
AI for Communications and Signal Processing, and Communications for AI

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Online graph learning

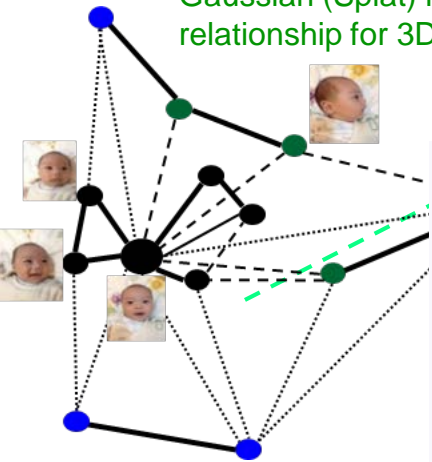
- Proposed model-driven online graph learning
- Social network analysis
- Brain graphs and prediction of Parkinson and other brain diseases
- [Prediction and tracking of rotational drivers for atrial fibrillation](#)

Attribute graph clustering

- Model-based neural networks
- Terrorist and gang groups identification
- Recommender system
- Image segmentation

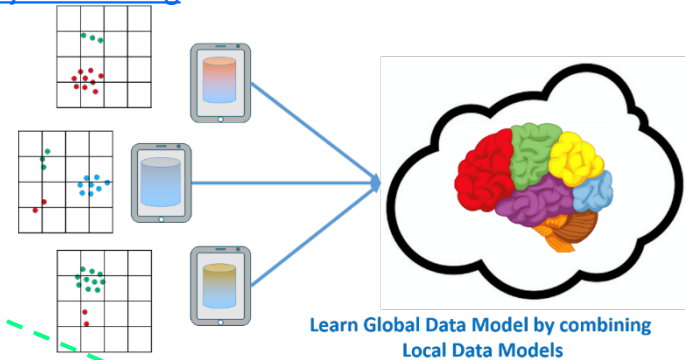
3D image reconstruction

- Kernel regression on multiview graphs of Gaussian (Splat) nodes to capture their spatial relationship for 3D image reconstruction



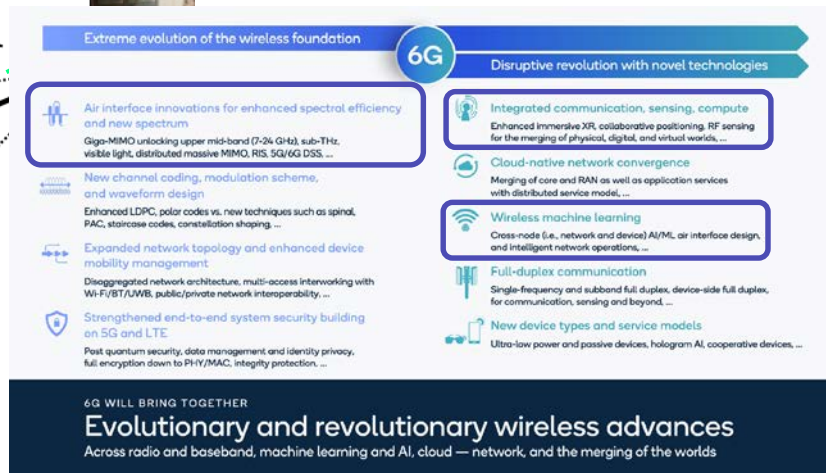
Federated and distributed learning (Communications for AI)

- Model agnostic federated learning in heterogeneous networks
- Latency rebalancing for asynchronous networks
- [Distributed data association in automotive radars for object tracking](#)



AI for communications (with mutual coupling and circular polarization)

- Modal-domain genAI-based channel tracking
- genAI-based user localization
- [Beamforming \(far-field with plane wave\) and beamfocusing \(near-field with spherical wave\)](#)
- Modal-domain channel prediction using pretrained SLM/LLM
- [Mutual coupling-aware wideband RIS beamforming using varactor-integrated RIS](#)



Extreme evolution of the wireless foundation

6G

Disruptive revolution with novel technologies



Air interface innovations for enhanced spectral efficiency and new spectrum

Giga-MIMO unlocking upper mid-band (7-24 GHz), sub-THz, visible light, distributed massive MIMO, RIS, 5G/6G DSS, ...



New channel coding, modulation scheme, and waveform design

Enhanced LDPC, polar codes vs. new techniques such as spinal, PAC, staircase codes, constellation shaping, ...



Expanded network topology and enhanced device mobility management

Disaggregated network architecture, multi-access interworking with Wi-Fi/BT/UWB, public/private network interoperability, ...



Strengthened end-to-end system security building on 5G and LTE

Post quantum security, data management and identity privacy, full encryption down to PHY/MAC, integrity protection, ...



Integrated communication, sensing, compute

Enhanced immersive XR, collaborative positioning, RF sensing for the merging of physical, digital, and virtual worlds, ...



Cloud-native network convergence

Merging of core and RAN as well as application services with distributed service model, ...



Wireless machine learning

Cross-node (i.e., network and device) AI/ML air interface design, and intelligent network operations, ...



Full-duplex communication

Single-frequency and subband full duplex, device-side full duplex, for communication, sensing and beyond, ...



New device types and service models

Ultra-low power and passive devices, hologram AI, cooperative devices, ...

