Collaborative Research: NRI: Dispersed Autonomy for Marsupial Aerial Robot Teams (Award #s 2133142 and 2133141)

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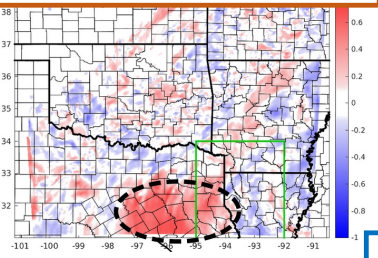
Motivation and Broader Impact

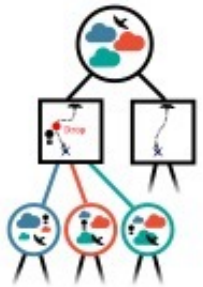
This work will realize the vision of an **autonomous airborne meteorologist** that performs online targeted observation and forecasting of complex weather.

Research Plan

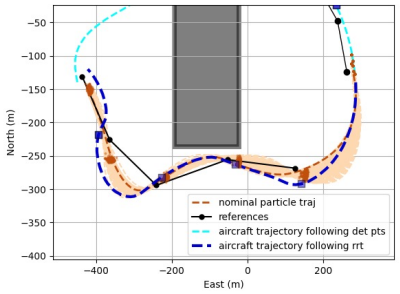
Air Launched Drifters

Ensemble Sensitivity Analysis and Subsetting

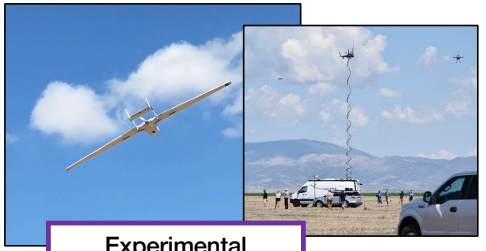




Information-Space Planning for ALD Deployment



Parallelized Path Planning in Uncertain Flow

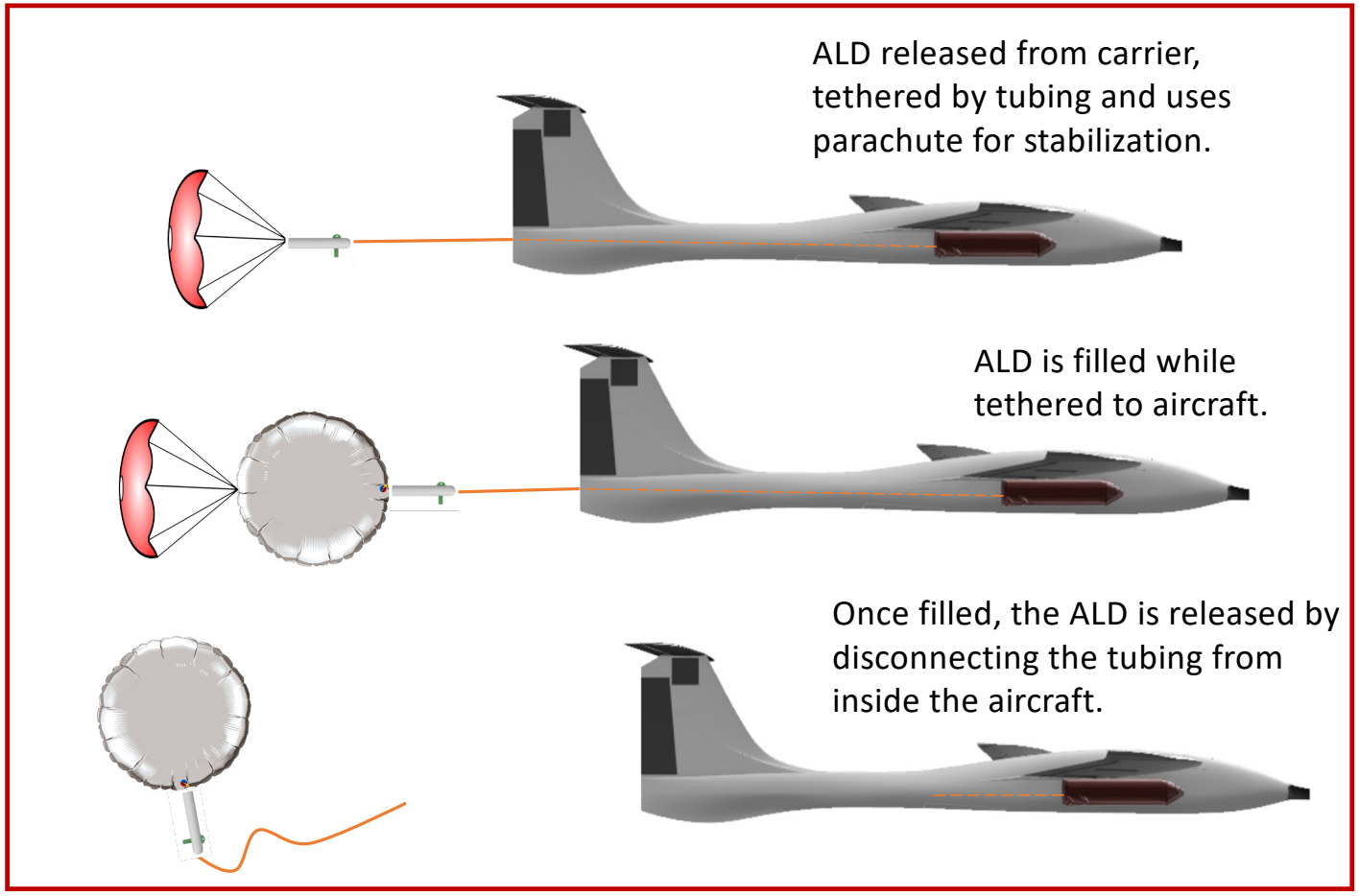


