Toward Unifying Communication-Computation-Storage in Parallel Data Systems

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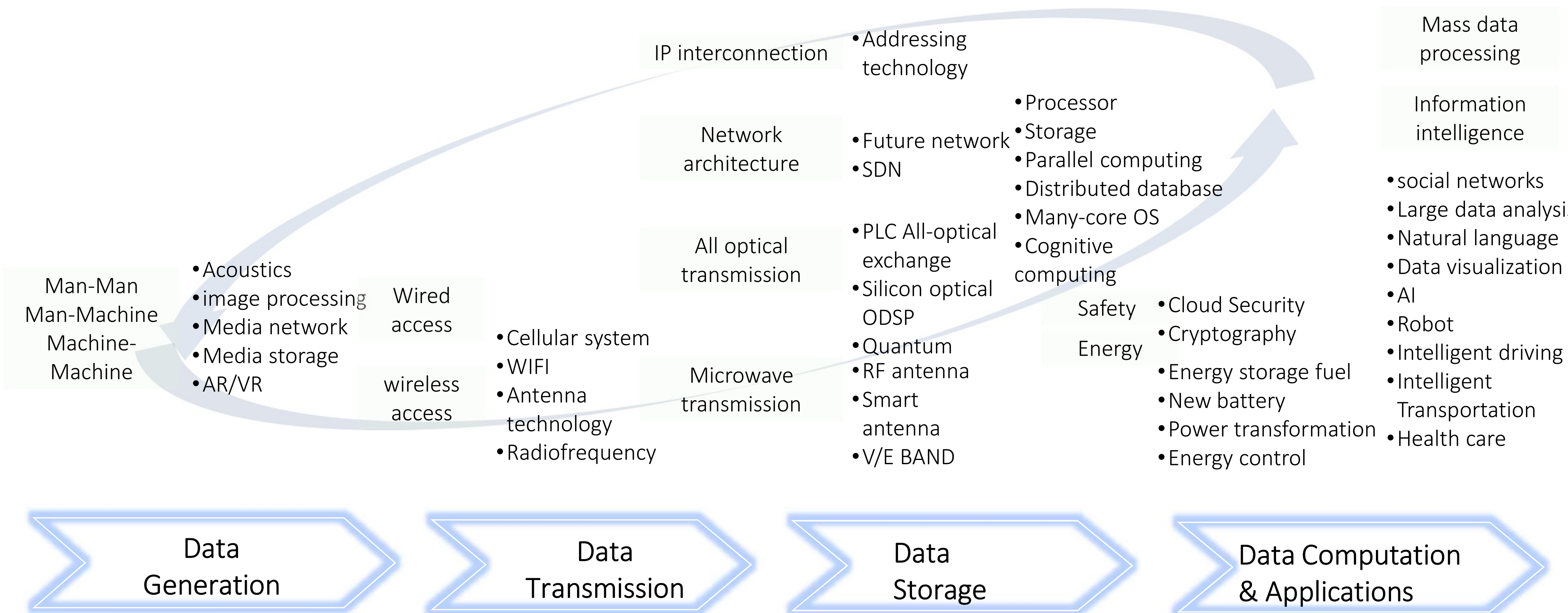
Scope: Full Coverage across Data Life Cycle



Challenge: Theoretical framework to the never-ending quest for higher performance?