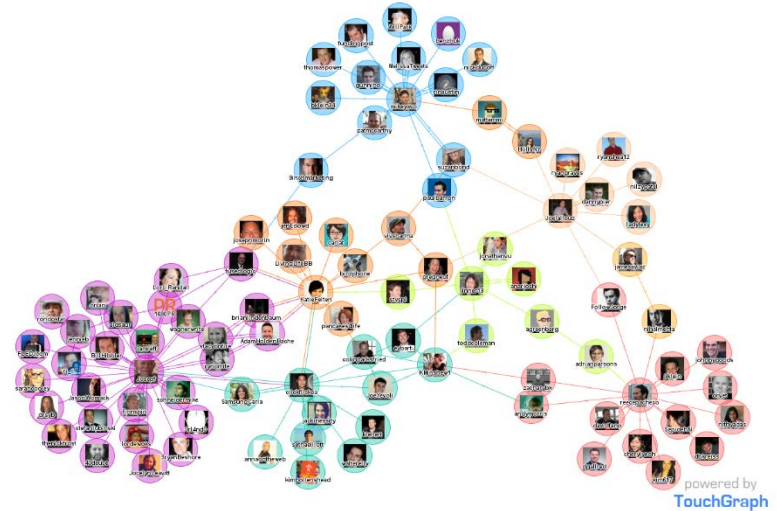
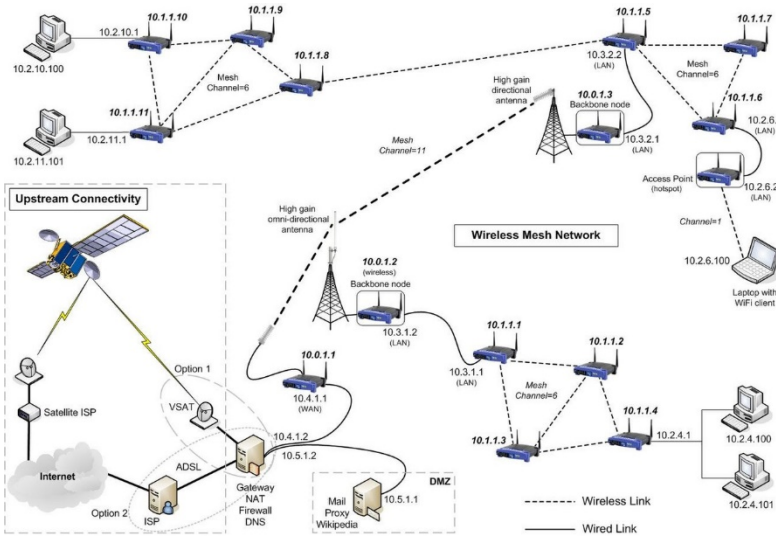
6G WILL BRING TOGETHER

Evolutionary and revolutionary wireless advances

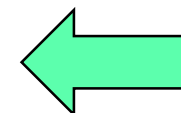
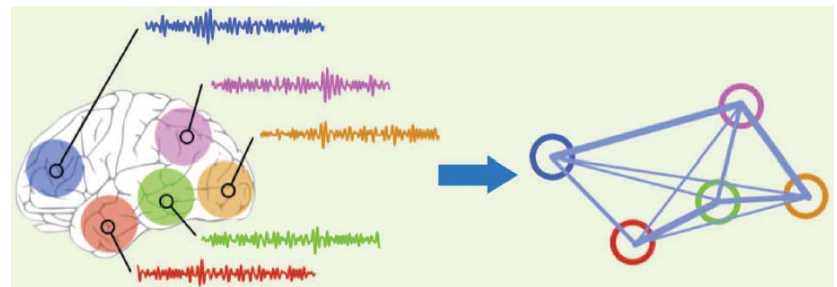
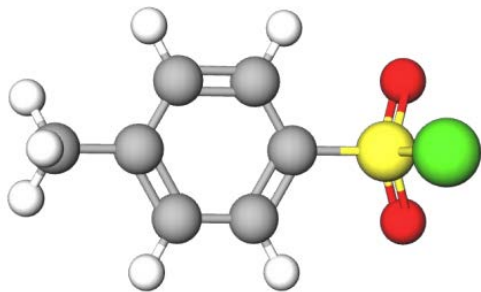
Across radio and baseband, machine learning and AI, cloud — network, and the merging of the worlds



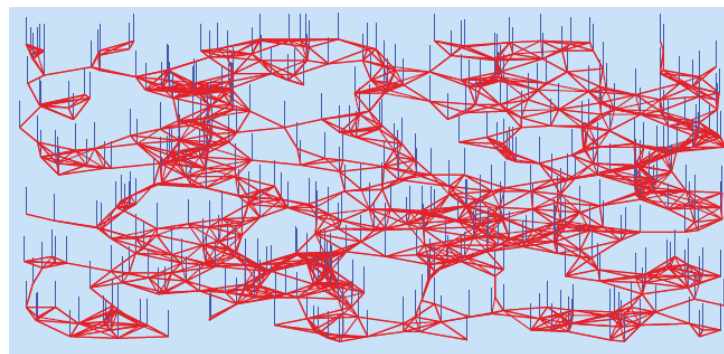
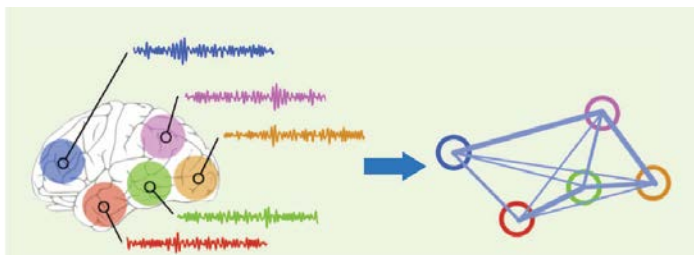
Networked non-Euclidean Data



3D Molecular Graph

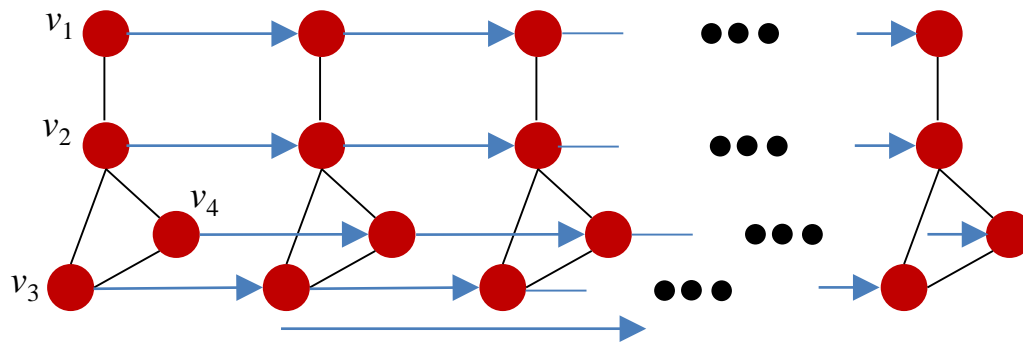


Online Graph Learning (Graph Tracking)



- Learn the **connectome** of the brain **over time**: map of the neural connections in the brain
 - **Structural** – white matter connection
 - **Functional** – statistical interdependencies between physiological time series from different brain regions
 - **Effective connectivity** – shows cause and effect of one neural element on another

Online graph learning (graph tracking)

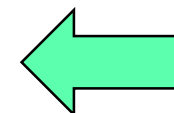


Z.-Y. Wu, C.C. Fung, J.-Y. Chang, H. Chuang and Y.-C. Lin, "Online graph learning via proximal Newton method from streaming data," <https://www.techrxiv.org/doi/full/10.36227/techrxiv.24311959.v1>.