Experimental Assessment

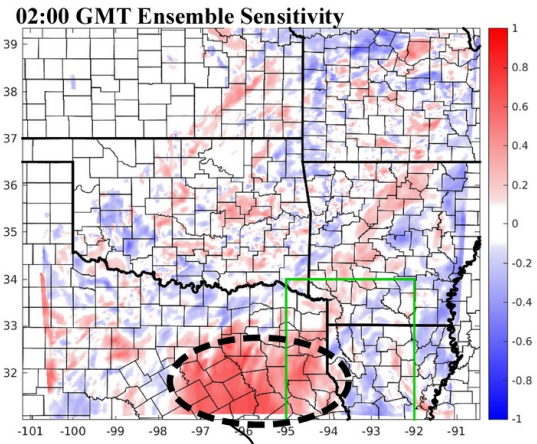
This project advances current practices through new devices and algorithms integrated, deployed, and evaluated on **marsupial aerial robot teams (MARTs)** whereby small uncrewed aircraft systems (SUAS) provide in-situ observations of the atmosphere through on-board sensors and air-launched pseudo-Lagrangian drifters. The project culminates in experimental assessment through a field campaign in complex weather conditions

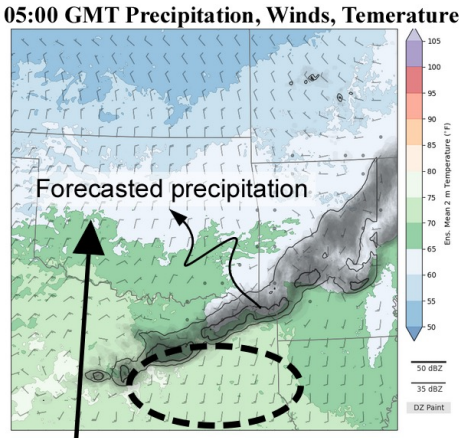
Semi-Lagrangian Air Launched Drifters (ALD) for Atmospheric Sensing

Prototype ALD demonstrating proof of concept



Ensemble Sensitivity Analysis





Sensitivity of 02:00 GMT conditions to...

