

OAK RIDGE National Laboratory

November 15, 2026

Building Resilient Self-Driving Laboratories with the INTERSECT Federated Ecosystem

Christian Engelmann, Andrew Ayres, Stephen DeWitt, Michael J. Brim, and Brett Eiffert

8th Annual Workshop on Extreme-Scale Experiment-in-the-Loop Computing (XLOOP) 2026

U.S. DEPARTMENT OF ENERGY

ORNL IS MANAGED BY UT-BATTELLE LLC
FOR THE US DEPARTMENT OF ENERGY

Background: Additive Manufacturing – 3D Printing of Anything

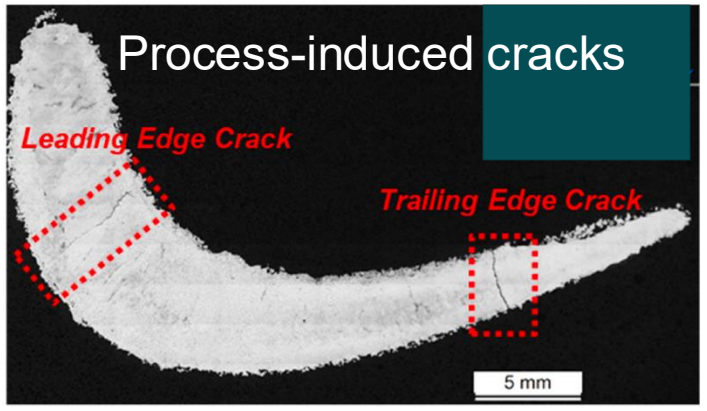
Building a part layer-by-layer by melting small amounts of powder/wire at a time

Potential for new, complex part topologies and optimized, location-specific material properties

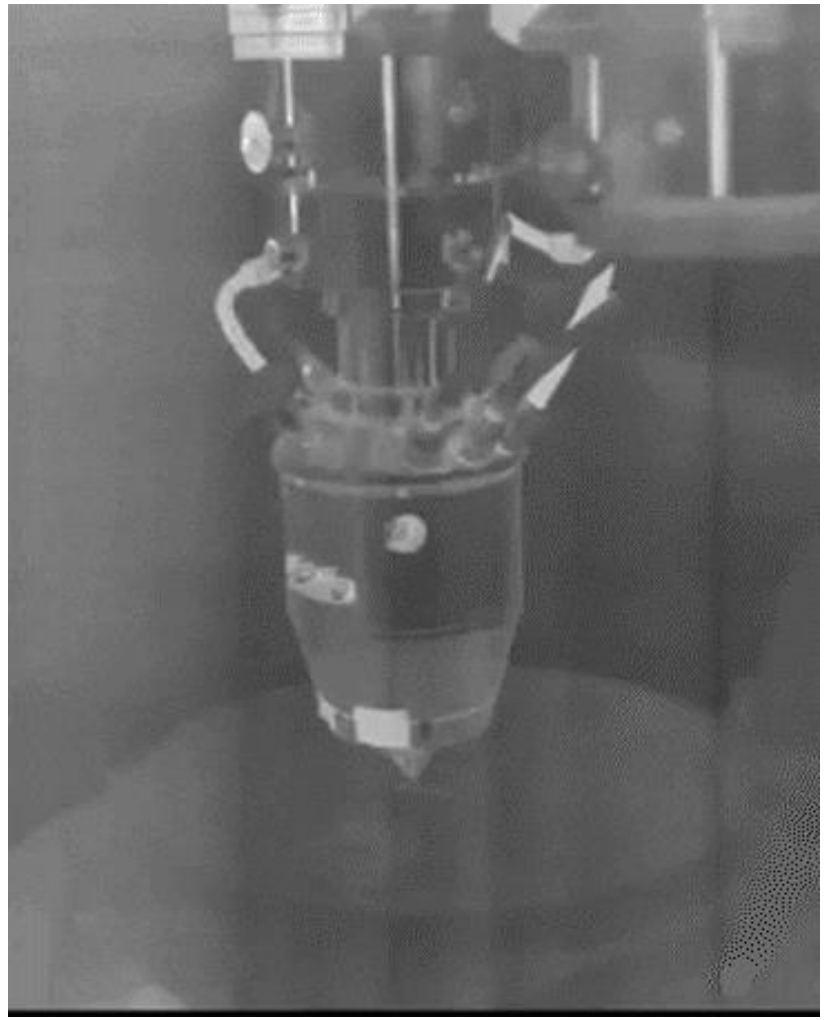
Part quality is sensitive to process parameters → Any change can require unintuitive process changes

