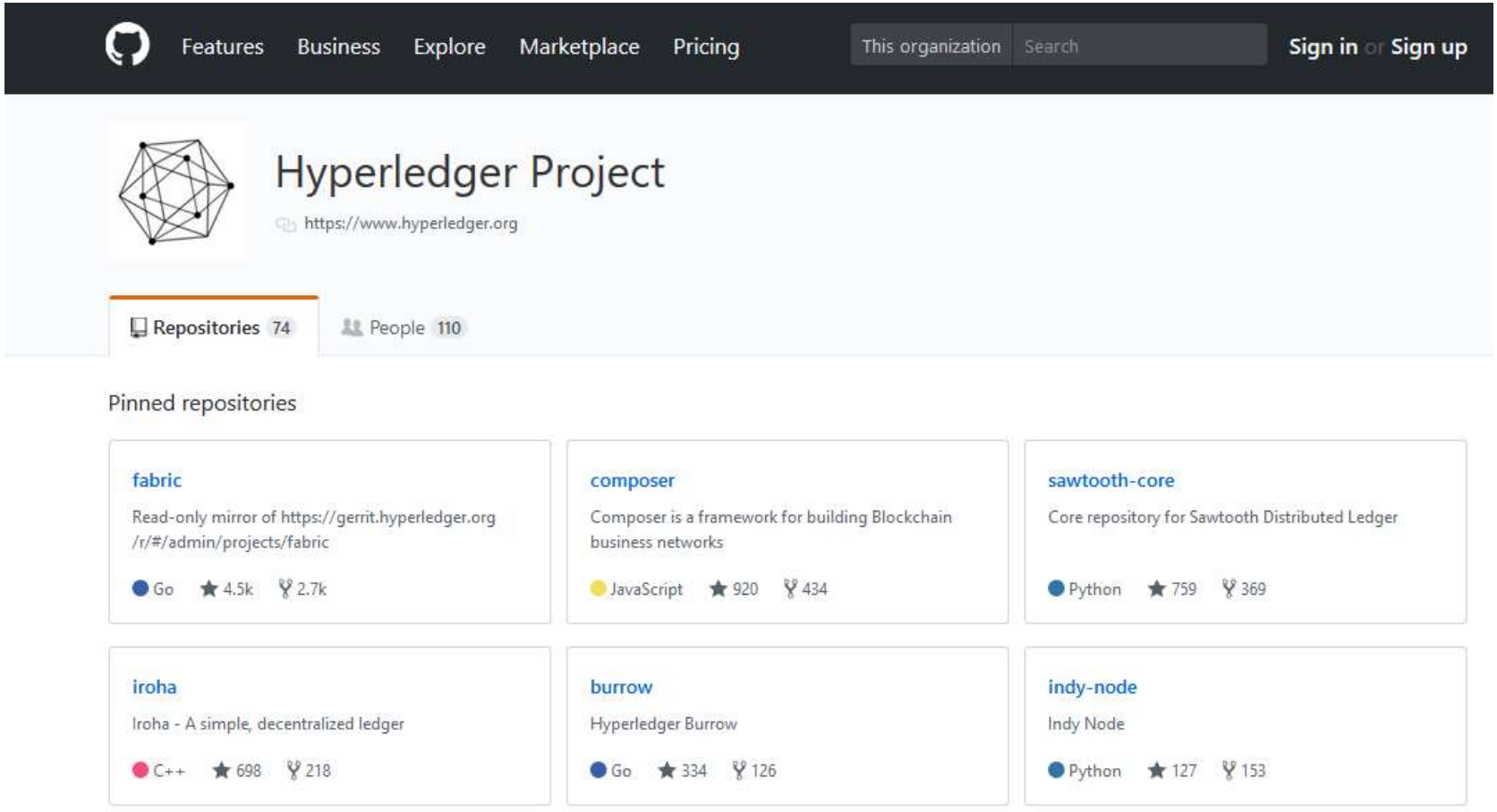
  https://chat.hyperledger.org/

- StackOverflow:

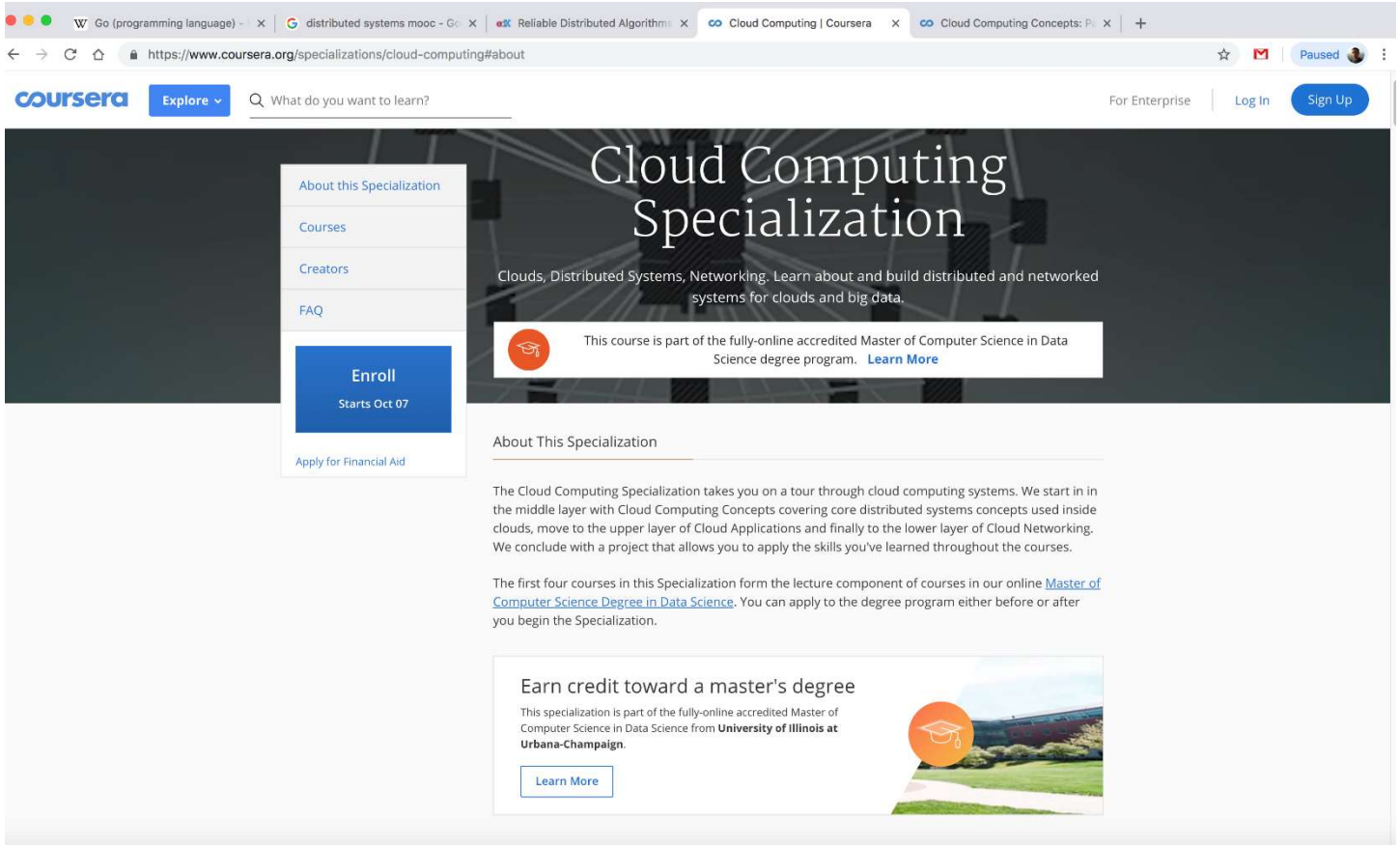
  https://stackoverflow.com/questions/tagged/hyperledger-fabric

Online resursi – Hyperledger

- Hyperledger Github:

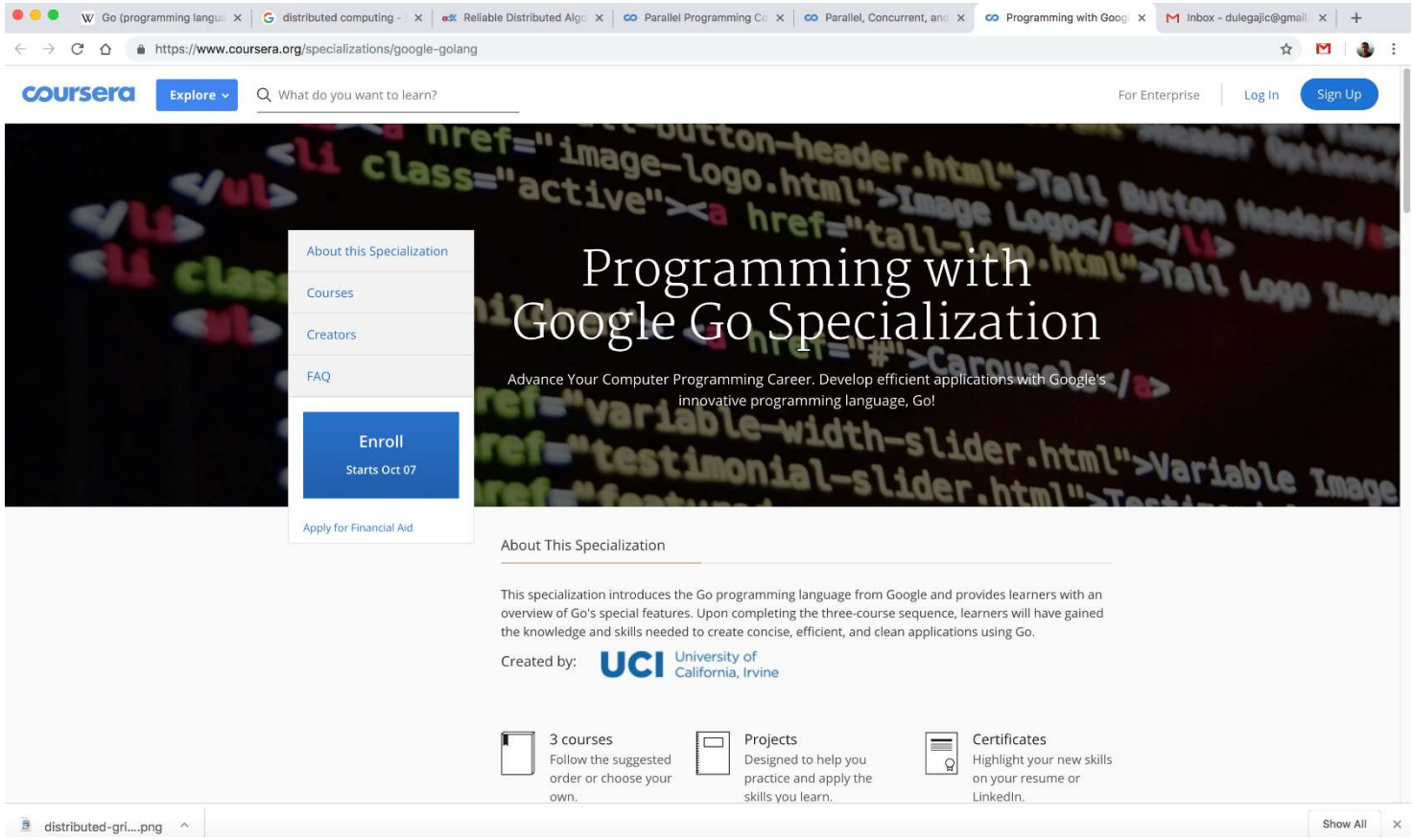


MOOCs – distribuirani sistemi



Link: https://www.coursera.org/specializations/cloud-computing

MOOCs – Go



Link: https://www.coursera.org/specializations/google-golang