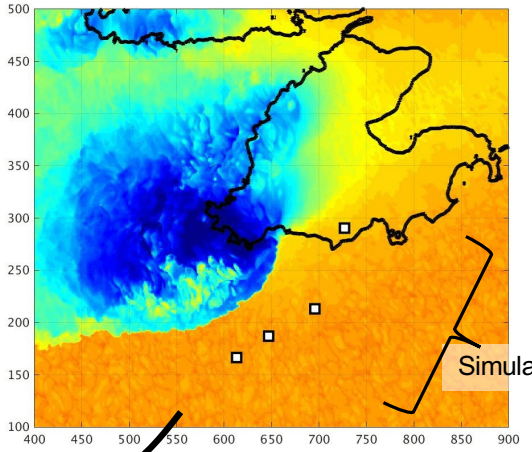
$$\frac{\partial R}{\partial \mathbf{X}} = \frac{\mathrm{Cov}(R, \mathbf{X})}{\mathrm{Var}(\mathbf{X})}$$

$R \equiv$ Forecast response

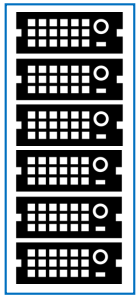
$\mathbf{X} \equiv$ Atmospheric state

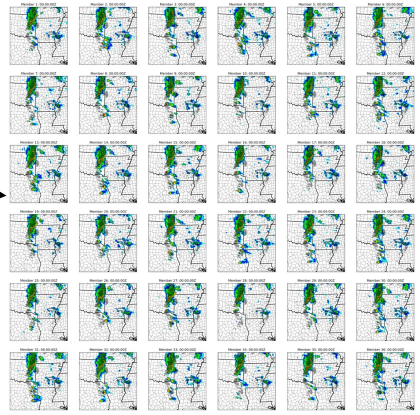
Ensemble sensitivity analysis (ESA) is the slope of the linear regression between a forecast response (R, e.g., precipitation) and the atmospheric state. Points in the domain with high sensitivity indicate where targeted observations have the potential to reduce the uncertainty in atmospheric state estimation and therefore improve numerical weather prediction

Observing System Simulation Experiments



Ensemble of NWP simulations

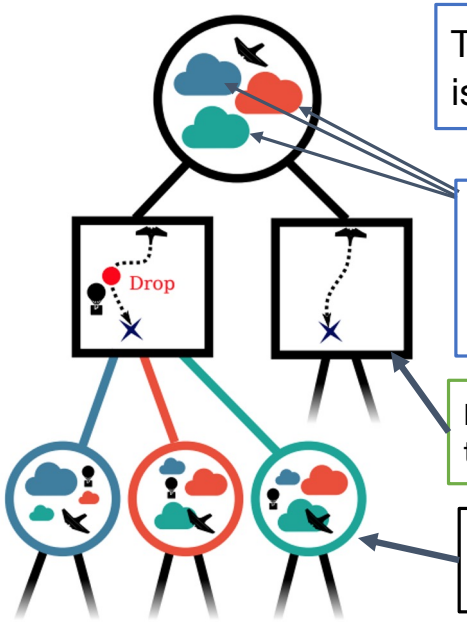




Information-Space Planning for ALD Deployment

GOAL: Plan feasible ALD deployment strategies to minimize atmosphere uncertainty

ρ - POMDP tree search: We use a modified version of the partially observable Markov decision process (POMDP) framework to formalise the goal as an optimization problem to be solved online with tree search.

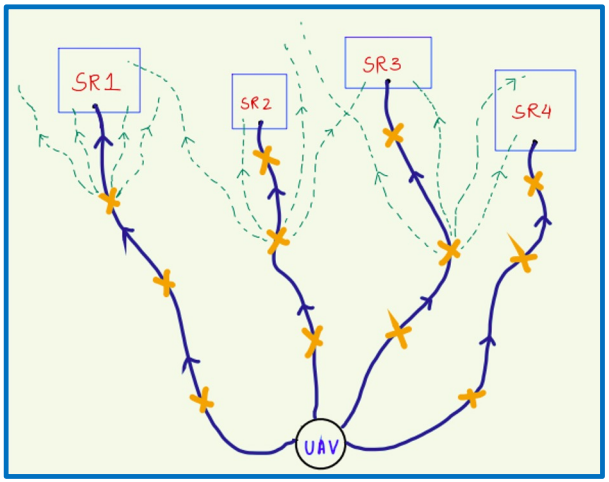


The **DESPOT-α** algorithm is used for tree search.

DESPOT-α plans in the information space using a set of **determinized scenarios**, each corresponding to a particular weather forecast.