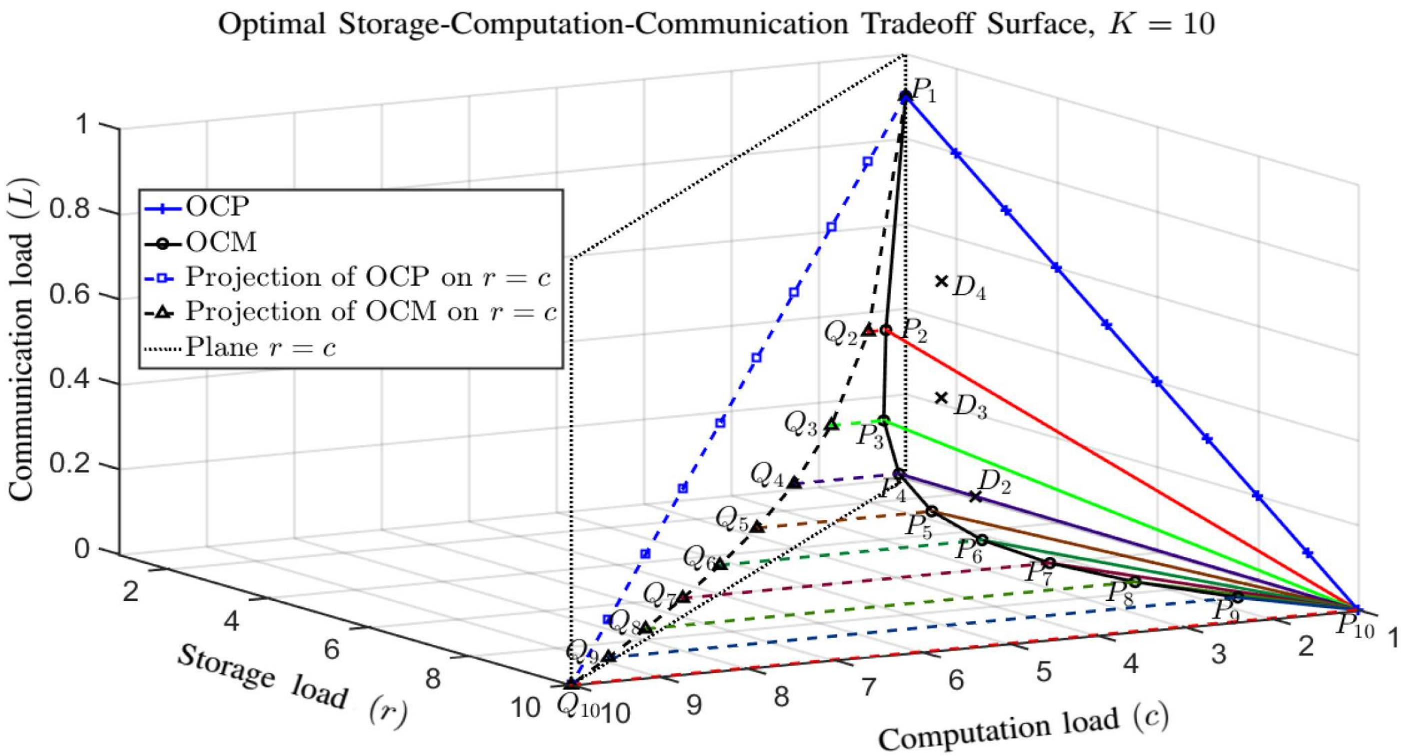


Fig. 3: The fundamental SCC region $\mathcal{R}$ for a system with $K = 10$ nodes. The figure illustrates the delimiting surface $\mathcal{F}$ formed by the triangles $\triangle P_1 P_2 Q_2$ and $\{\triangle P_{i-1} P_i P_K\}$ and the trapezoids $\{\boxminus P_i Q_i Q_{i+1} P_{i+1}\}$. The three points D_2, D_3, D_4 can be achieved by the new PDA design.