Produce p dy to use im d”

Auto ntrol

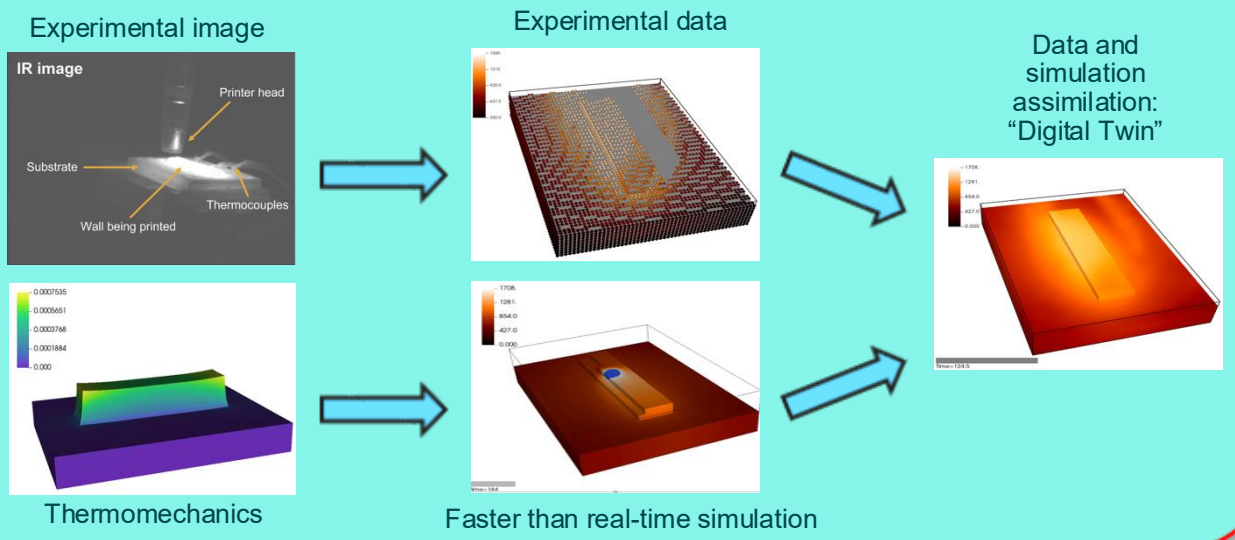


Lee, et al, Additive Manufacturing, 2020.