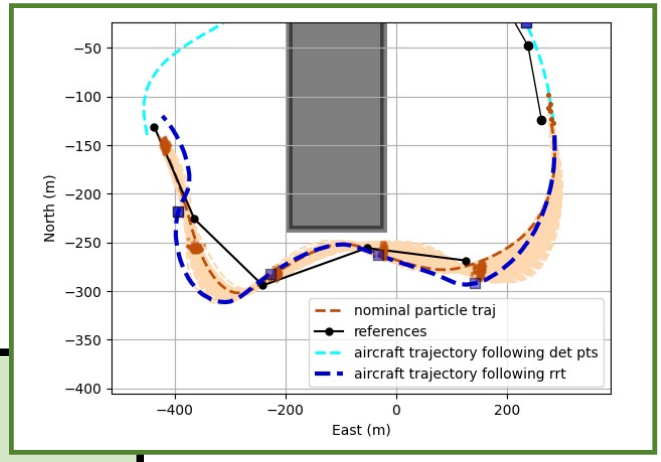
Priority actions reduce the tree branching factor.

Lower bounds are used to prune the search tree.



Heuristic policies follow paths towards sensitive regions, deploying drifters along the way. This yields a set of **priority actions** to consider in tree search, and a **lower bound** on information gathered

Parallelizable Motion Planning in Uncertain Flow Fields



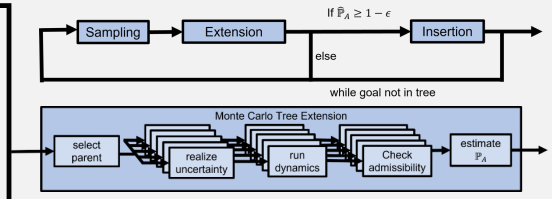
Dispersed Computing

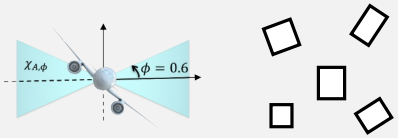
- Nonlinear Dynamics Model
- Weather Forecasting System
- Uncertainty Models

Dispersed Computing

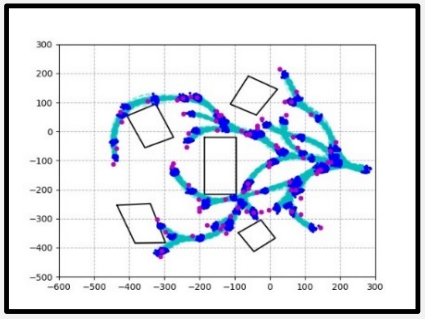
Monte Carlo Sample-Based Planner

$$\min_{\rho} \quad T$$
$$\text{subject to} \quad \rho_0 = \boldsymbol{x}_0$$
$$\mathbb{P}(\rho_{0:T} \in \chi_{A,r}) \geq 1 - \epsilon_r + d$$
$$\mathbb{P}(\rho_{0:T} \in \chi_{A,\phi}) \geq 1 - \epsilon_\phi + d$$
$$\mathbb{P}(x_T \in \chi_f) \geq 1 - \epsilon_f + d$$





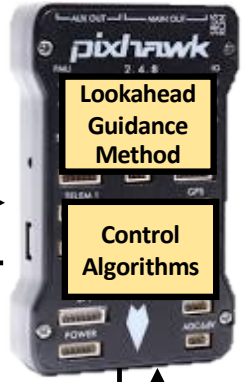
Admissible Search Tree



Waypoint Guidance & Control

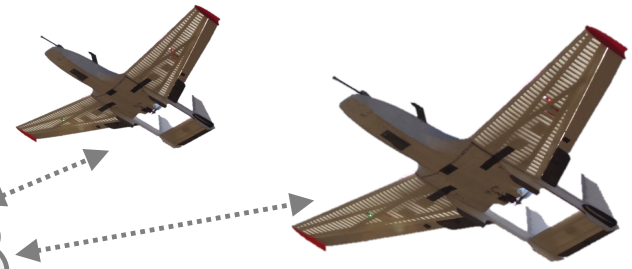
1 Hz Telemetry Uplink

2 Hz Telemetry Downlink



Onboard Sensors

Innovative Integration: Dispersed Autonomy Architecture + Experimental Field Assessment



Mobile Network Technology

5G, LTE

weather sensors

MAVLINK
MICRO AIR VEHICLE COMMUNICATION PROTOCOL
ROS

Meshed Network Communication

MANET, ad-hoc, WiFi

computing cluster

- Multiple Users
- Physics-based Models
- Machine Learning
- Remote Sensing
- Historical/Big Data
- High Performance Computing