Ref: Qifa Yan, Sheng Yang, and Michele Wigger, Sept. 2019

From Systematic Tradeoffs to Theoretical Unification

Communication-Computation-Storage (CCS) Tradeoff Framework

- **Problem Model**: *Define the class of problems under study, in terms of major components, common pipelines, basic operations, etc.*
- **Tradeoff Space**: *A 3-dimensional space consisting of the following axis, where each axis represent one factor for tradeoff and a quantitative measurement of cost:*
  - *L-Axis: Communication Cost*
  - *C-Axis: Computation Cost*
  - *R-Axis: Storage Cost*

  *The **feasible region** refers to the subspace of the whole tradeoff space, where points are achievable by certain tradeoff algorithms.*
- **Tradeoff Algorithms**: *Each tradeoff algorithm is a refinement of the abstract problem model, implementing the common pipeline with algorithm-specific details. Each tradeoff algorithm, with each parameter fixed, gives a point in the tradeoff space, whose coordinates are the cost of that algorithm along each dimension.*
- **Tradeoff Optimality**: *Results about optimality of tradeoff algorithms, in particular the boundary of the feasible region, called the **Optimal Tradeoff Surface**, which represents what the best tradeoff algorithm can achieve.*

Multi-Party Tradeoff Framework

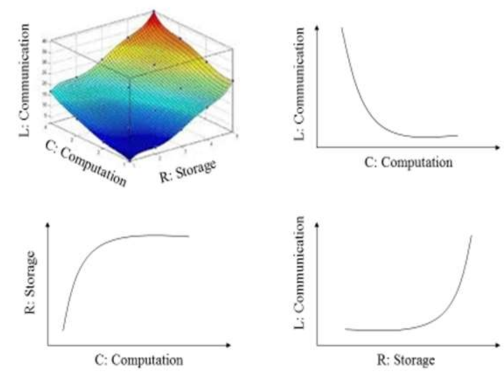
- **Problem Model**: *The same as CCS framework.*
- **Tradeoff Space**: *Similar to CCS framework, except for having K (K>1) dimensions instead of 3 dimensions:*
  - $X^{(1)}$-Axis, $X^{(2)}$-Axis, …, $X^{(K)}$-Axis,
- **Tradeoff Algorithms**: *The same as CCS framework.*
- **Tradeoff Optimality**: *Similar to CCS framework, except for the **Optimal Tradeoff Hyper-surface** instead of Optimal Tradeoff surface.*

Definition-1 (Monotonic Hyper-Surface): Given a (k-1)-dimensional hyper-surface Σ embedded in a k-dimensional space Ω (k>2), Σ is monotonic if one of the following conditions holds: (1) k=2 and the curve Ω is either non-increasing or non-decreasing in any dimension; or (2) k>2 and fixing any dimension at an arbitrary valid value, the resulting (k-2)-dimensional hyper-surface is monotonic.

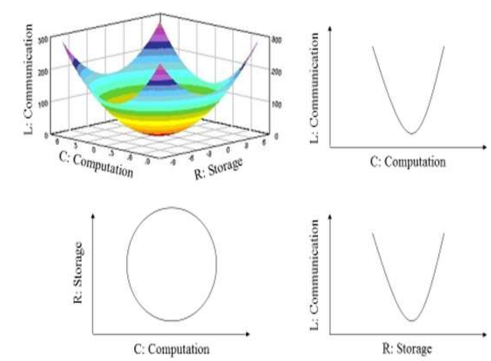
Theorem-1: *For any multi-party tradeoff framework, the joint optimal hyper-surface exists if one of the individual optimal hyper-surface exists and is monotonic.*

Theorem-2: *Super Optimal Tradeoff is achievable iff the coordinate origin is within the **feasible region**.*

Monotonic surface (top) vs convex surface (bottom)



monotonic surface.



