



The Internet Computer and its networks

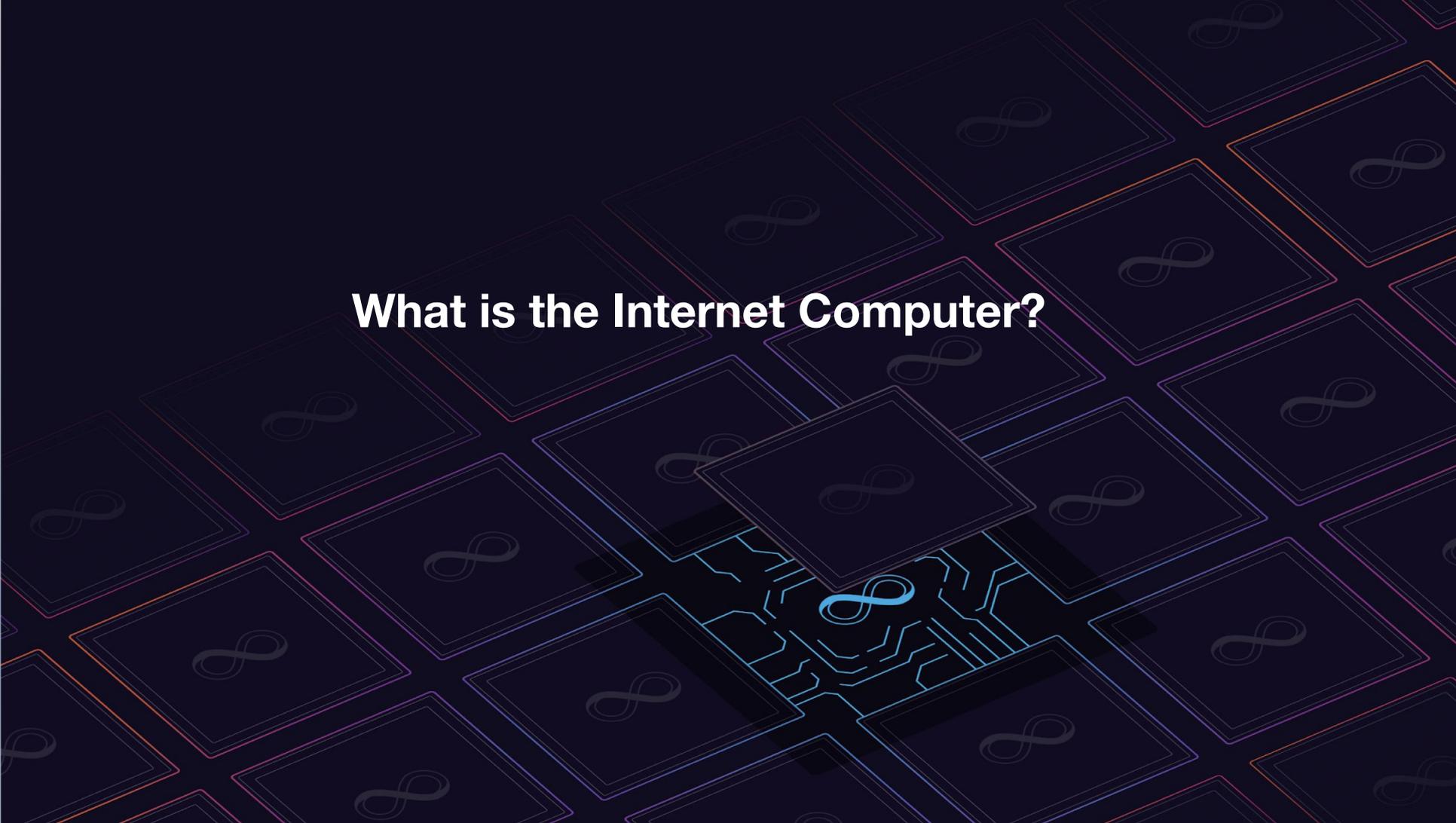
Yotam, Yvonne-Anne, Rüdiger, April, 2022

We are hiring: dfinity.org/careers

Agenda

- 1) What is the IC?
- 2) What are its networking patterns and requirements?
- 3) Show me the numbers!
- 4) Q&A

What is the Internet Computer?

The background features a dark blue field with a grid of overlapping squares. Each square contains a faint infinity symbol. In the center, a more complex pattern of lines and squares, resembling a circuit board or a data network, is visible, with a prominent blue infinity symbol at its core.

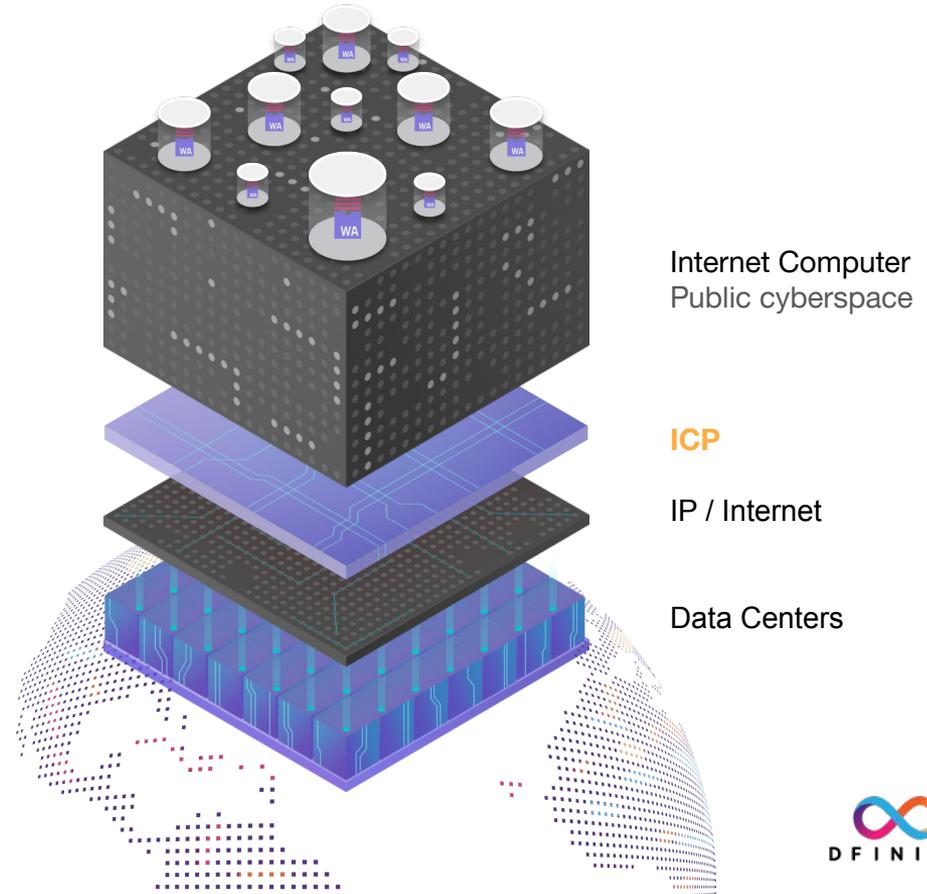
What is the Internet Computer?

Platform to run **any computation**,
using blockchain technology for
decentralisation and security

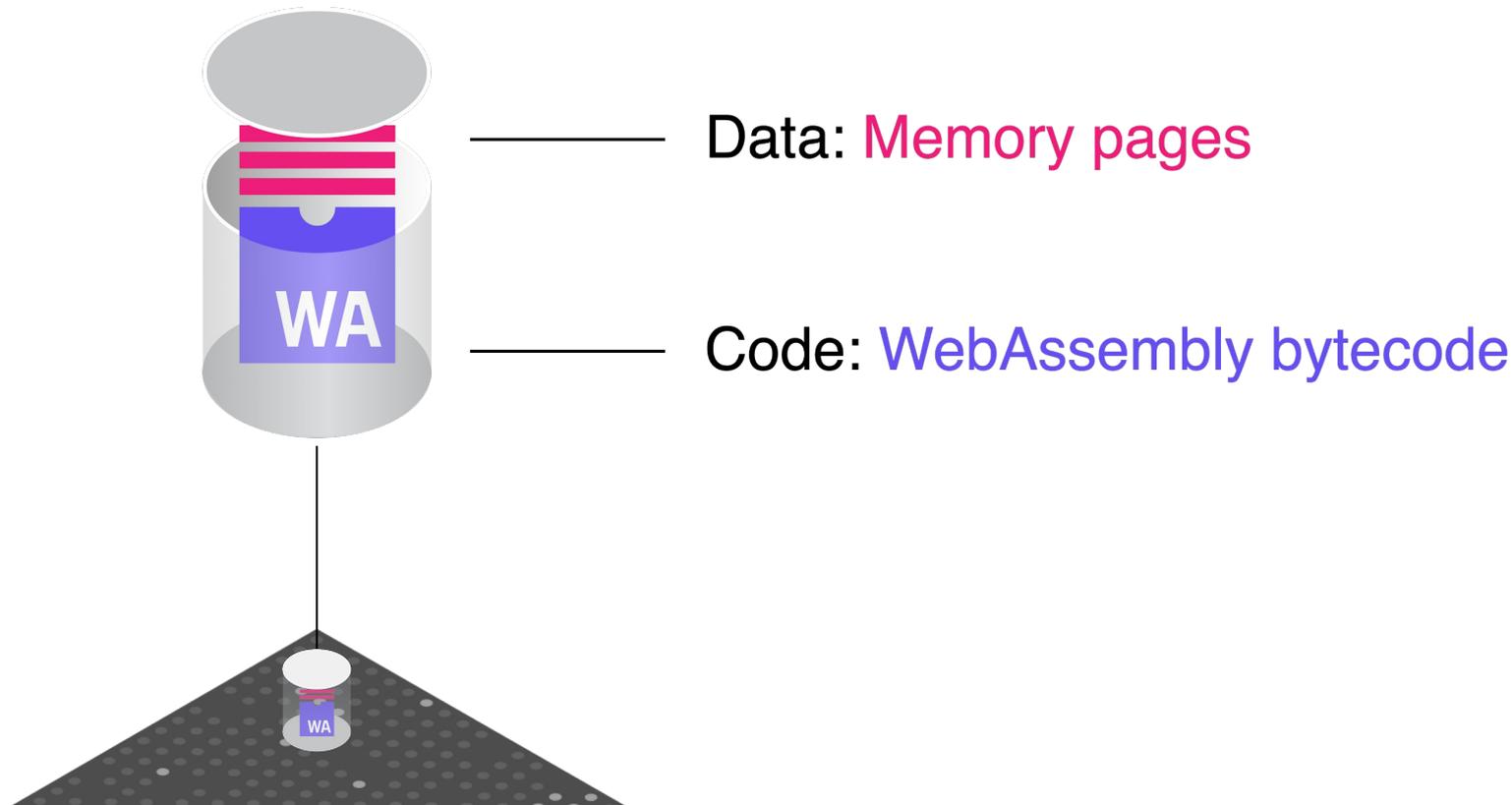
Internet Computer Protocol (ICP)