H. Chuang, Z.-Y. Wu and C.C. Fung, "Online topology learning using causal graph process model with proximal Newton method," *under review*, 2026.

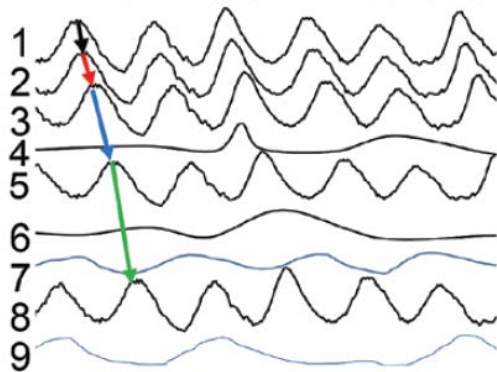
H.-M. Chiu, C.C. Fung, and A. Ortega, "Graph learning and augmentation based interpolation of signal strength for location-aware communications," *Proc. of the 28th European Signal Processing Conference*, Amsterdam, The Netherlands, Jan. 2021.

<https://doi.org/10.23919/Eusipco47968.2020.9287685>

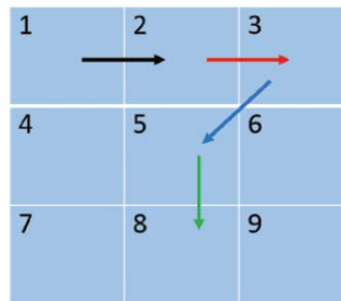


Identification of Rotational Drivers (RDs) for Atrial Fibrillation

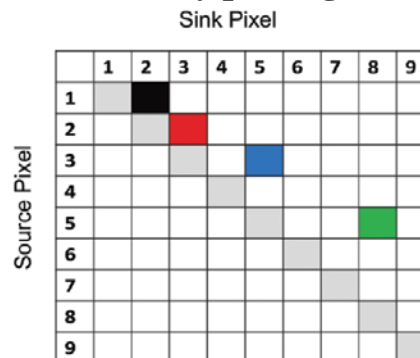
Intracardiac electrogram (iEGM)



Granger causality vector map



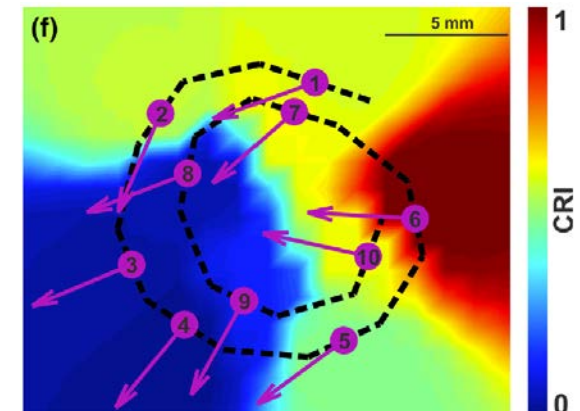
Causality pairing index



Possible solutions:

- Using linear and nonlinear vector autoregressive model to overcome spatial resolution problem
- Online solution to track the transient behavior of iEGM (RDs)

RD that causes atrial fibrillation



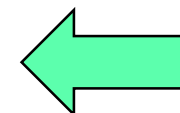
Challenges:

- Low spatiotemporal resolution of the mapping
 - Lead to false positive RDs
- Variability in the iEGM signals causes RDs to exhibit a winding and transient behavior

