Programmable Storage

Carlos Maltzahn, UC Santa Cruz

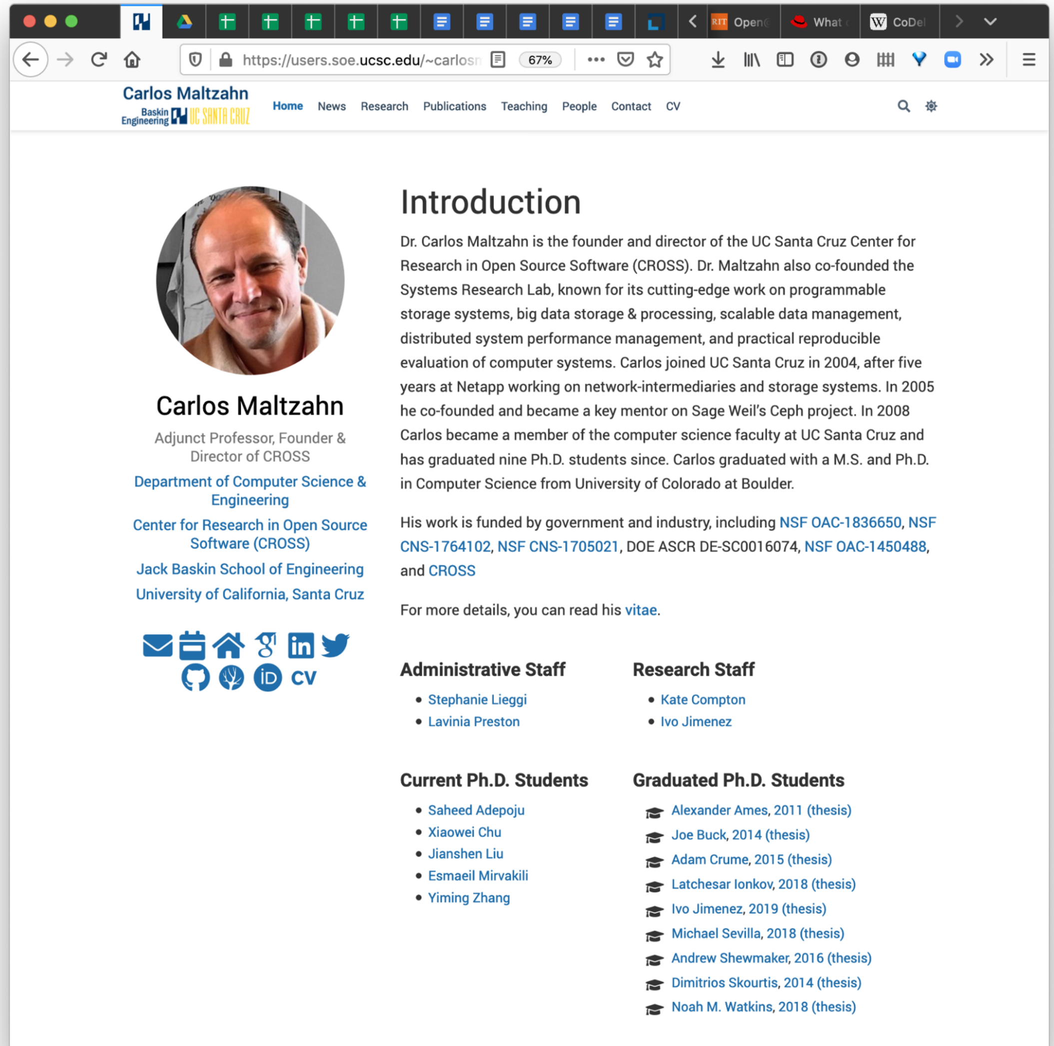
10/6/2020

Snowmass Community Planning Meeting

Opportunities for computing R&D to advance particle physics

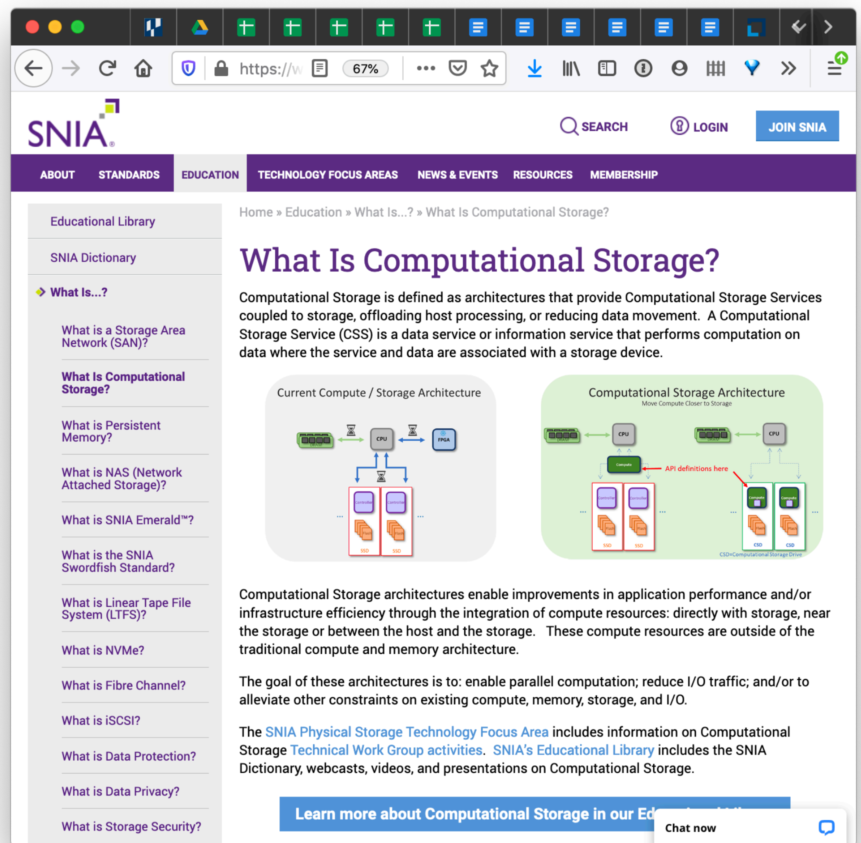
Carlos Maltzahn

people.ucsc.edu/carlosm



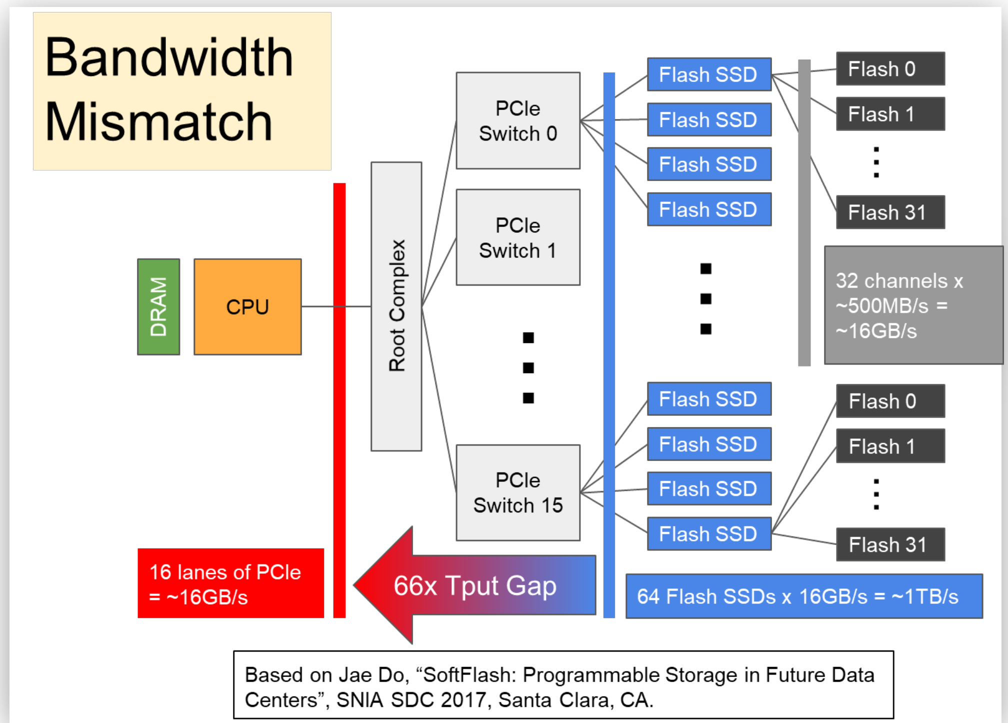
Computational Storage: History

- Idea dates back to mainframes
  - First Channel I/O processors in IBM 709, 1957
- Network Attached Secure Disks (NASD)
  - Research project at CMU, 1997-2001
    - Encryption, compression, data management (“active storage”)
  - SCSI T10 Object Storage Device (OSD) v1 and v2 standards
    - Only offloads part of file system functionality
- Ceph
  - Research project at UC Santa Cruz, 2005-2007
  - Designed for OSDs
  - Broke OSD standard with P2P communication for failure management
  - Implemented for hosts, not devices
- SkyhookDM Plugin for Ceph