Coordination of nodes in **independent** data centers, jointly performing any computation for **anyone**

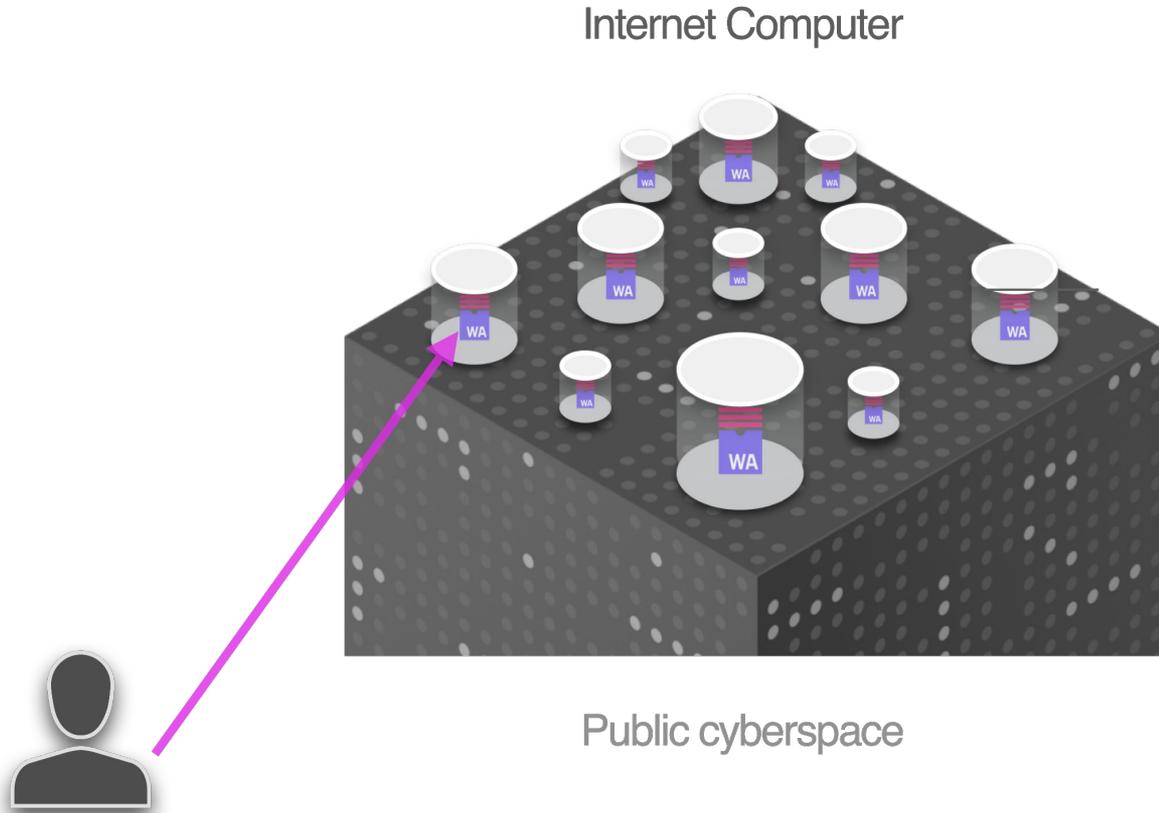
- Create Internet Computer blockchains
- Guarantee safety and liveness of smart contract execution despite Byzantine participants



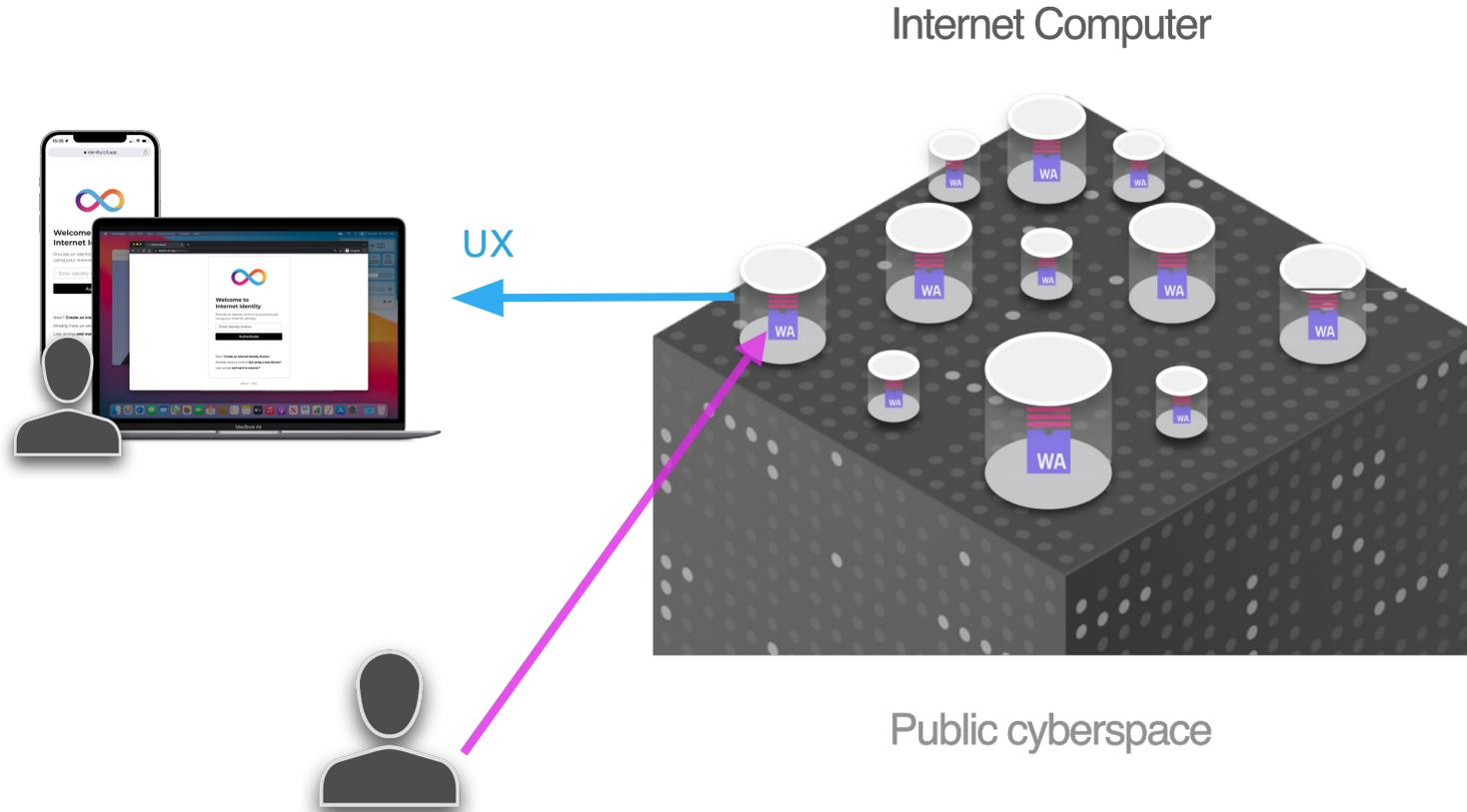
Canister Smart Contracts



Developers and users interact directly with Canisters



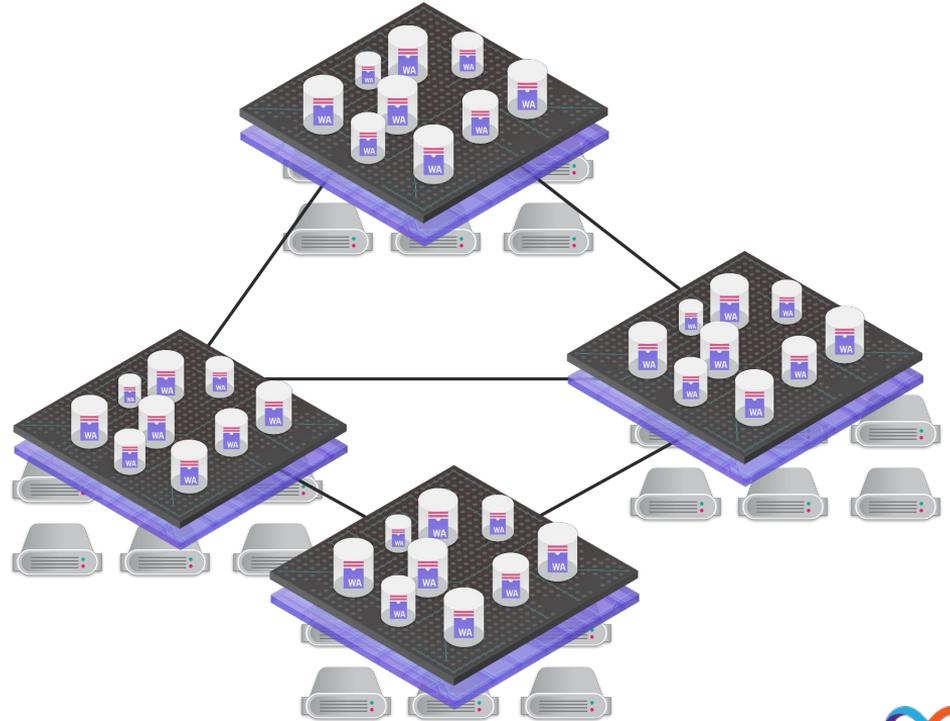
Developers and users interact directly with Canisters