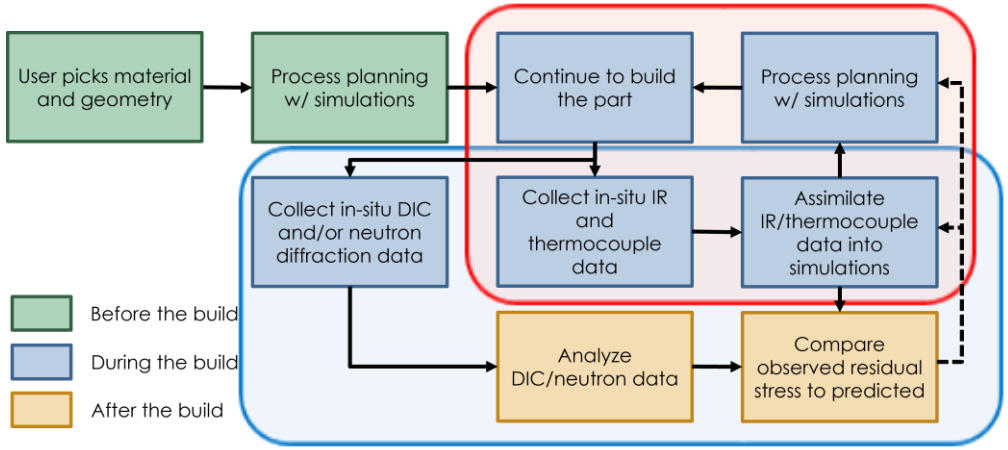


Background: Autonomous Additive Manufacturing with INTERSECT

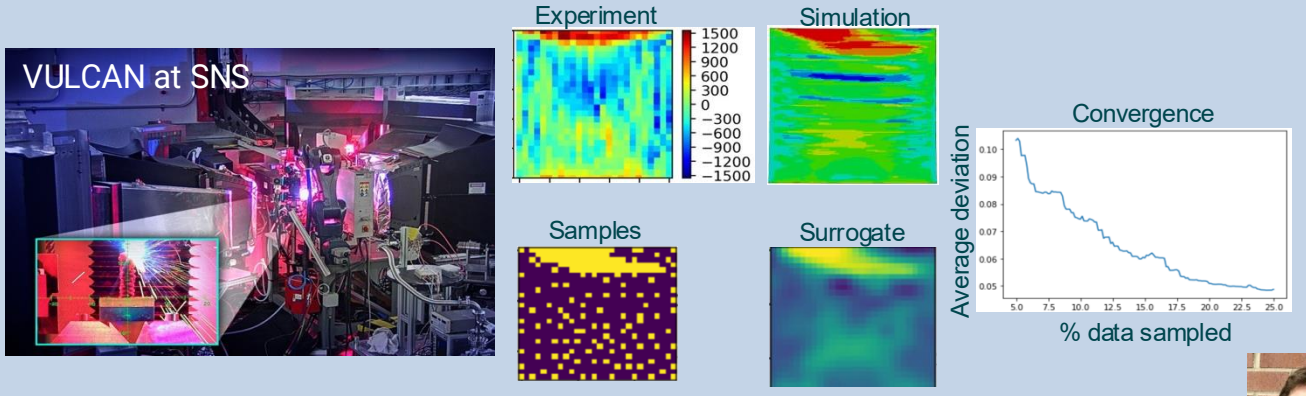
Additive Manufacturing Digital Twin



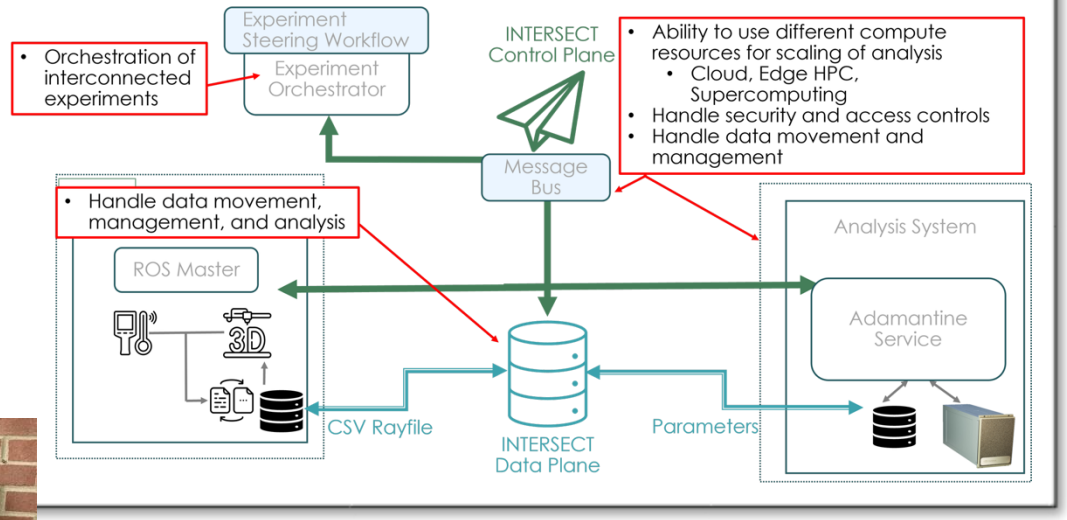
Additive Manufacturing Autonomous Workflow

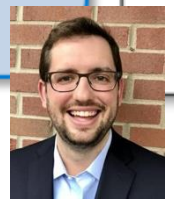


Additive Manufacturing / SNS Integration



INTERSECT Software Services





Stephen DeWitt (ORNL PI)

Goal and Contributions

Overarching Goal

Address the critical challenge of failures in federated ecosystems for instrument science, which disrupt experiments and waste valuable instrument, network, and computing resources.

Provide a consistent design methodology that lets scientists pick and choose the right solution for the resilience problem at hand and deploy it with ease.