  - CROSS incubator project at UC Santa Cruz since 2016
  - Offloads data management of tabular data
  - Turns Ceph into an Apache Arrow-native store (since 2020)
- Computational Storage
  - SNIA Technical Working Group (TWG) since 2019
  - Focus on storage devices
- Eusocial Storage Devices
  - CROSS research project at UC Santa Cruz since 2017
  - P2P communication, specialization into “castes”
  - I/O stack flexible about offloading: pushdown, pushback
  - Leverages Smart NICs



Computational Storage: Why now?

- Storage devices are getting very fast
  - CPU/DRAM/PCIe cannot keep up
  - CPU/DRAM/PCIe tax for storage increases
- Disaggregation in data centers
  - Multi-tenant workloads are too diverse for any kind of packaging
  - Better to dynamically assemble systems from parts
- Storage fabrics are expensive
  - NVMe requires host kernel resources
  - Ethernet is much cheaper and keeps getting faster
  - New IP protocols are getting very fast: e.g. HTTP/3



Programmable Storage

A programmable storage system or device exposes internal subsystem abstractions as “interfaces” to enable the creation of higher-level services via composition.

Collaborators: Jeff LeFevre (UCSC), Ivo Jimenez (UCSC), Esmaeil Mirvakili (UCSC), Jayjeet Chakraborty (NIT), Aditi Gupta (NIT), Aaron Chu (UCSC), Xiongfeng Song (Rice)

Programmable Storage

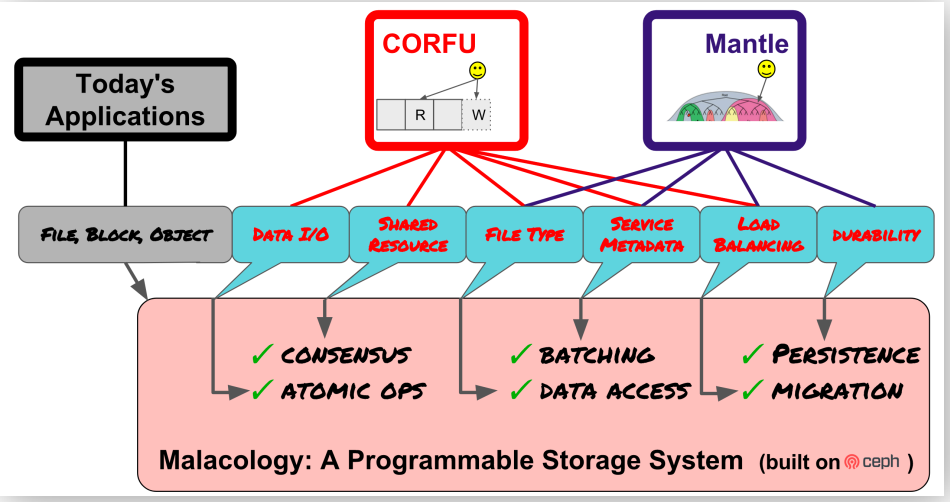
Computational Storage + Programmability

For storage systems:

- Storage has to be correct, otherwise data loss
- Correct software takes time
- Reuse as much as possible → Composability
- Composability important for optimization

For storage devices:

- Storage device industry has very low margins
- Products must fit existing market and have a minimum life time
- Programmable devices to reduce market risk
- Greater opportunity for innovation

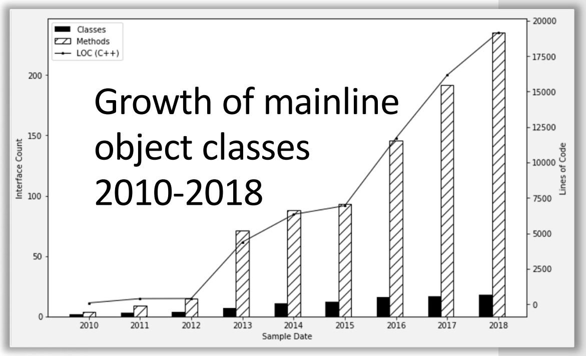


What is SkyhookDM?