Scalability: Nodes and Subnets

Nodes are partitioned into subnets

Canister smart contracts are assigned to different subnets



Scalability: Nodes and Subnets

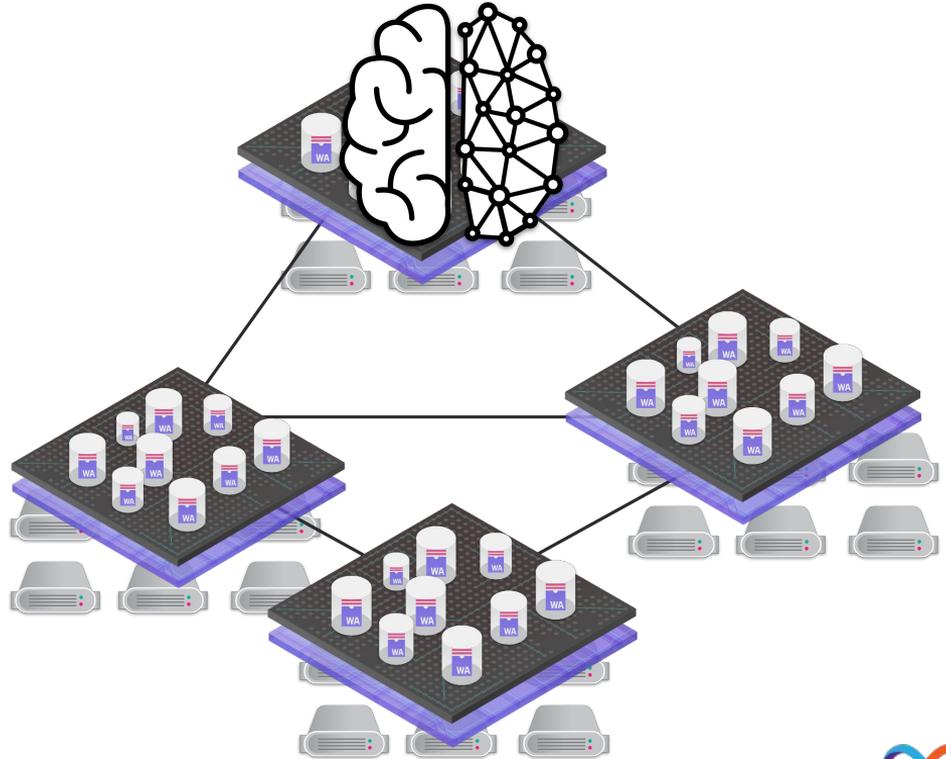
Nodes are partitioned into subnets

Canister smart contracts are assigned to different subnets

One subnet is special: it host the **Network Nervous System (NNS)** canisters which govern the IC

ICP token holders vote on

- Creation of new subnets
- Upgrades to new protocol version
- Replacement of nodes
- ...



State Machine Replication

State:

- canisters and their queues

Inputs:

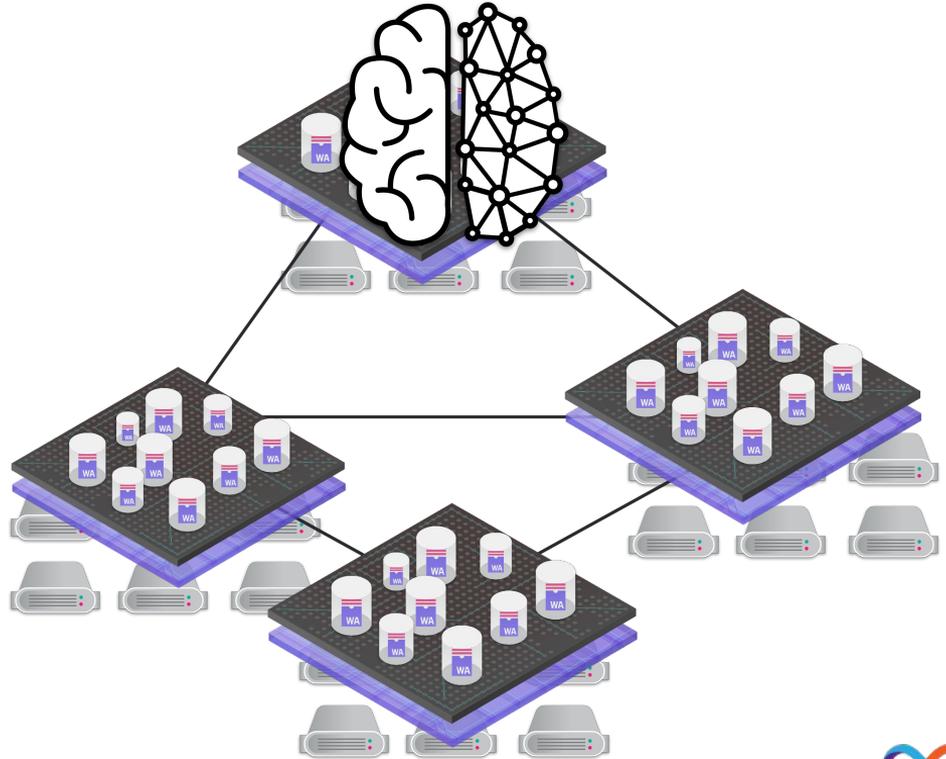
- new canisters to be installed,
- messages from users and other canisters

Outputs:

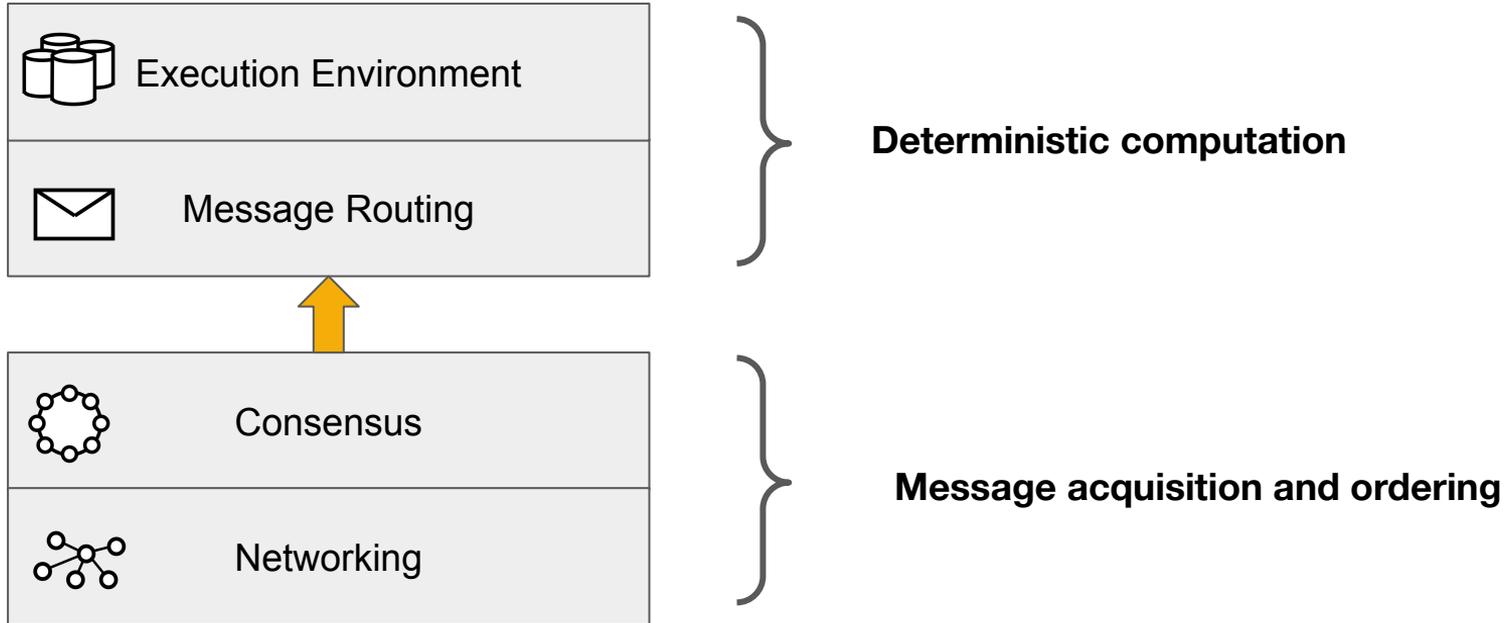
- responses to users and other canisters

Transition function:

- message routing and scheduling
- canister code



ICP Layers



Comparison with other Blockchain Systems



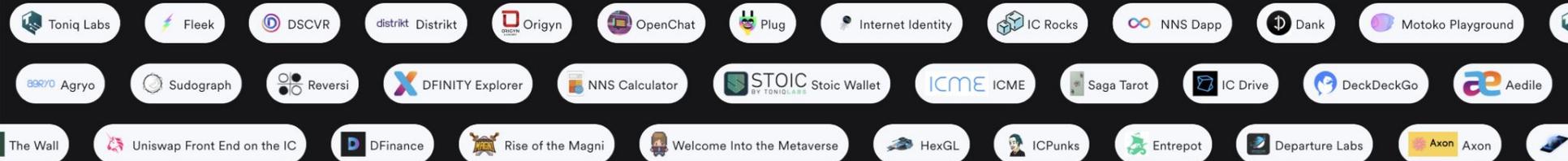
Layer-1 Performance Comparison

	 Ethereum	 Cardano	 Solana	 Avalanche	 Algorand	 Internet Computer
Transaction Speed	15-20 TPS	2 TPS	2,000-3,000 TPS	4,500 TPS	20 TPS	11,500 TPS 250,000 QPS
Transaction Finality	14 minutes	10-60 minutes	21-46 seconds	2-3 seconds	4-5 seconds	1 second
Scalability	Not very scalable	Not very scalable	Not very scalable	Not very scalable	More scalability	Indefinite scalability
Node Count	6,000 nodes	3,173 nodes	1,603 nodes	1,243 nodes	1,997 nodes	443 nodes
Storage Costs	\$73,000,000 / GB	Inadequate data storage	\$1,000,000 / GB	\$988,000 / GB	IPFS off-chain storage	\$5 / GB
Cloud Service Dependency	70% of nodes run on AWS	Unclear how many are cloud	Most nodes run on cloud	Unclear how many are cloud	Most nodes run on cloud	Independent data centers

<https://coincodex.com/article/14198/layer-1-performance-comparing-6-leading-blockchains/>



Fast Growing Ecosystem



FLEEK

Fleek brings decentralized web-hosting to the Internet Computer. With thousands of webpages deployed, Fleek enables anyone to deploy their content on Web3.0

[fleek.co](#)

#Infrastructure #Tools

DISTRIKT

Distrikt is a completely decentralized, community-owned professional network. Users of the platform will vote on upgrades, and no user data will ever be mined or sold. Create your account, secured by Internet Identity today.