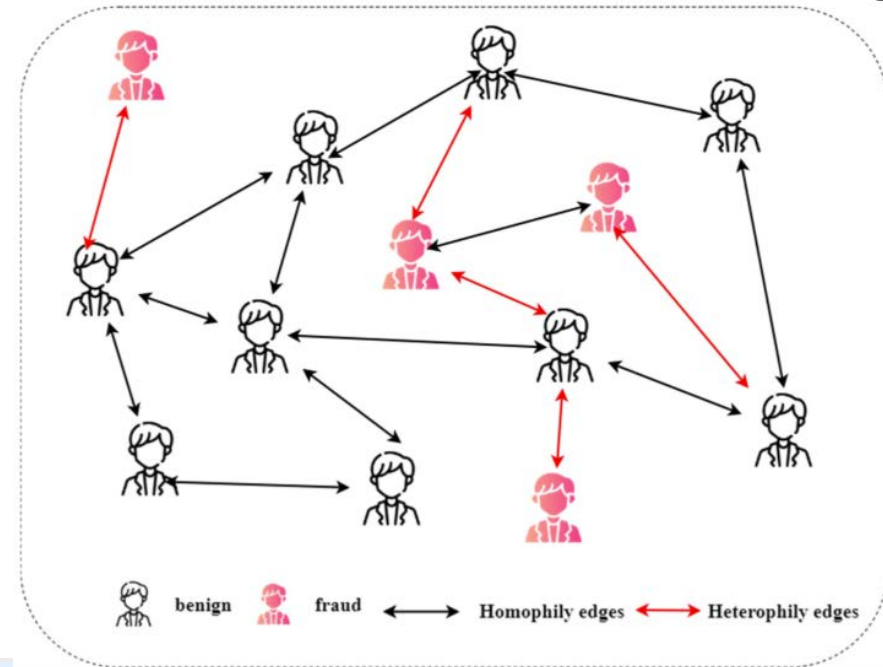
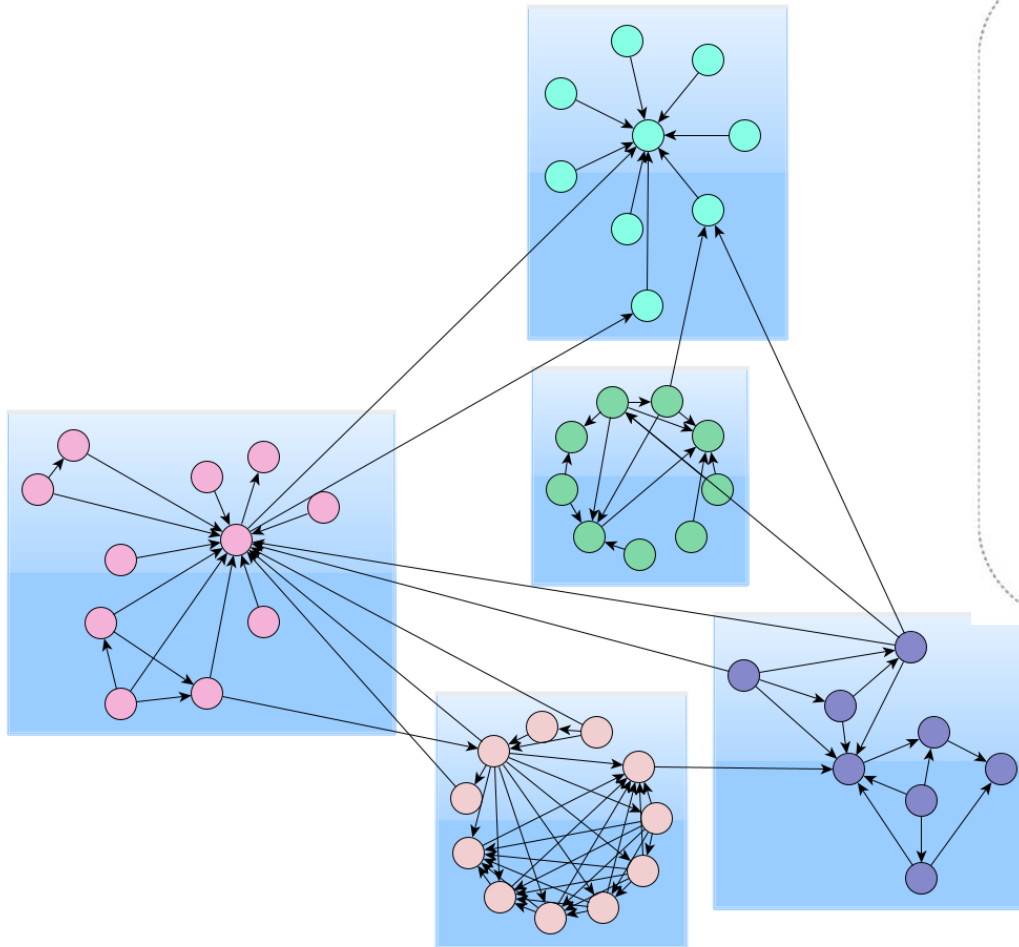
M. Rodrigo *et al.*, “Identification of dominant excitation patterns and sources of atrial fibrillation by causality analysis,” *Annals of Biomedical Engineering*, Feb. 2016.

B.S Handa *et al.*, “Granger causality-based analysis for classification of fibrillation mechanisms and localization of rotational drivers,” *Circulation: Arrhythmia and Electrophysiology*, pp. 258- 273, Mar. 2023.

Z.-Y. Wu, C.C. Fung, J.-Y. Chang, H. Chuang and Y.-C. Lin, “Online graph learning via proximal Newton method from streaming data,” <https://www.techrxiv.org/doi/full/10.36227/techrxiv.24311959.v1>.

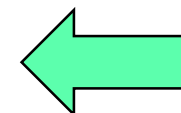


Attribute Graph Clustering

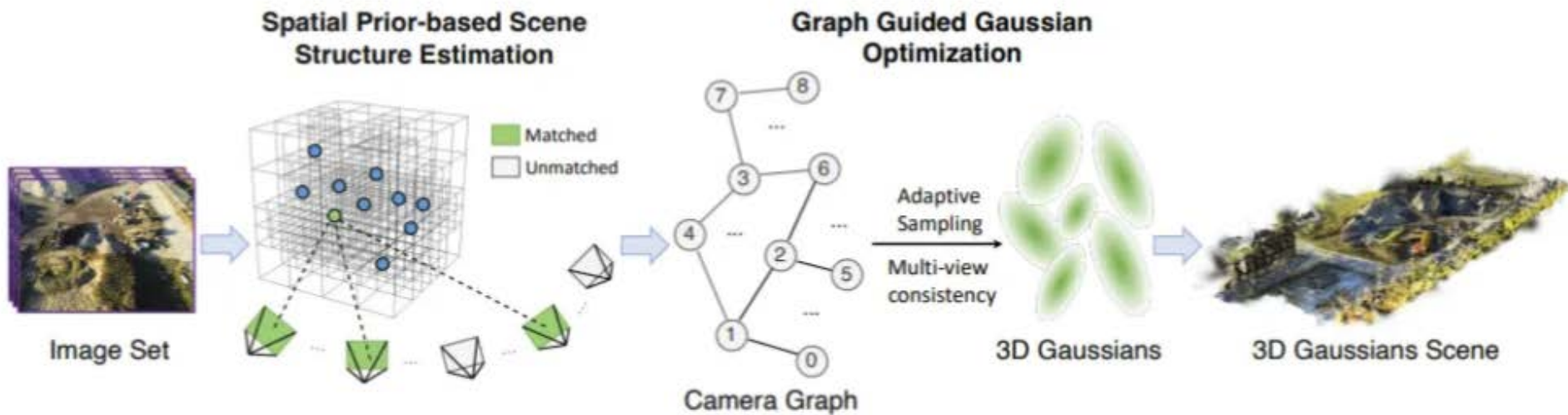


I.A. Chikwendu, X. Zhang, C.C. Ukwuoma, O.C. Chikwendu, Y.H. Gu and M.A. Al-antari, "Spectrum-constrained and skip-enhanced graph fraud detection: Heterophily in fraud detection with spectral and spatial modeling," *Symmetry*, vol. 17(4), 476, 2025.