***Resilience needs to be an integral part of the ecosystem through co-design**, such that the burden for providing it is on the system by design and not on the operator/user as an afterthought.*

Contributions

A resilient federated ecosystem architecture: an implementation blueprint using resilience design patterns, a resilient system-of-systems (SoS) architecture, and a resilient microservices architecture.

A software development kit (SDK) ensuring resilience through reliable service communication with asynchronous and synchronous failure detection and notification.

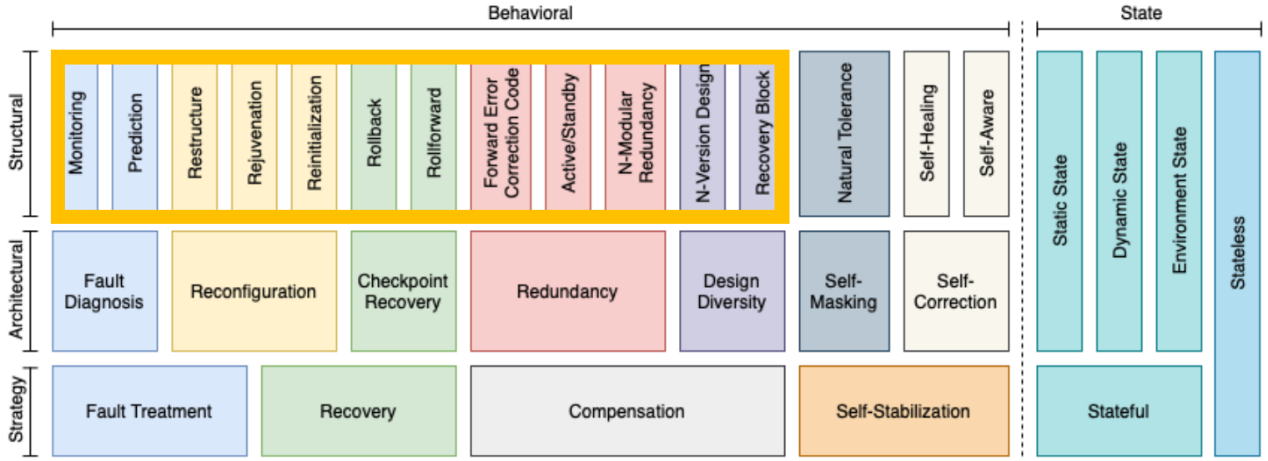
A demonstration of a resilient autonomous additive manufacturing (AAM) cross-facility experiment with fail-stop and fail-over of a real-time feedback loop.

Resilient INTERSECT Architecture

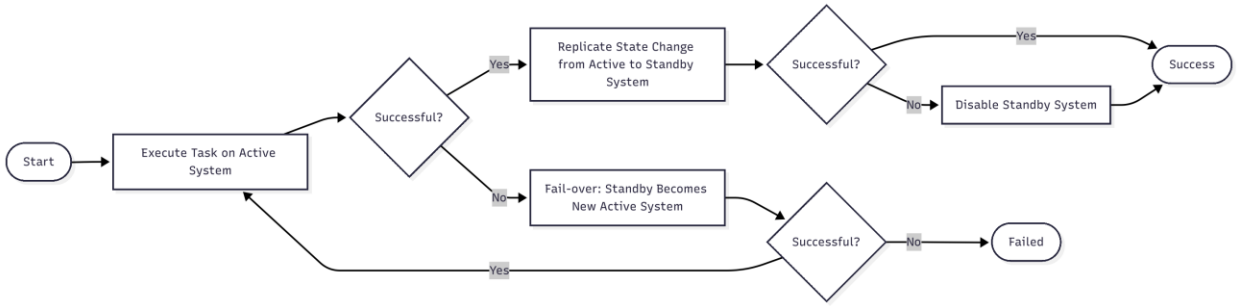
A consistent methodology applying **resilience design patterns** across systems, services, microservices, and workflows.

Resilient system-of-systems (SoS) architecture classifies fault, error, and failure types and scopes, and catalogs notification, mitigation, and containment, applied at three scopes: systems, services, and microservices.

Resilient microservices architecture applies the patterns at microservice scope and adds a basic retry pattern (retry count and delay, e.g., exponential backoff).



The HPC resilience design patterns leveraged in the INTERSECT resilience design patterns subset (rectangular selection).