19 000 users

[www.distrikt.io](#)

#Social #Dapp

ORIGN

The Orign Foundation is blending luxury goods, with NFTs by providing digital verifications for physical objects. Only possible on the Internet Computer.

[www.origyn.ch](#)

#Enterprise #NFT

OPENCHAT

Decentralized messaging has been a pipe-dream for decades. With the advent of the Internet Computer, real-time messaging is now possible on a blockchain.

50 000 users

[7o6iv-biaaa-aaaf-aaas-aaic](#)

#Social #Dapp

INTERNET IDENTITY

Internet Identity guarantees that your data isn't visible, tracked, or mined. The blockchain authentication system enables users to sign in to dapps on the Internet Computer and sites across the web anonymously and securely.

1 000 000+

[Identity-ICD.app](#)

#Authentication #Dapp #Infrastructure

IC ROCKS

IC.Rocks is a complete "block explorer" for the Internet Computer – built by the community. Tracking everything from transactions, to network upgrades, to cycles, IC.Rocks enables anyone to explore the inner-workings of the Internet Computer.

[ic.rocks](#)

#Infrastructure #Explorer

NNS DAPP

The NNS front-end dapp allows anyone to interact with the Internet Computer's Network Nervous System with a user-friendly UI. Served completely end-to-end through blockchain, this dapp allows you to manage ICP, stake neurons, participate in voting, and earn rewards.

[nns.dapp](#)

#Dapp #Infrastructure #Wallet #NNS

DANK

Dank is the first Decentralized Bank built on the Internet Computer, developed by Fleek. Through a collection of Open Internet Cycles for users and developers, Dank makes cycles management seamless.

[dank.io](#)

#Infrastructure #DeFi

TONIQ LABS

Toniq Labs is the creator of Entrepot NFT marketplace, Stoic Wallet, Exponent, and Rise of the Magni, Chronic NFTs and more. Try out their projects that range from NF Is to wrapped cycles to games built on, and for, the Internet Computer blockchain.

[igjov-waiaa-aaad-qjave-cci](#)

#Infrastructure #Dapp

CANLISTA

The Internet Computer community canister registry. Find, publish and extend applications and services built on the Internet Computer.

[l7g3t-daaa-aaase-qahq-cci](#)

AGRYO

Agryo is the global risk intelligence provider that enables financial institutions to assess and manage financial risks in the crop field level for underwriting agriculture insurance, loans, and trade finance globally, as well as meet sustainability goals.

SUDOGRAPH

Sudograph is a GraphQL database for the Internet Computer. Its goal is to become the simplest way to develop applications for the IC by providing flexibility and out of the box data management.

PLUG

Plug Wallet, built and open sourced by Fleek, is a browser extension that allows you to access your ICP, Cycles and other tokens – as well as log into Internet Computer dapps with one click. Download it here.

100 000 users

[plugwallet.io](#)

REVERSI

Reversi is one of the first canister smart contracts deployed to the Internet Computer and is a completely decentralized multiplayer game. Play against a friend (or foe) in real-time, from any browser, anywhere in the world.

[reversi.dapp](#)

DFINITY EXPLORER

DFINITY Explorer, a project started in 2016, is an open-source, community-built dashboard and explorer for the Internet Computer, providing live information and statistics about

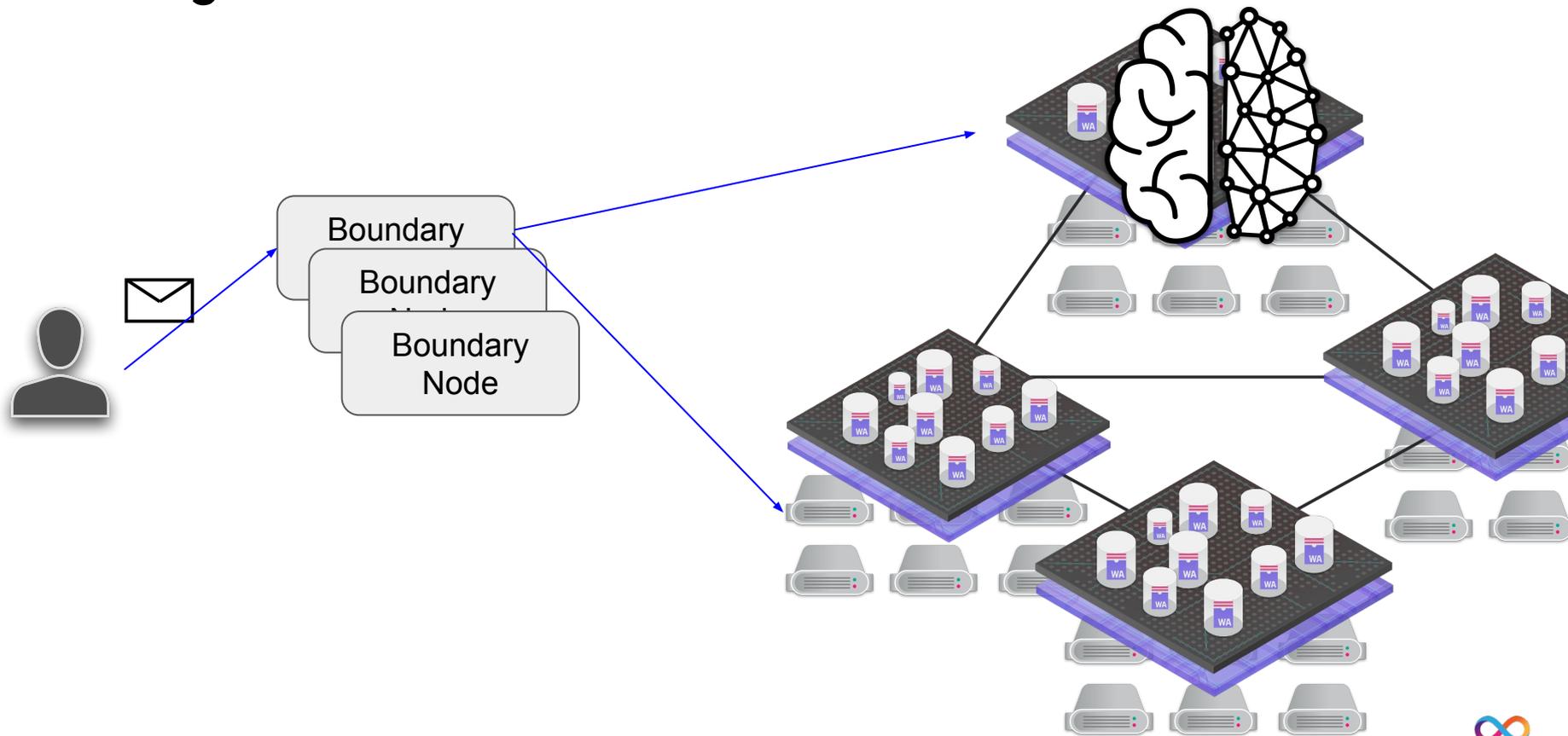
NNS CALCULATOR

The Network Nervous System Calculator is a calculator that allows users to edit variables and estimate voting rewards based on number of proposals voted on, length of stake,

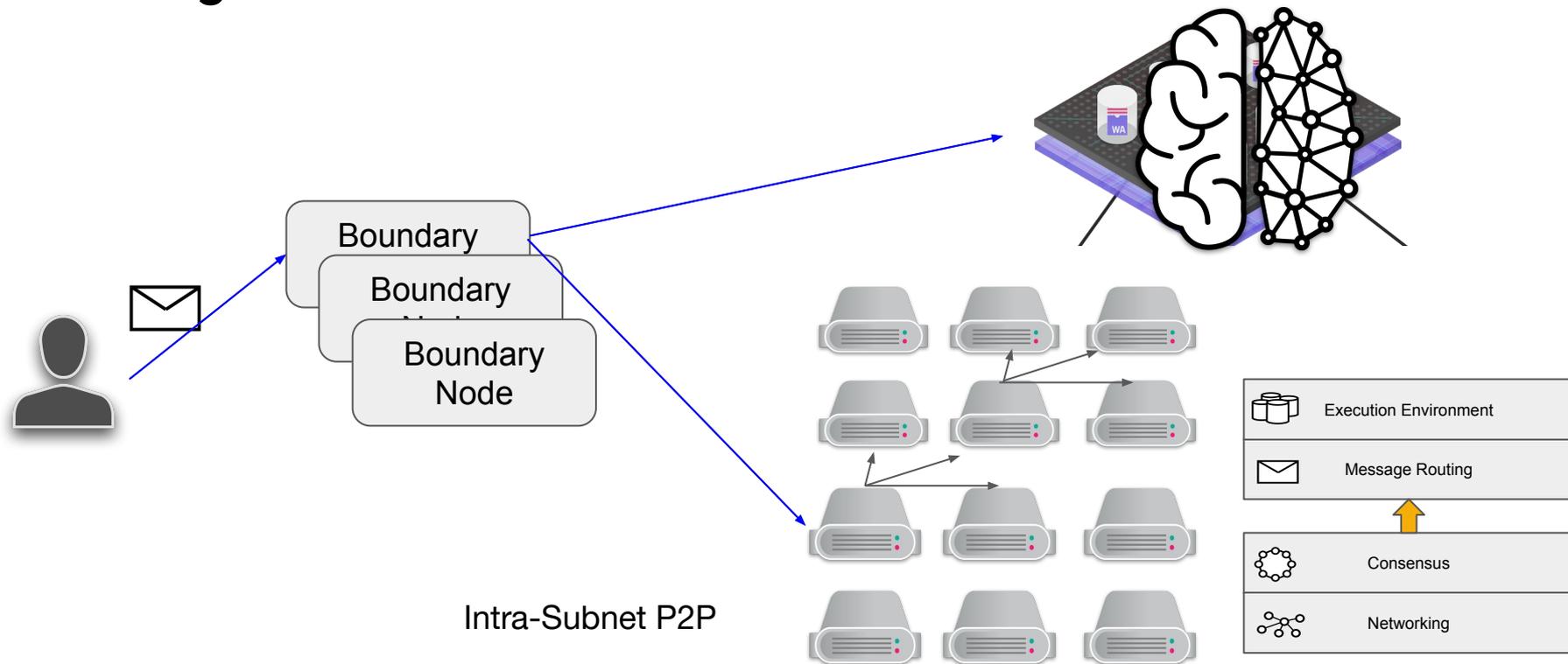
IC Networking

The background features a dark blue grid of squares, each containing a faint infinity symbol. A central square is highlighted with a glowing blue circuit-like pattern, suggesting a network or data flow.