J.-H. Lee and C.C. Fung, "Attribute graph learning using model-driven neural networks," *under preparation*, 2026.



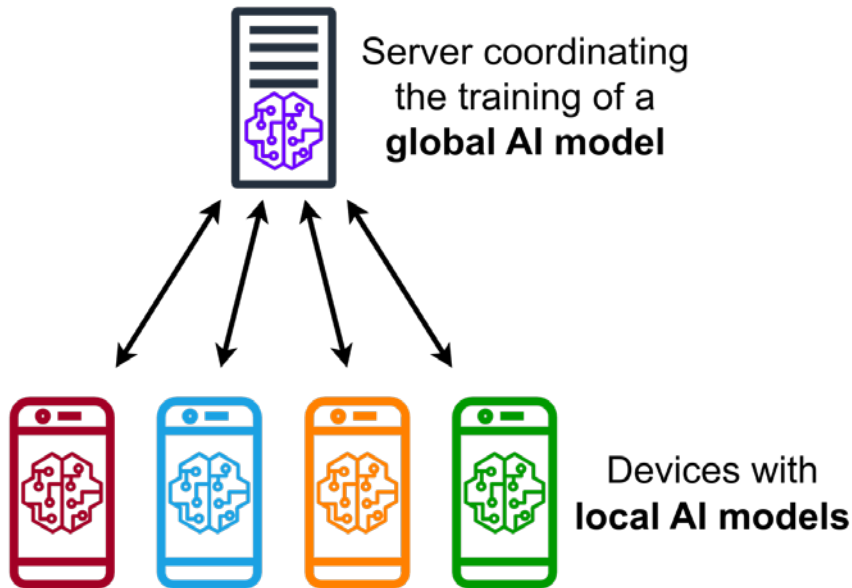
Graph-Guided 3D Image Reconstruction with Gaussian Splats



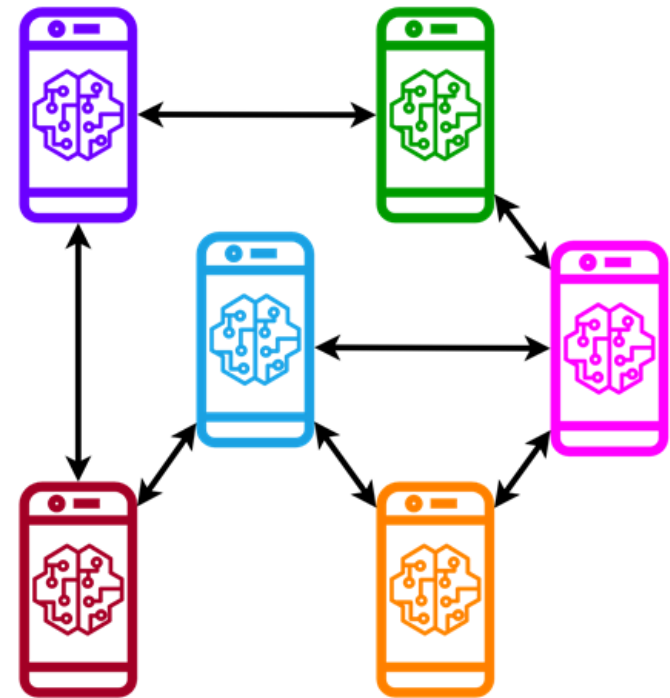
C. Cheng, G. Song, Y. Yao, Q. Zhou, G. Zhang and H. Wang, "Graph-guided scene reconstruction from images with 3D Gaussian splatting," *Proc. of the 13th Intl. Conf. on Learning Representations*, 2025.



Model Agnostic Federated and Distributed Learning



https://en.wikipedia.org/wiki/Federated_learning

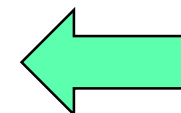


https://commons.wikimedia.org/wiki/File:Federated_learning_%28centralized_vs_decentralized%29.png