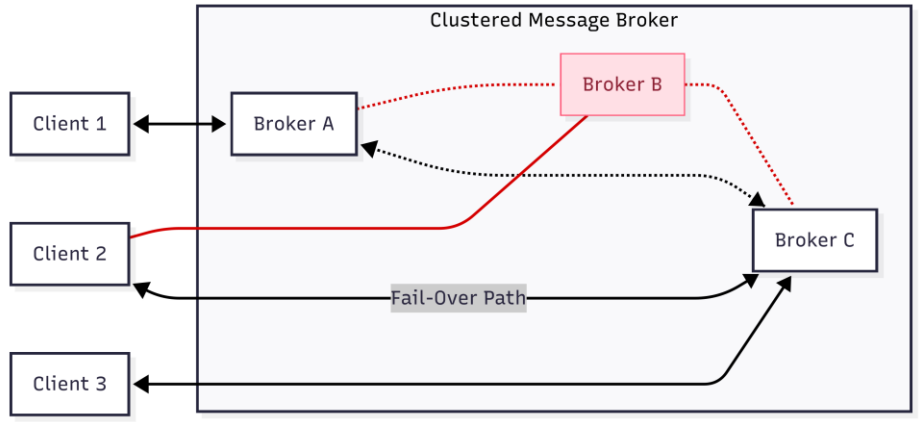
The active/standby workflow pattern can execute a standby task, which may be located on another resource, when the active task fails.

Resilient INTERSECT Software Development Kit

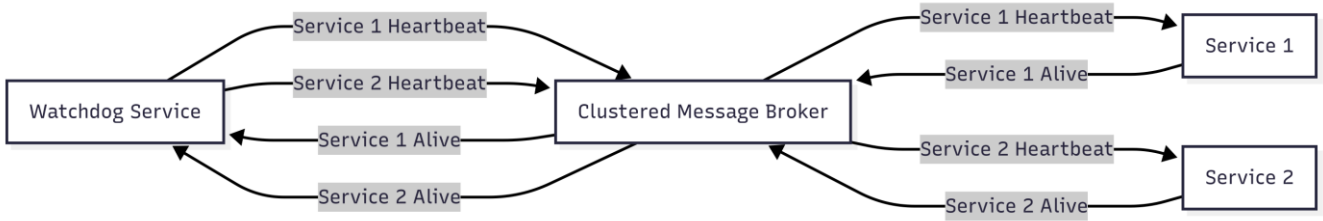
Resilient message broker, a clustered RabbitMQ shares state across brokers; a broker failure triggers fail-over to another in the group, ensuring message delivery.

Watchdog service asynchronously detects service failures via heartbeat messages at configurable intervals and timeouts, and notifies a configurable destination service.

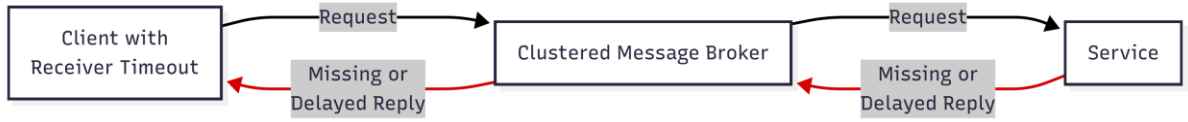
Communication timeout synchronously detects failures using a configurable timeout on replies, notifying the waiting service.



The INTERSECT SDK's clustered broker ensures reliable message delivery despite broker service failures. In this example, clustered RabbitMQ Broker C takes over for failing Broker B.



The INTERSECT SDK's watchdog sends out heartbeat messages in regular intervals to specific detect service outages. Messages are routed though the clustered broker.