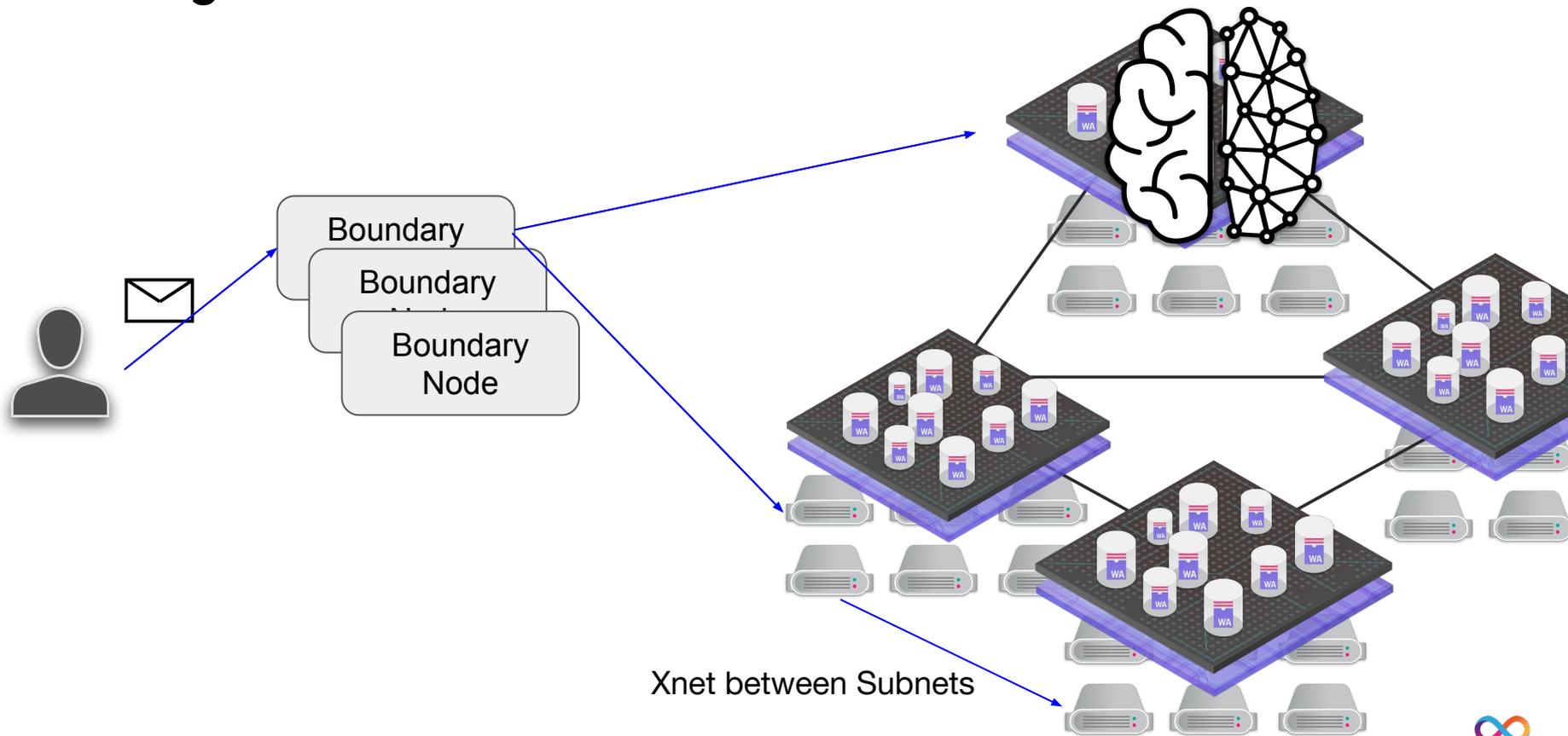
Following a canister call



Following a canister call



Following a canister call



Requirements 1/2

- **Bounded-time/eventual delivery despite Byzantine faults**

Up to a certain maximum volume of valid artifacts that are not dropped by any honest node reaches all honest nodes in bounded time/eventually despite attacks (under certain network assumptions).

- **Reserved resources for different components/peers**

Memory/bandwidth/CPU guarantees for different components and peers

- **Prioritization for different artifacts**

Not all artifacts are equal, different priorities depending on attributes (e.g., type, size, round,...). Priorities change over time.

Requirements 2/2

- **High efficiency**

High throughput is more important than low latency

Avoid duplicates: don't waste bandwidth downloading same artifact "too many times"

- **DOS/SPAM resilience**

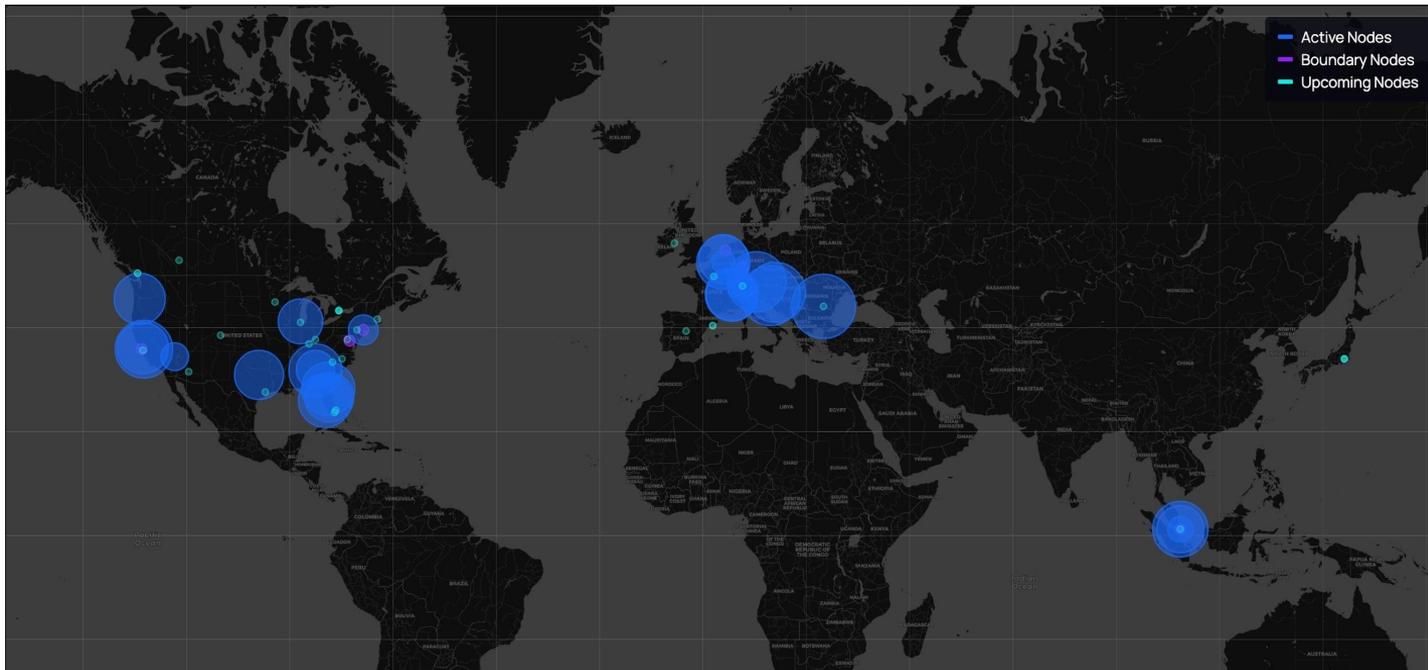
Bad participants cannot prevent progress.

