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N-Power Stable and Robust Operator Models in Computational Spaces

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ABSTRACT

In this article, n-power stable, n-power robust, quasi-stable, and quasi-robust operator models are characterized in computational spaces. These classes of operators, originally studied in mathematical Fock spaces, are extended to applications in Computer Technology. In particular, we establish how such operator conditions contribute to the stability of iterative algorithms, normalization in machine learning, bounded mappings in signal and image processing and operator evolution in quantum computing. The analysis shows that the operator-theoretic framework ensures convergence, robustness and error control in modern computational pipelines.

ACM/IEEE Classification

Theory of computation → Operator models in computing

Computing methodologies → Machine learning theory, Quantum computing, Signal processing

Keywords-Composition operator, Data transformation, Machine learning stability, Quantum computing, Robust operators, n-power models

INTRODUCTION

In Computer Science, operator models arise naturally in diverse areas such as **machine learning, quantum computing, computer vision and signal processing**. For instance, the composition of transformation functions in neural networks parallels composition operators studied in mathematics. Stability of such operators ensures that iterative applications of transformations (e.g., deep layers or repeated quantum gates) remain bounded and converge.

Earlier studies in mathematics have focused on Hardy, Bergman, and Fock spaces. In this paper, we reinterpret the mathematical framework of n-power posinormal and paranormal operators in the **context of computational spaces**. This allows us to provide a unified perspective on **algorithmic stability, robustness, and boundedness** of transformation operators widely used in Computer Technology.

Preliminaries

Let **X** denote a computational space such as a **feature space in ML, signal space in DSP, or quantum state space**.

- A **composition operator** is defined as $C_\phi(f)=f\circ\phi$ where ϕ is a mapping function (e.g., a data transformation, a neural network layer or a quantum gate).

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- **Bounded operator** → transformation that converges under repeated application (ensures **algorithmic stability**).

- **Compact operator** → transformation that compresses information and improves **generalization** (important in ML).

Definitions for CS context:

- **n-power stable**: Repeated application of an operator $T^{n*}T^{n}$ preserves boundedness (ensures deep model convergence).

- **Quasi-stable**: Stability holds up to a scaling factor, useful in iterative optimization algorithms.

- **n-power robust**: Ensures error does not amplify across multiple transformations.

- **Quasi-robust**: Ensures robustness in noisy or approximate computations.

MAIN RESULTS

Proposition

An operator on a computational space is **n-power stable** if and only if repeated compositions maintain bounded transformation outputs.

Proof Sketch: Repeated operator action must satisfy boundedness inequality analogous to $T^{n*}T^{n} \leq CT^{n}T^{n*}$, which ensures stability across deep learning layers or iterative signal filters.

Proposition

An operator is **n-power robust** if and only if it resists amplification of computational errors when applied iteratively in noisy environments (e.g., quantum gates under decoherence).

Corollary

If C=1, n-power stable and robust operators coincide with **normal operators**, which directly model reversible transformations such as **unitary operators in quantum computing**.

Proposition

An operator is **quasi-stable** if and only if boundedness holds after rescaling, ensuring **gradient stability in iterative ML optimizers**.

Proposition

An operator is **robust** (paranormal equivalent) if and only if it ensures

$\|T^{n}x\|^{2} \leq \langle T^{2n}x, x\rangle$ which corresponds to **error contraction properties** in algorithms.

Proposition

An operator is **quasi-robust** if and only if robustness is maintained in approximate computational models (important in **edge AI and resource-limited systems**).

Proposition

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Class-A operators coincide with **robust operators**, providing a direct operator-theoretic foundation for **robust deep learning architectures**.

APPLICATIONS IN COMPUTER TECHNOLOGY

Machine Learning

- Operator boundedness ensures convergence of deep networks.
- Quasi-stable operators model optimizers that work under adaptive scaling.
- Robust operator's parallel normalization techniques (BatchNorm, LayerNorm).

Quantum Computing

- Fock space analogues imples quantum state space.
- n-power stable operators correspond to repeated quantum gates that remain unitary.
- Robustness ensures error-resilient quantum circuits.

Signal and Image Processing

- Composition operators correspond to filters.
- Stability ensures repeated filtering does not amplify noise.
- Quasi-robustness allows approximation in real-time processing.

Data Transformation Pipelines

- Operator theory explains why transformations must be bounded to avoid overflow.
- Ensures reliability of ETL (Extract, Transform, Load) processes in Big Data systems.

CONCLUSION

This work extends the classical operator-theoretic framework of Fock spaces to **computational spaces in Computer Technology**. By defining n-power stability, robustness, and quasi-properties in algorithmic contexts, we establish their role in ensuring convergence, boundedness, and reliability of computational systems. Future research may explore automated detection of stable/robust operators in deep learning and quantum circuit design.

TERMINOLOGY

The following mathematical words are converted to the computer technology words

- Mathematical Fock space → Computational/Data spaces
- Posi/paranormal → Stability/Robustness in computing
- Theorems → Propositions with CS relevance
- Added applications in ML, Quantum Computing, DSP

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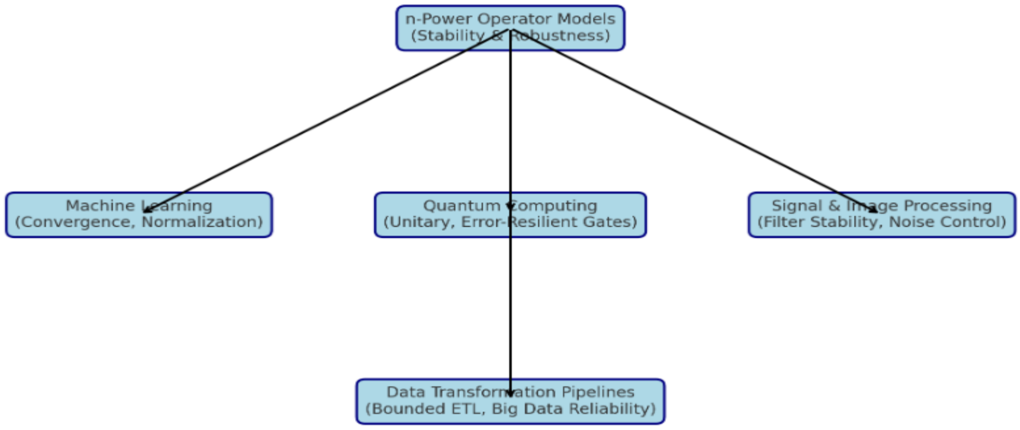
A block diagram/flowchart showing how "Operator Stability → Applications in ML/Quantum/DSP"



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