ceph

tree -d
ceph/src

```
├── cls
|   ├── cephfs
|   ├── hello
|   ├── journal
|   ├── lock
|   ├── log
|   ├── lua
|   ├── numops
|   ├── rbd
|   ├── refcount
|   ├── replica_log
|   ├── rgw
|   ├── sdk
|   ├── statelog
|   ├── tabular
|   ├── timeindex
|   ├── user
|   └── version
```



Growth of mainline object classes 2010-2018

SkyhookDM

An object “class” for Ceph

- No upstream modifications required
- Inherits Ceph’s properties now and in the future
- Can use all other object extensions
- **Not a database**

Storing *tabular* data in objects

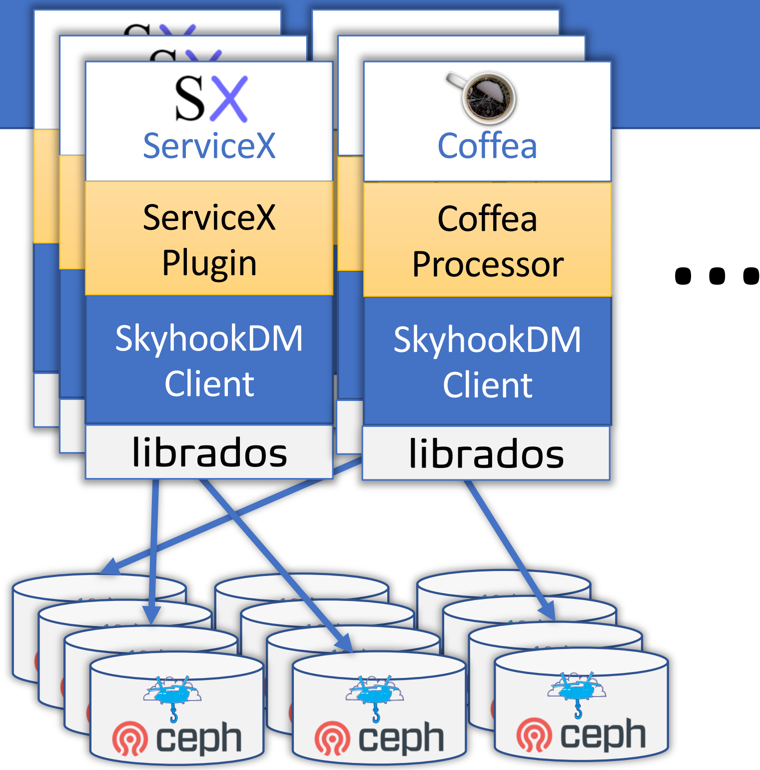
- Using APACHE ARROW

Object read/write operations

- Select, Project, Aggregate
- Create, append rows/columns
- Indexing
- Intra- & inter-object transformations

SkyhookDM Client

- Client maps *tables* to *sets of objects*
  - Map is also stored in objects
- Client API designed for *plugins*
  - Allows *pushdown* to *scale out* tabular data operations
  - Reduces data movement (CPU cycles!)
- IRIS-HEP
  - Connting to Coffea and ServiceX
- CROSS
  - Plugins for Postgres, Spark, Pandas, HDF5



How does SkyhookDM fit into DOMA?

ServiceX Plugin and Coffea Processor:

ServiceX creates one table per *transformation request*

- Partitions table and assigns transformer to each partition
- Each transformer creates and writes an object row-by-row
- ServiceX provides table metadata, incl. partitioning to SkyhookDM

Table names are arbitrary strings, globally unique

- Column names are arbitrary strings, unique within table
- Rows have a key, unique within table

Coffea Processor:

SkyhookDM can create views across arbitrary sets of tables

- View names are arbitrary strings, globally unique
- Views can be either by reference or by copy (i.e. materialized)
- SkyhookDM stitches views on a best-effort basis
- Key mappers can map one kind of key to another and can be stored

Design allows evolution of higher-level automation.

- Table naming conventions might indicate compatibility to other tables
- View naming conventions might allow automatic reuse of materialized views
- Column naming conventions might allow versioning
- Naming convention might allow automatic garbage collection