- **Low accessibility requirements for users**

Support browser and IPv4 access

Networking of the IC

- **Geographically distributed:** datacenters all over the world



Networking of the IC

- **Geographically distributed:** datacenters all over the world
- **Decentralized:** a subnet is composed of nodes in different datacenters
 - Some nodes in the same subnet may be very far apart
 - Independent node providers with different skills and DC contracts
 - Communication over public internet
 - High latencies possible
 - Many transient network failures
- **Secure:** a subnet should make progress even if up to $\frac{1}{3}$ of the nodes are faulty / malicious
 - We can't trust specific nodes (e.g., geographically close by)
 - Even nodes in the same subnet should not trust each other

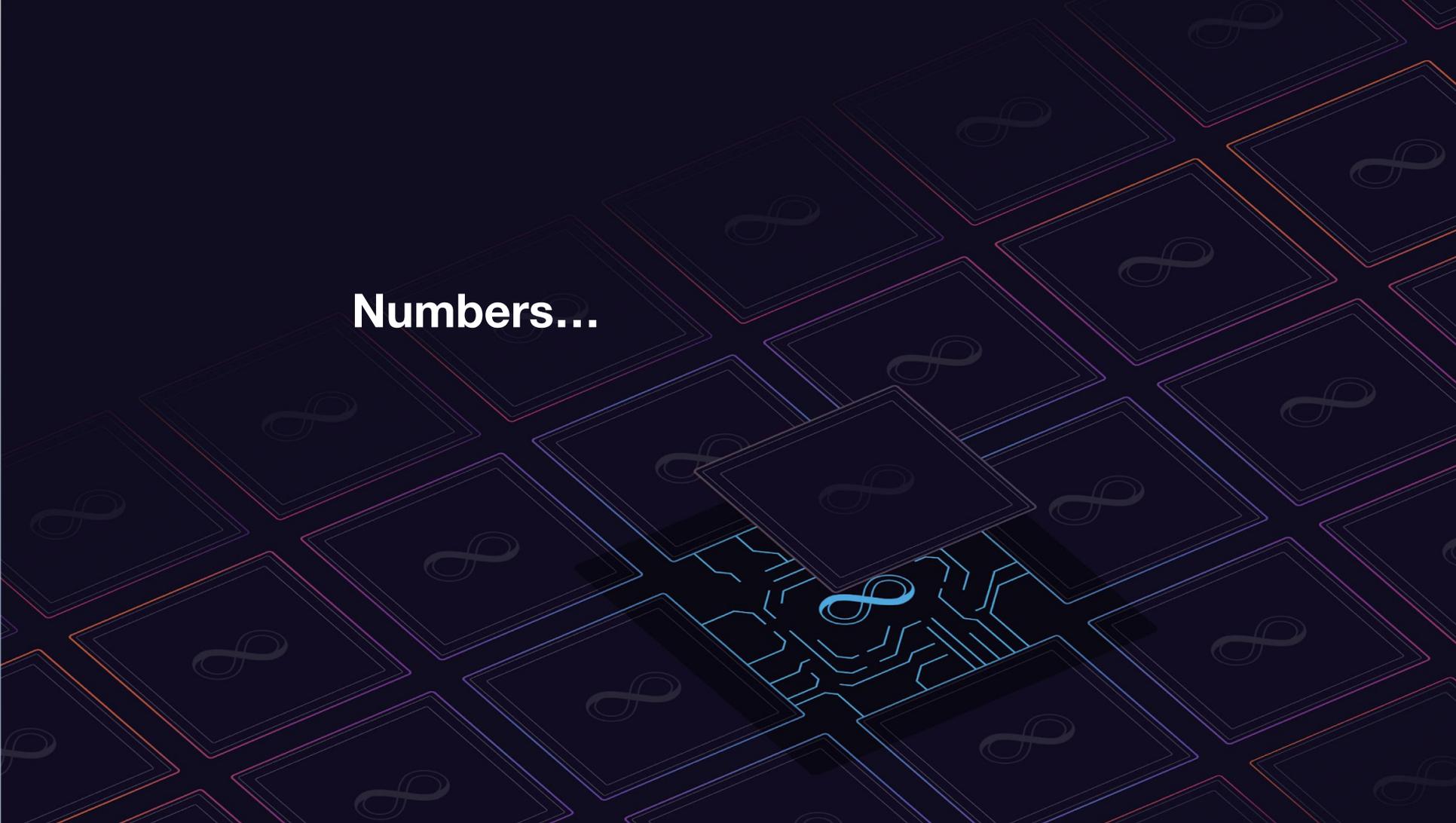
Intra-Subnet P2P Networking

- Peer-to-peer network of nodes
 - Gossip protocol for artifact distribution
 - Advert - Request - Response
 - Eventual / bounded time delivery with priorities (~reliable broadcast optimized for Consensus)
- Untrusted communication
 - TLS / TCP to all nodes in the subnet, certificates in NNS
 - Authenticity and integrity of artifacts can be verified by higher layers
 - Nodes can still do evil

Xnet Inter-Subnet Networking

- Canisters on one subnet can send messages to canisters on other subnets, called “cross-net communication” (or Xnet)
- Currently this is done quite naively, where any node on one subnet can fetch messages from any other node on the other subnet with a HTTPS request
- We can probably improve this on several aspects:
 - Scalability: decide which nodes connect to which, and when
 - Performance: leverage the fact that some nodes in both subnets are close to each other (content is signed by the subnet, so we do not need to trust a specific node up to some extent)

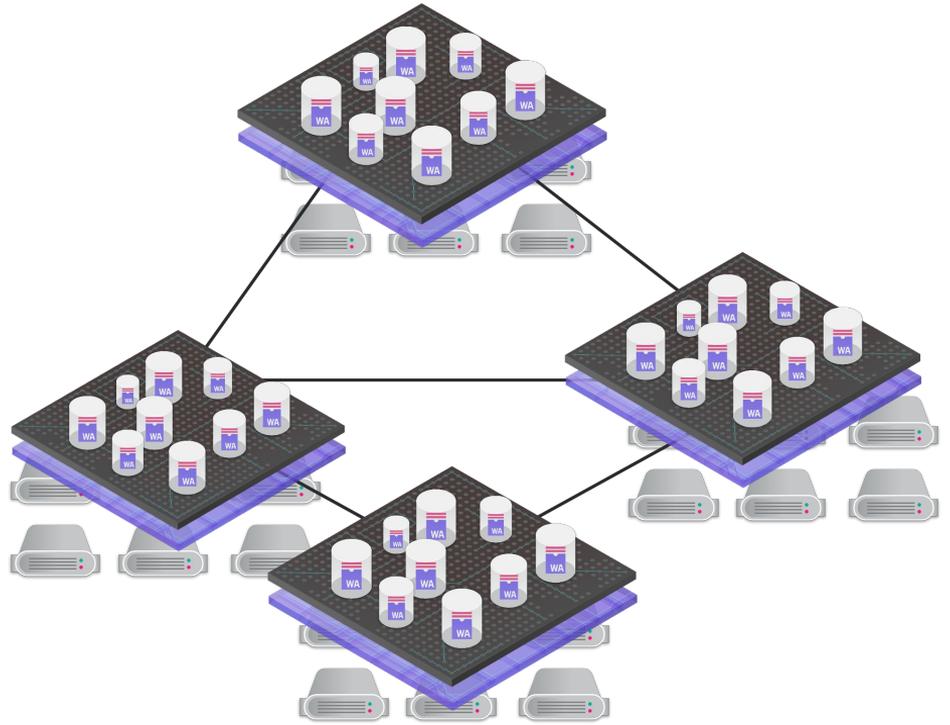
Numbers...



The IC in Current Numbers

Application Layer:

- 60K+ canisters (smart contracts/dapps)
- > 2 Mio registered identities
- ~1TB total state (and counting...)



<https://dashboard.internetcomputer.org/>

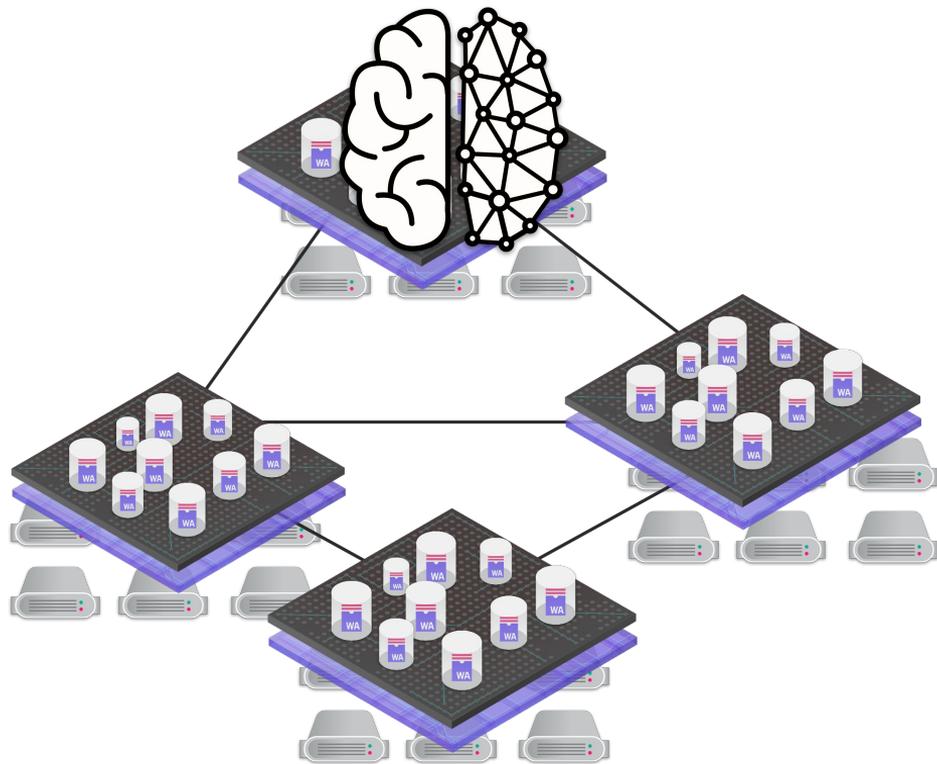
The IC in Current Numbers

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Governance:

- So far:
 - 56K+ NNS proposals
 - 3.4M+ ICP transactions

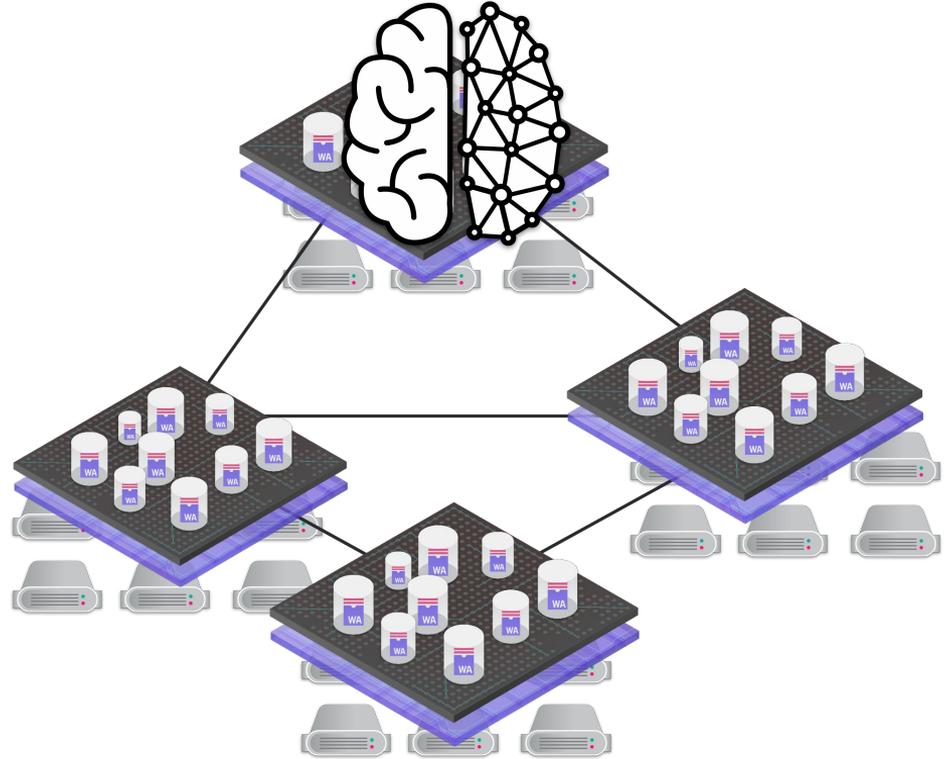


<https://dashboard.internetcomputer.org/>

The IC in Current Numbers

Consensus

- 758M+ blocks created
- ~34 blocks per second
- ~2800 transactions per second

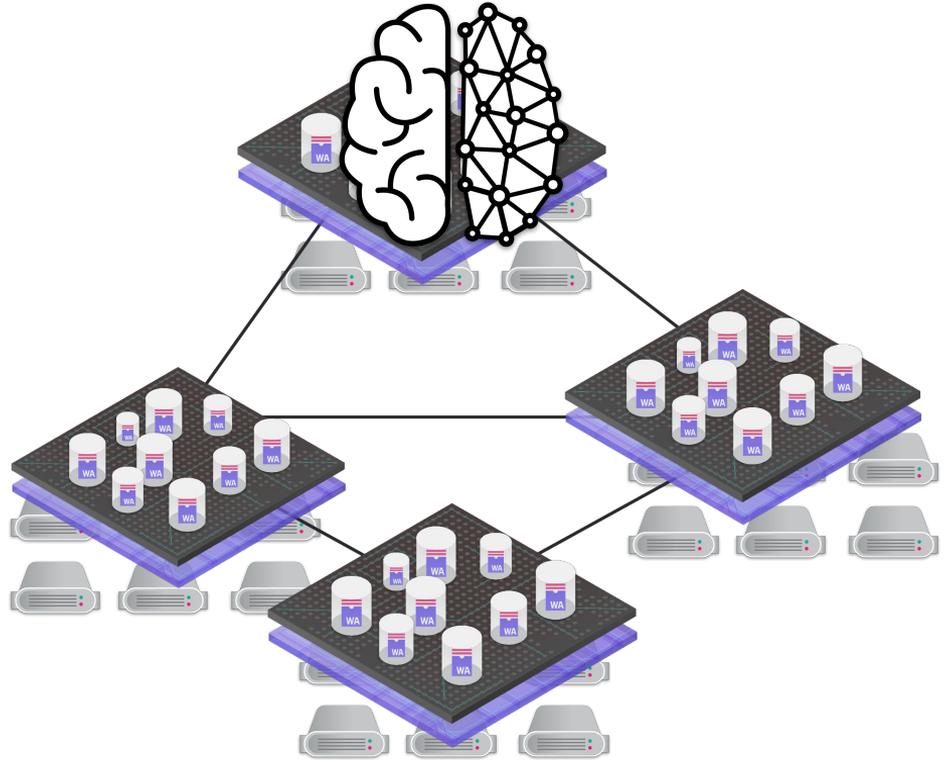


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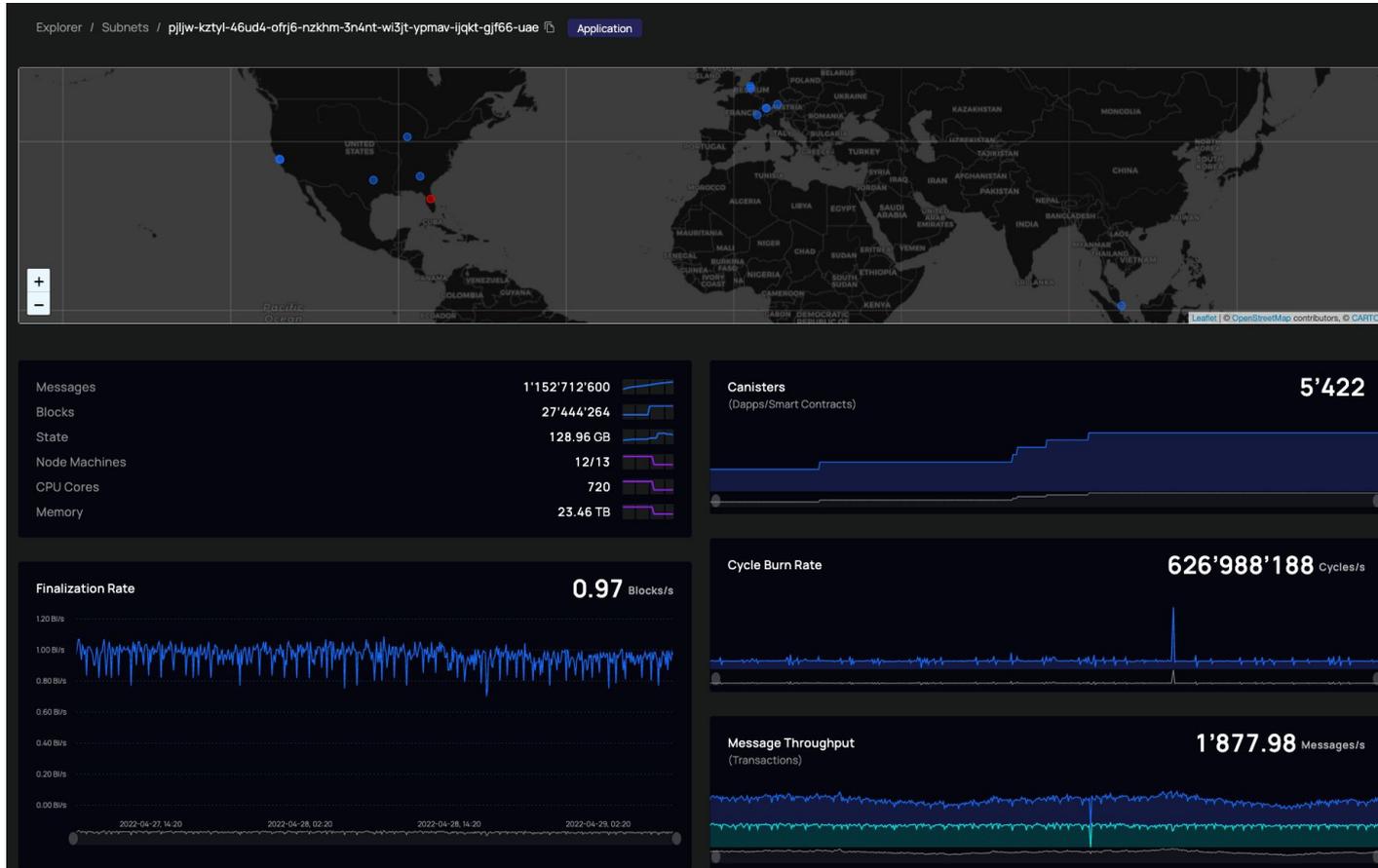
The IC in Current Numbers

Network Layer:

- 477 nodes
 - From 54 node providers
- 33 subnets
 - 40 nodes in NNS subnet
 - 13 nodes in App subnets
- Avg $\frac{2}{3}$ dissemination latency:
 - NNS avg=1.39s, 95%=3.3s
 - App avg=0.57s, 95%=1.1s



Example Subnet Dashboard



Research on the IC

The background features a dark blue grid of squares. Each square contains a faint, light-colored infinity symbol. The grid is composed of multiple overlapping layers of squares, creating a sense of depth. The lines of the squares are colored in various shades, including purple, blue, and orange. In the lower right quadrant, there is a stylized, glowing blue circuit board pattern that resembles a microchip or integrated circuit.

Open Research Problems

- Intra-subnet communications scalability (growing size of subnets)
- Inter-subnet communications scalability (growing number of subnets)
- Ongoing firewall rule management
- Resilience against malicious activity
- Monitoring of node and network behavior
- Dynamic load balancing
- Caching
- Canister addressing

Testnets

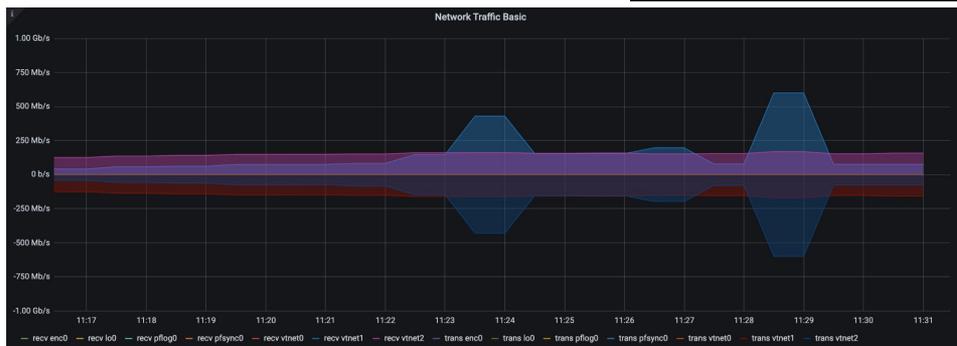
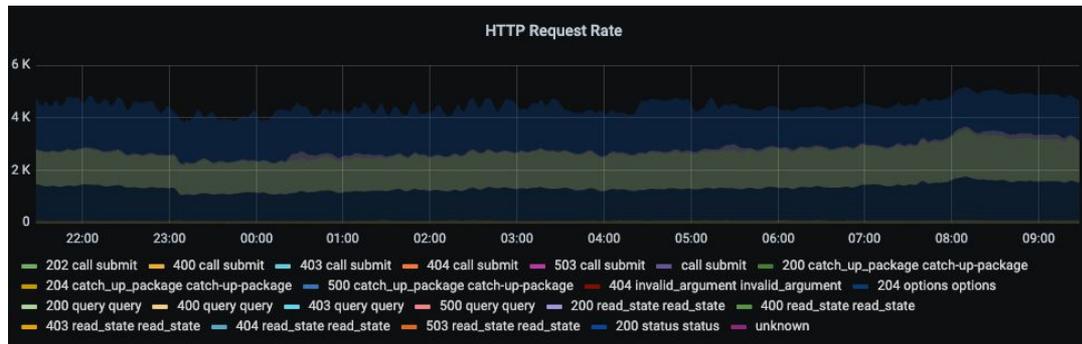
DFINITY-internal infrastructure