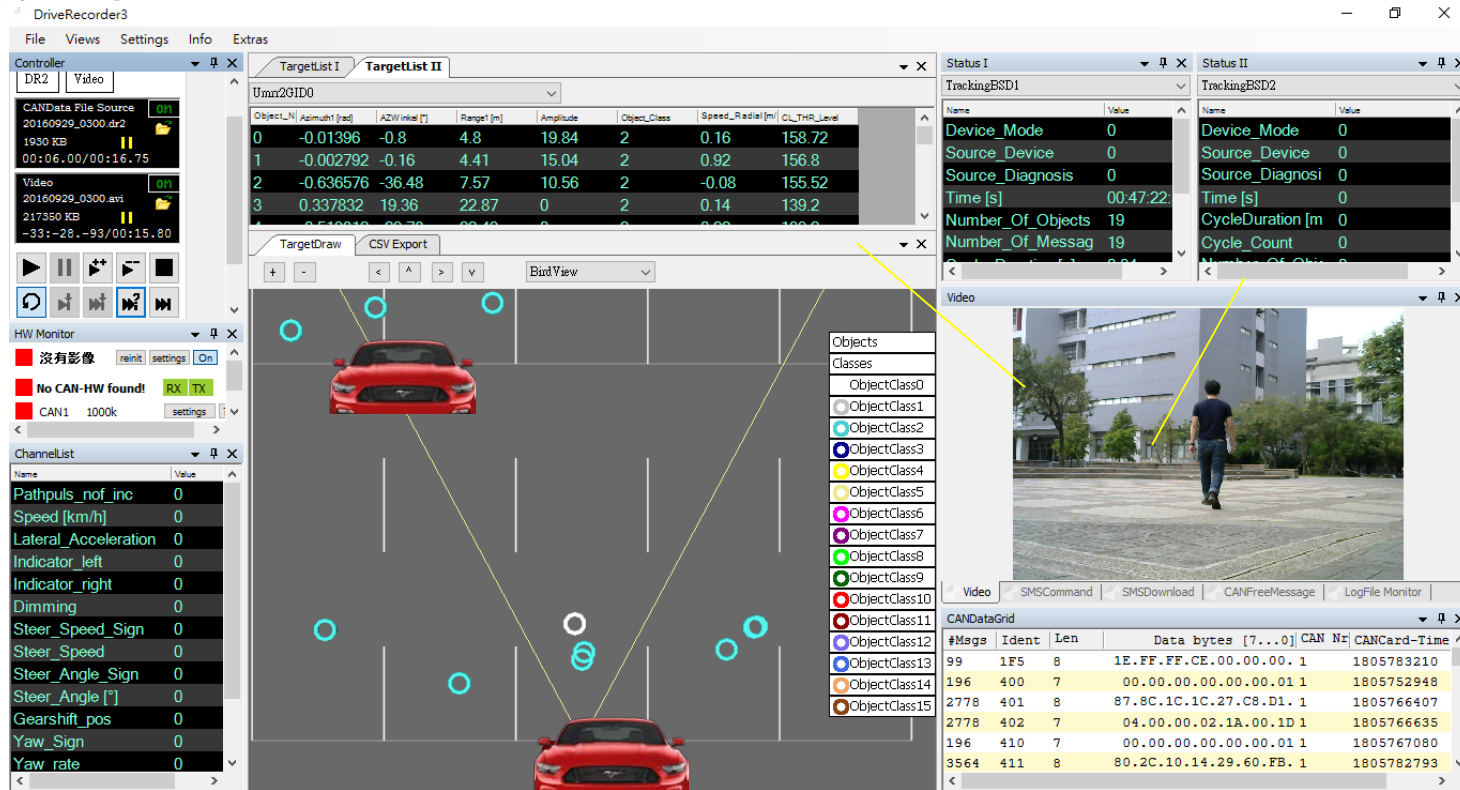
S. Hubert and C.C. Fung, "Neural network based latency rebalancing technique for asynchronous federated learning," *under preparation*.

M. Servetnyk and C.C. Fung, "Distributed dual averaging based data clustering," *IEEE Trans. on Big Data*, vol. 9(1), pp. 372-379, Jan./Feb. 2023. <https://doi.org/10.1109/TBDATA.2023.3146169>.

M. Servetnyk, C.C. Fung, and Z. Han, "Unsupervised federated learning for unbalanced data," *Proc. of the IEEE Global Communications Conference*, Taipei, Taiwan, Dec. 2020. <https://doi.org/10.1109/GLOBECOM42002.2020.9348203>



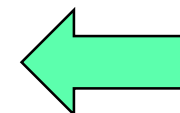
Comm for AI Application: 3D mmWave Radars



C.-N. Chan and C.C. Fung, "RFCM for data association and multitarget tracking using 3D radar," *Proc. of the IEEE Intl. Conf. on Speech, Acoustics and Signal Processing*, Calgary, AB, Canada, Apr. 2018.

M. Servetnyk, C.C. Fung, and Z. Han, "Unsupervised federated learning for unbalanced data," *Proc. of the IEEE Global Communications Conference*, Taipei, Taiwan, Dec. 2020.

M. Servetnyk and C.C. Fung, "Distributed dual averaging based data clustering," *IEEE Trans. on Big Data*, vol. 9(1), pp. 372-379, Jan./Feb. 2023.



Score-Guided Diffusion Model based Modal-Domain Channel Tracking and User Localization

Forward process with conditional distribution $q(\mathbf{x}_k | \mathbf{x}_{k-1})$

$$q(\mathbf{x}_k | \mathbf{x}_{k-1}) \sim \mathcal{N}(\sqrt{\alpha_k} \mathbf{x}_{k-1}, \beta_k \mathbf{I}_{r_T, r_R})$$



$$\begin{aligned} q(\mathbf{x}_{k-1} | \mathbf{x}_k, \mathbf{x}_0) &\propto q(\mathbf{x}_{k-1}, \mathbf{x}_k | \mathbf{x}_0) \\ &= q(\mathbf{x}_k | \mathbf{x}_{k-1}, \mathbf{x}_0) q(\mathbf{x}_{k-1} | \mathbf{x}_0) \\ &\stackrel{\uparrow}{=} q(\mathbf{x}_k | \mathbf{x}_{k-1}) q(\mathbf{x}_{k-1} | \mathbf{x}_0) \end{aligned}$$

Markovian assumption

This shows the forward distribution $q(\mathbf{x}_k | \mathbf{x}_{k-1})$ is actually proportional to $q(\mathbf{x}_{k-1} | \mathbf{x}_k, \mathbf{x}_0)$, which is what the reverse process is attempting to learn through parameterization

Reverse process estimating conditional distribution $q(\mathbf{x}_{k-1} | \mathbf{x}_k)$

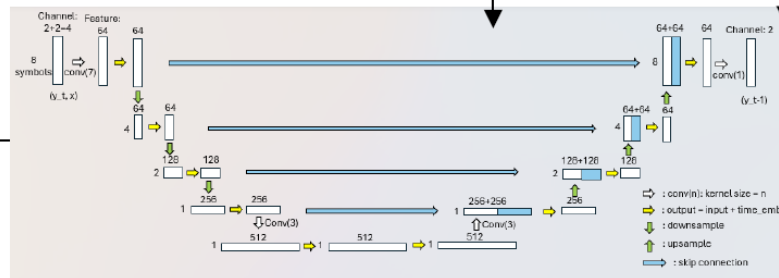
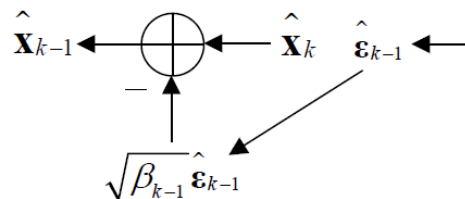
marginal distribution (prior):

$$s_\theta(\mathbf{x}_k, k) = \nabla_{\mathbf{x}_k} \log p_k(\mathbf{x}_k)$$

likelihood:

$$\nabla_{\mathbf{x}_k} \log p_k(y | \mathbf{x}_k)$$

Guidance to direct the model to give estimate of \mathbf{x}_0 that is associated with the observation y