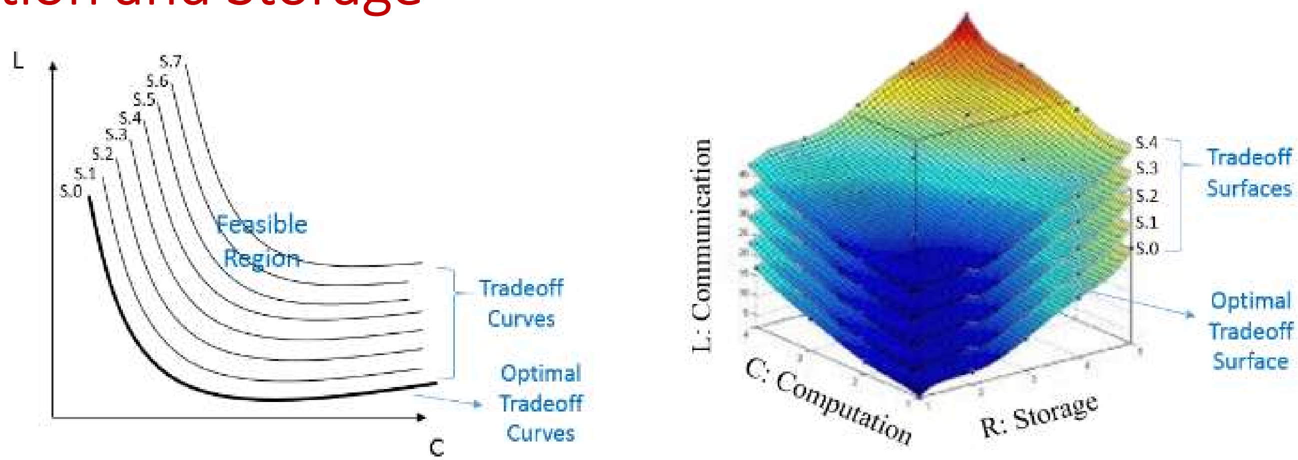
convex surface.

Exists Fundamental Theory of Unified interpretation for Communication, Computation and Storage

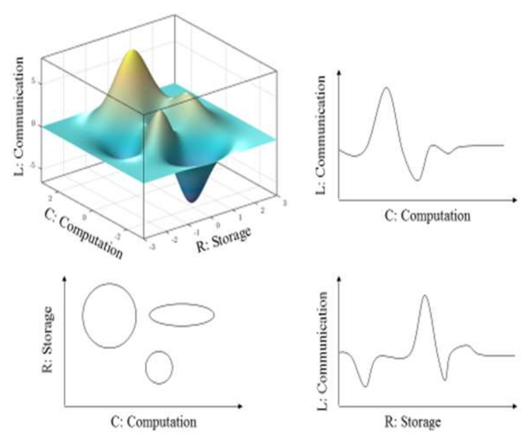
Claim-1:
Super Optimal Tradeoff is not achievable in most cases (but works with MR, PS, DHT caching, etc)

Theorem-2:
Super Optimal Tradeoff is achievable if and only if the coordinate origin is within the feasible region.

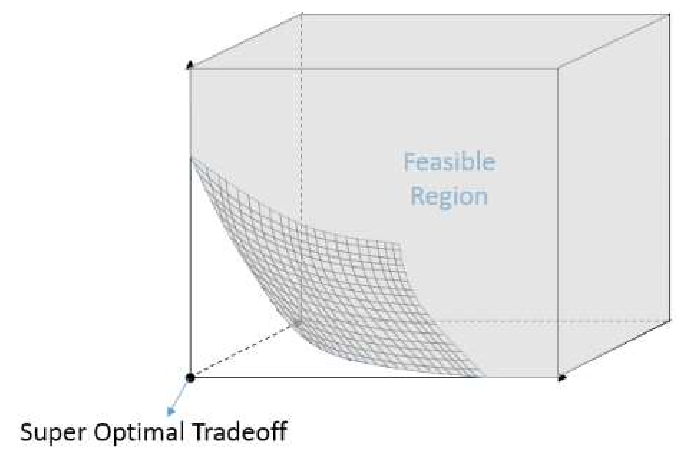
Conjecture-1:
There exists a fundamental theory that provides a unified interpretation for Communication, Computation and Storage



Foliation in 2D (left) and 3D (right) tradeoff space.



general surface.



Super optimal tradeoff outside of the feasible region.

Thanks!