- Deploy complete IC instances in our 5 data centers (2 more in May)
 - Chicago, San Francisco, Des Moines, Frankfurt, Zurich, ..
- Variable size and VM capabilities
- Can be used for experiments, metrics, correctness and performance tests

Metrics

We can collect two general types of metrics:

- Code metrics
 - On mainnet
 - On testnets
- Infrastructure metrics



Logging

- Events can be logged in the code
- Log can be fetched from testnet machines
- Policy monitoring with MonPoly from Prof. Basin's group

Case Study: “Idle” vs. Workload Traffic

31 nodes deployment

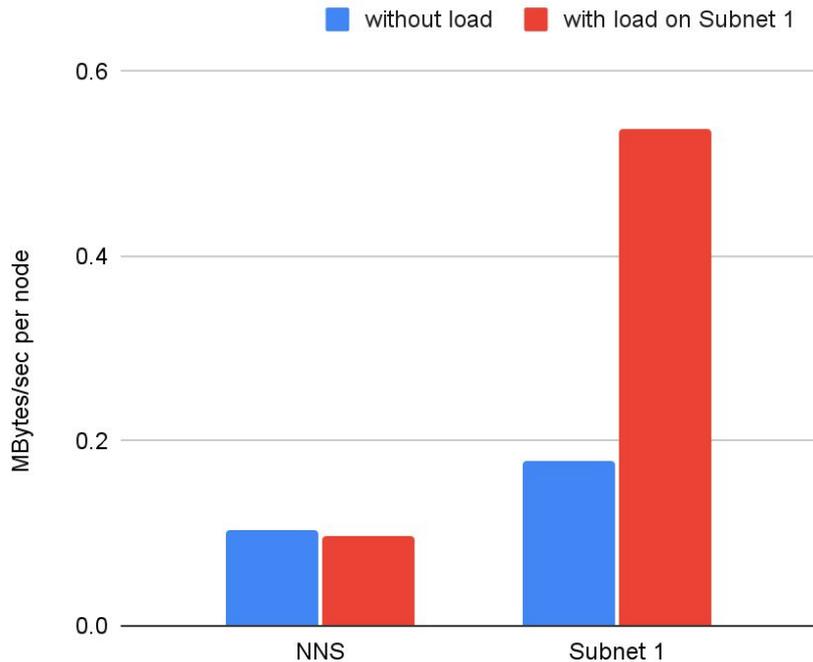
- 13 in NNS
- 18 in Subnet 1

Workload generation

- only in Subnet 1
- 100 requests per sec
- 1 kb each

Conclusion

- ICP produces 0.1-0.2MBytes/s for the protocol to make progress.



Case Study: “Intra DC” == Internet

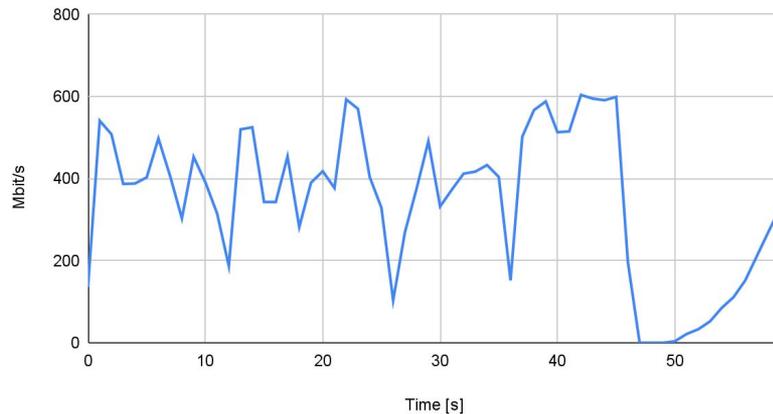
iperf between testnet hosts

- Chicago to San Francisco
- 60s in total

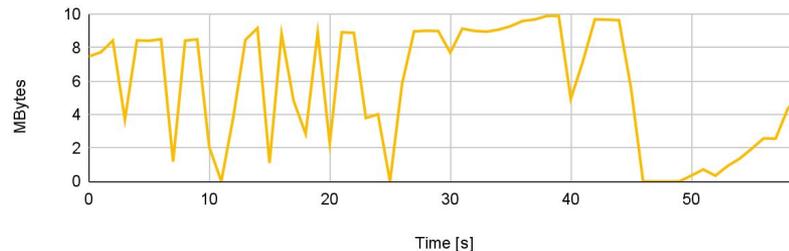
Conclusion

- Packet loss has a significant impact on the achieved throughput.

CH1 -> SF1 TCP (Throughput/Retransmissions)



CH1 -> SF1 TCP (CWND)



Case Study: RTT and Packet Loss

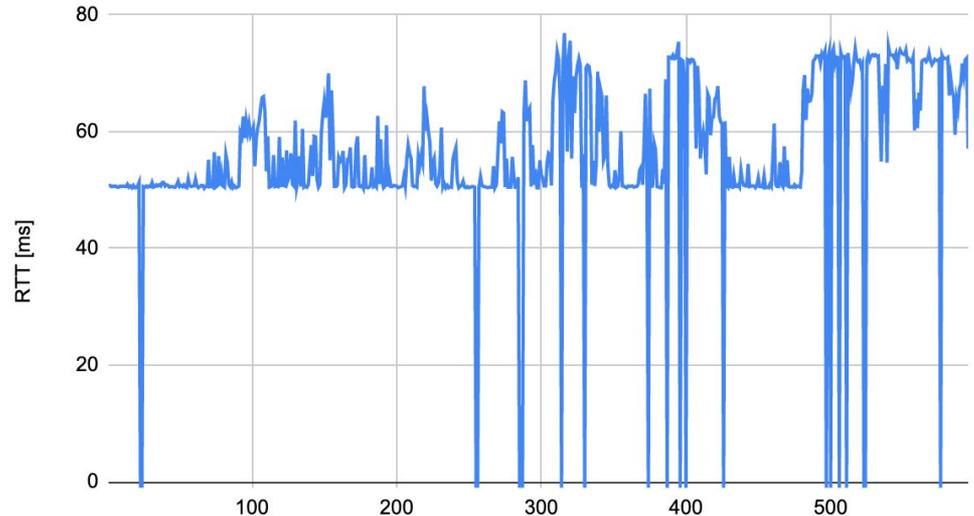
ping between testnet hosts

- Chicago to San Francisco
- every 1s for 10mins

Conclusion

- Extremely high packet loss (3.5%).
- Path change towards the end?

ping: CH1 -> SF1





DFINITY

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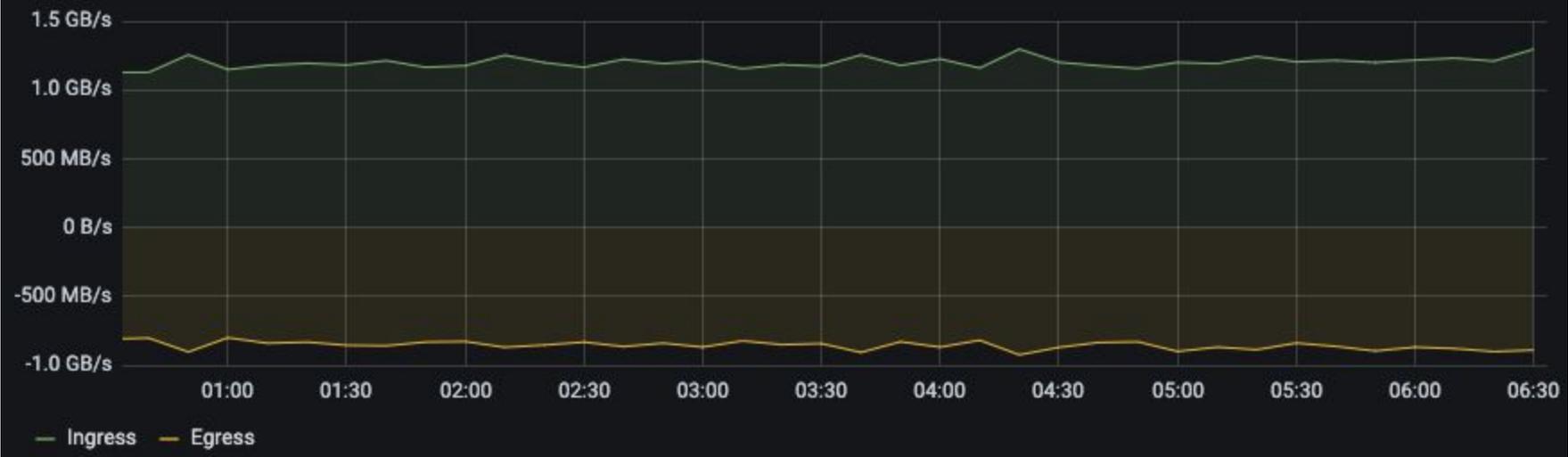
ruediger.birkner@dfinity.org

We are hiring: dfinity.org/careers

More information

- Infographic: [here](#)
- Technical Library: [here](#) (videos of talks) and [here](#) (blogposts)
- 200,000,000 CHF Developer Grant Program [here](#)
- DFINITY SDK: [here](#)

Total IC Bandwidth



Boundary node HTTP requests/second (Stacked)