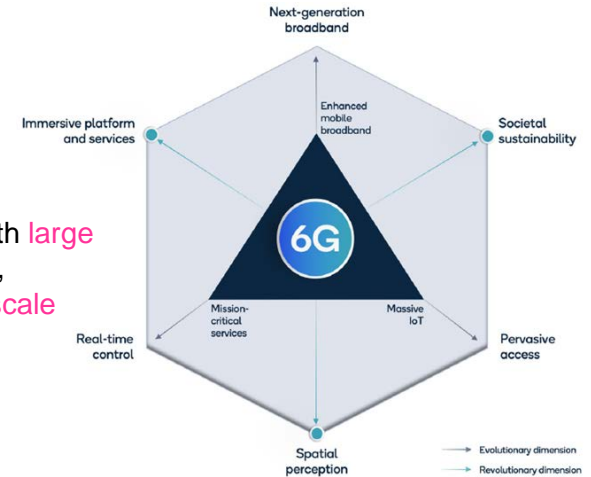
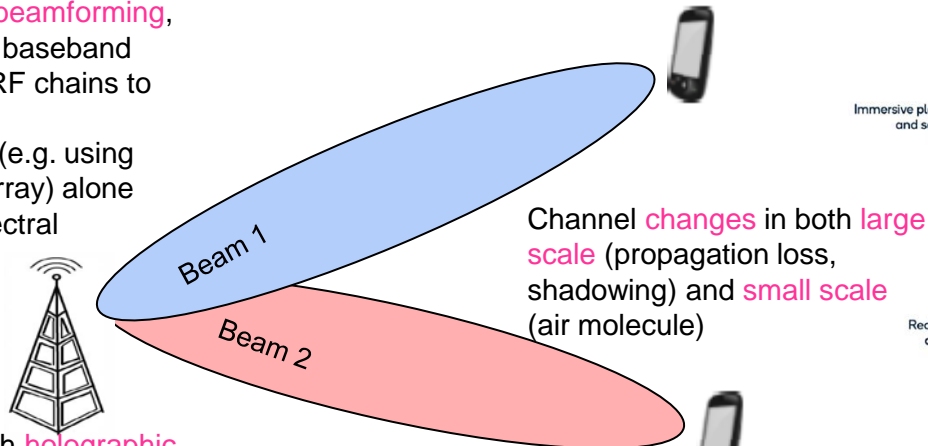
$$p_\theta(\mathbf{x}_{k-1} | \mathbf{x}_k) \approx q(\mathbf{x}_{k-1} | \mathbf{x}_k, \mathbf{x}_0)$$

The UNet (or MLP), or ε -net, parameterizes by θ , is used to approximate the noise added in the forward process by learning $q(\mathbf{x}_{k-1} | \mathbf{x}_k)$

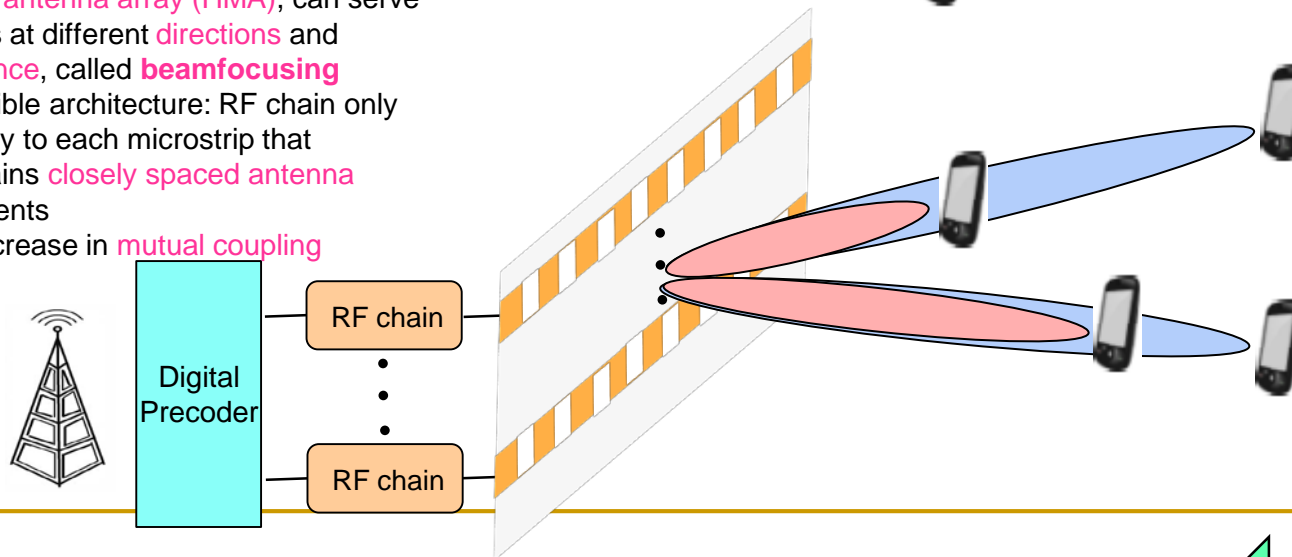


Mutual Coupling-Aware Modal-Domain Tracking, Prediction, Beamforming and Beamfocusing

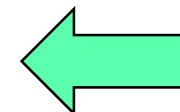
1. (Digital) **Precoding**, or **beamforming**, boosts the SINR in the baseband
2. Requires (expensive) RF chains to every antenna
3. Antenna beamforming (e.g. using phase array antenna array) alone cannot achieve the spectral efficiency required