Cloud Components

computing cluster

- Sensor Fusion
- Environmental Modeling
- Coordination

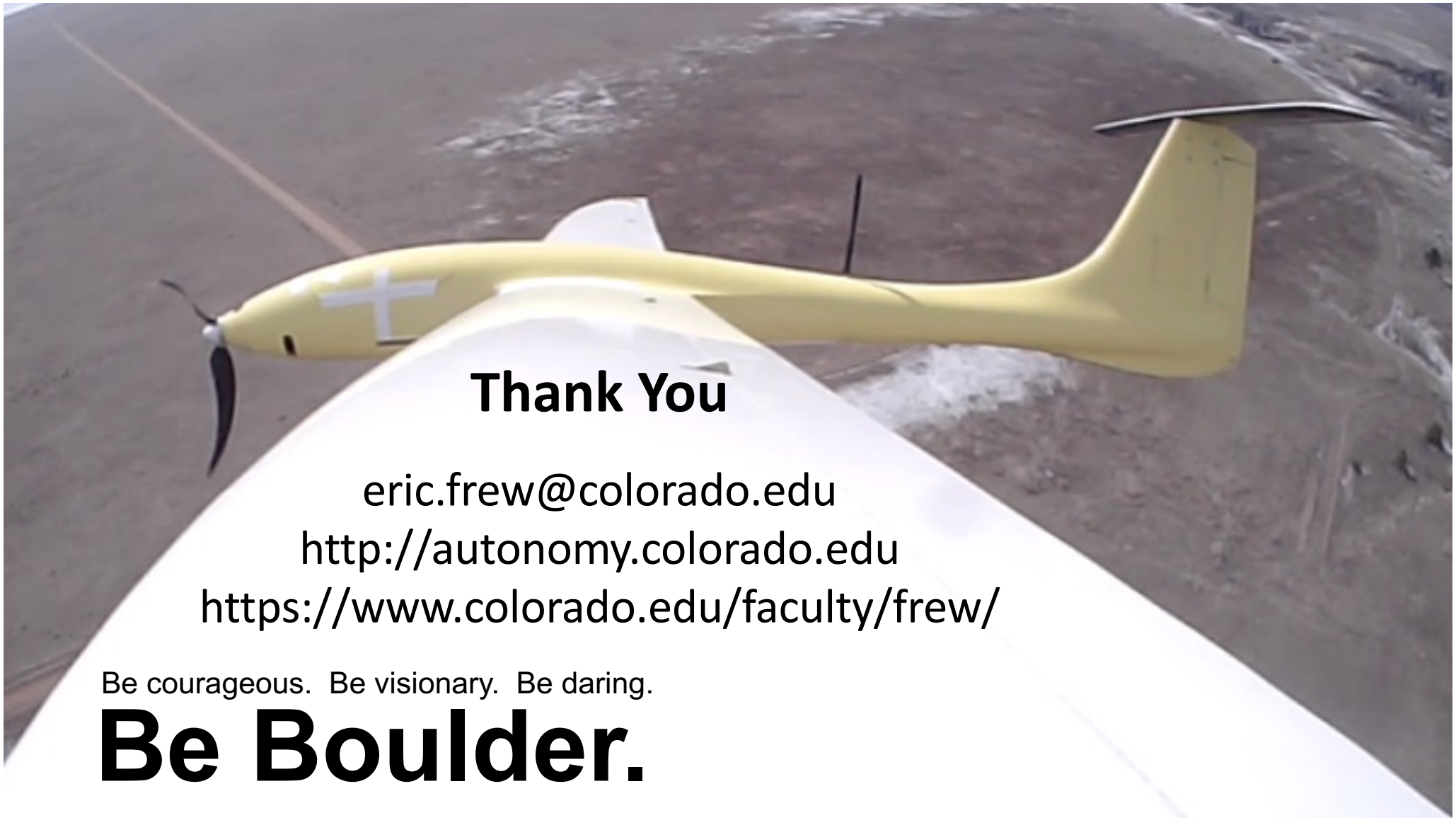
Edge Component

RAAVEN UAS

Air-launched drifters

- Perception
- Local Planning
- Decentralized Decision-Making

Local Component



Thank You

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Be courageous. Be visionary. Be daring.

Be Boulder.