Pareto optimality reveals the core computations of the human brain

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Abstract

The human brain supports complex behaviors through diverse functional connectivity patterns. We propose Pareto optimality as a novel framework to understand this functional organization. According to Pareto theory, systems optimizing multiple competing goals do so by balancing trade-offs along a low-dimensional "Pareto front" defined by archetypes that each optimize a single goal. Applying Pareto analysis to resting-state fMRI data (HCP, N=1200), we found that individual connectomes lie on a low-dimensional triangle. The three archetypes represent core computational goals: minimizing energetic cost, supporting cognitive control and goal-directed behavior, and enabling internal processing and memory. These goals are reflected in connectivity patterns, network topology, information flow, behavioral and clinical associations. The framework generalizes beyond rest to task-based brain states, and a simple neural model illustrates the trade-offs' computational basis. Pareto optimality offers a principled approach to decompose brain function into core computations across conditions, populations, and stages of life.

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