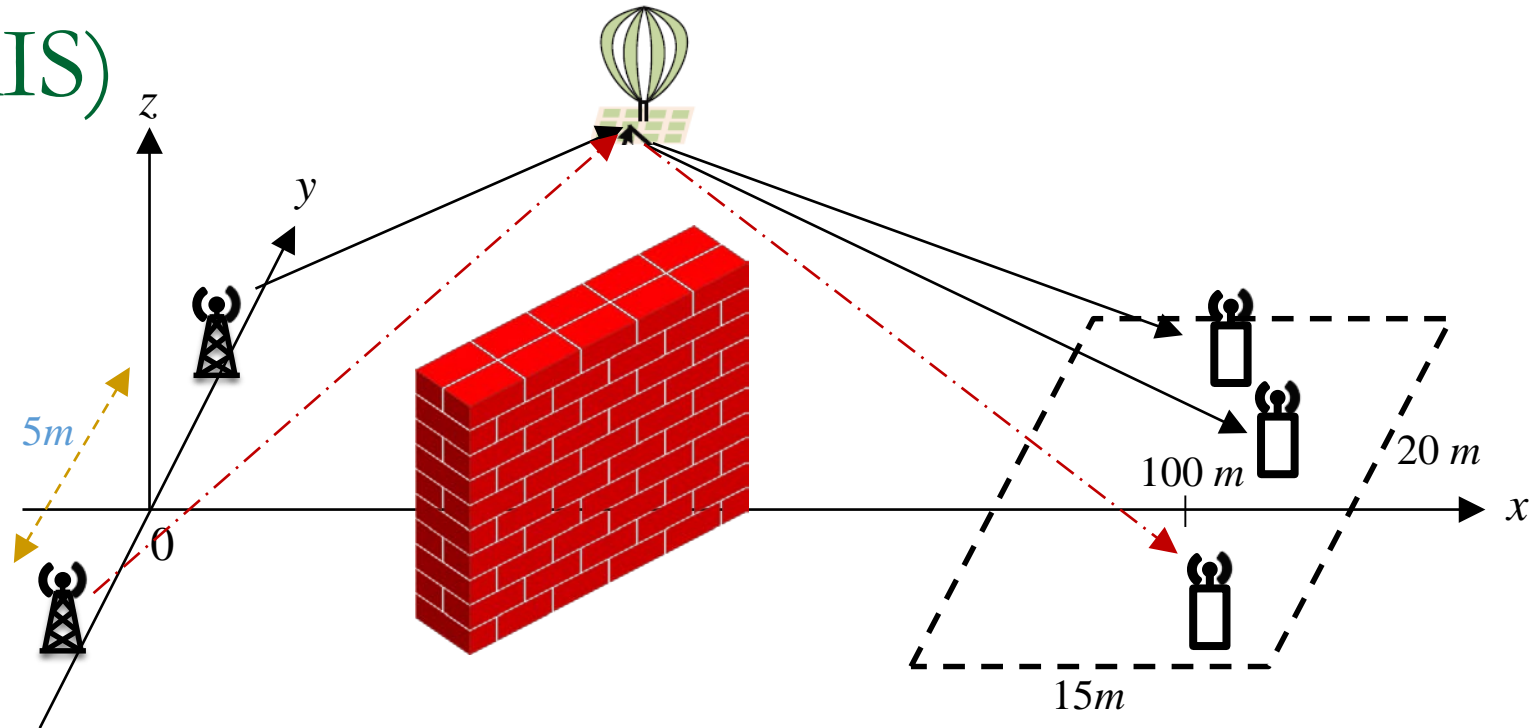
1. (Digital) **Precoding**, with **holographic meta antenna array (HMA)**, can serve users at different **directions** and **distance**, called **beamfocusing**
2. Possible architecture: RF chain only supply to each microstrip that contains **closely spaced antenna elements**
 - Increase in **mutual coupling**



1. Cell-free HMIMO systems will require different HMA access points (APs) to simultaneously serve multiple users
 - Distributed precoding design, perhaps using multiagent RL
2. Scalability issue

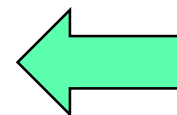


Aerial Intelligent Reconfigurable Surface (AIRS) and Reflective Intelligent Surface (RIS)



T. Chao, **C.C. Fung**, Z.-E. Ni and M. Servetnyk, “Joint beamforming and aerial IRS positioning design for IRS-assisted MISO system with multiple access points,” *IEEE Open Journal of the Communications Society*, vol. 5, pp. 612-632, Dec. 2023. <https://ieeexplore.ieee.org/document/10373864>.

A.M. Huroon, Y.-C. Huang, **C.C. Fung** and L.-C. Wang, “Generalized Bender’s Decomposition (GBD) for reconfigurable intelligent surface-assisted transmission strategy problem”, *Proc of the IEEE VTS Asia Pacific Wireless Communications Symposium (VTS-APWCS)*, Seoul, Korea, Aug. 2022. <https://doi.org/10.1109/APWCS55727.2022.9906491>



Potential Problems

- **Multiview and Multilayer attribute graph clustering**
 - Different graph and/or attribute views describing the same phenomenon
- **Online attribute graph clustering**
 - Model agnostic meta learning (MAML)
- **Kernel regression on multiview graphs of Gaussian (Splat) nodes**
 - Capture their spatial relationship for 3D image reconstruction
 - How to combine the different views?
- **Online graph learning**
 - Score-guided DDIM tracker?
- **Robust federated learning in heterogeneous networks**
 - Communications side: RSMA-based latency rebalancing scheme
 - Learning side: Model agnostic federated learning
- **Score-guided DDIM-based modal-domain channel tracking for**
 - Wideband channels
 - Hybrid-field channels
- **(Mutliagent) Deep reinforcement learning based hybrid robust beamforming and beamfocusing for holographic (ultra-large) MIMO (HMIMO) systems**
- **Mutual coupling-aware wideband RIS beamforming using varactor-based RIS**
 - Provide continuous phase shifts



What skills are required/learned to be successful?

- Good in mathematics and programming
 - Linear algebra, optimization, statistics, Matlab+Python/Julia
- Willingness and courage to explore and learn new (cross-disciplinary) subjects
- Ingenuity
- Be vocal, especially with your adviser



THEN MY GROUP IS FOR YOU!!!

Stop by and talk to me (ED 639)!

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or Google “Carrson Fung”