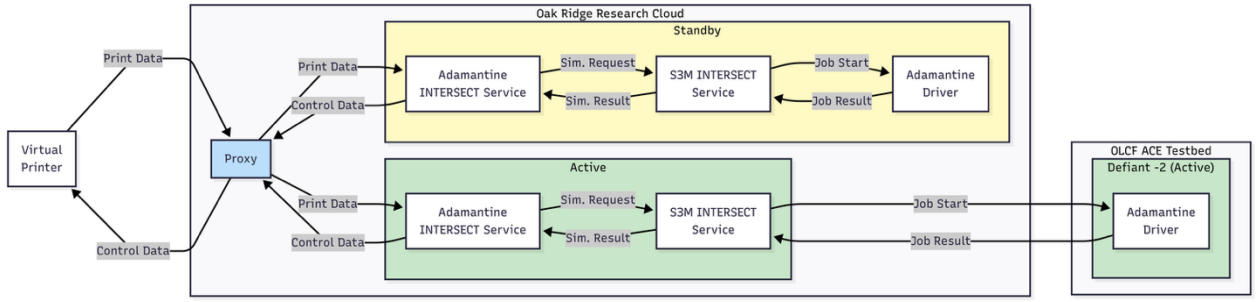
The INTERSECT SDK's communication timeout waits for a reply from a service within a configurable time to detect an outage. Messages are routed though the clustered broker.

Resilient INTERSECT Autonomous Additive Manufacturing

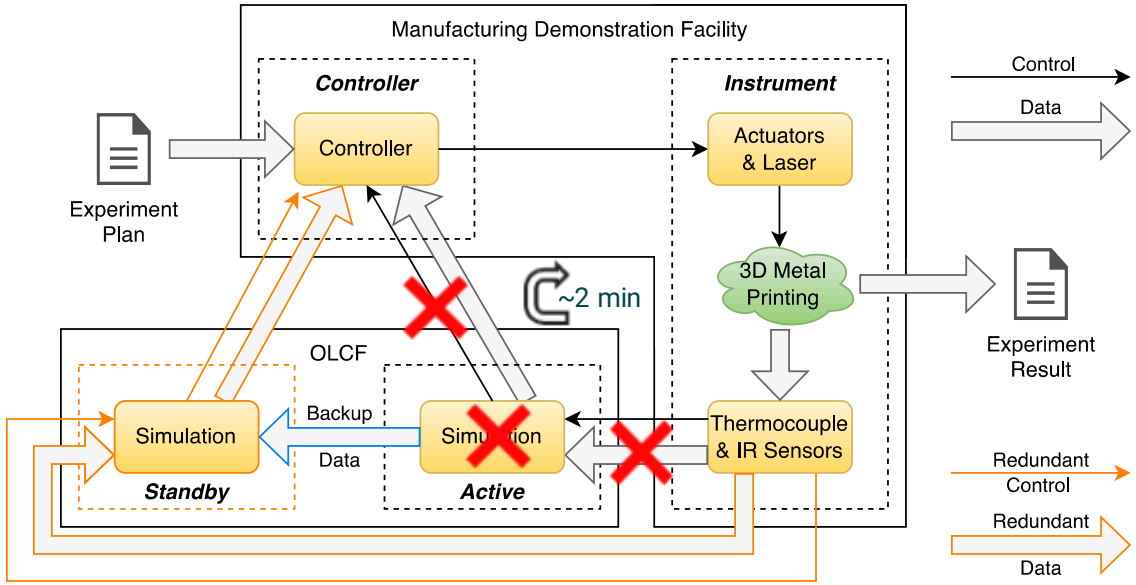
Deployment: clustered RabbitMQ broker and watchdog-integrated proxy on the Oak Ridge Research Cloud; Adamantine and S3M INTERSECT services as active/standby.

Parameters: 30 s heartbeat with 3 missed intervals (asynchronous detection); 5 s proxy request timeout and 60 s simulation-result timeout (synchronous detection).

Result: all injected failures detected and fail-over succeeded; the real-time feedback loop was never interrupted; a proxy failure triggered a fail-stop of the printer.



The demonstration setup for the resilient federated INTERSECT AAM experiment.



Active/standby setup of the resilient federated INTERSECT AAM experiment.

Conclusions

We created a ***resilient INTERSECT federated ecosystem architecture*** that provides an implementation blueprint using resilience design patterns, a resilient SoS architecture, and a resilient microservices architecture.

We developed a ***resilient INTERSECT SDK*** that ensures reliable service communication and asynchronous and synchronous failure detection and notification.

We demonstrated the ***resilient INTERSECT AAM cross-facility experiment*** that offers fail-stop and fail-over resilience capabilities of a real-time feedback loop using the resilient INTERSECT ecosystem architecture and SDK.

Resources & Artifacts

Architecture: intersect-architecture.readthedocs.io

SDK: github.com/INTERSECT-SDK

Demo: doi.org/10.5281/zenodo.21708367