ROLE OF AI IN GNSS

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Institute of Navigation – Alberta Section
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University of Calgary

INTRODUCTION

- Reports of **AI's influence range from wonderful to existential** – **evolving impact** on specific industrial sectors and society is **far from clear**
- History as a guide – **predictions tend to be wrong**
- **Attempts to use AI** – to improve GNSS technological performance
- Specific AI algorithms – **successfully used to make specific improvements**
- **Slow introduction of AI in GNSS** and PNT – compared to other fields of geomatics
- **Trends** – summarized
- **Recommendations** – provided

GLOBAL NAVIGATION SATELLITE SYSTEM LABORATORY

- Established in 2006 in Geomatics Engineering at Department of Earth and Space Science and Engineering
- Professor Bisnath has 30 years of GNSS research and applications experience
- *GNSS **measurement error mitigation***
- *GNSS **measurement processing** for positioning, navigation and timing (**PNT**)*
- ***Sensor fusion***
- *Scientific / engineering / mass market **applications***
- *PNT **resilience***
- *Application of **AI***

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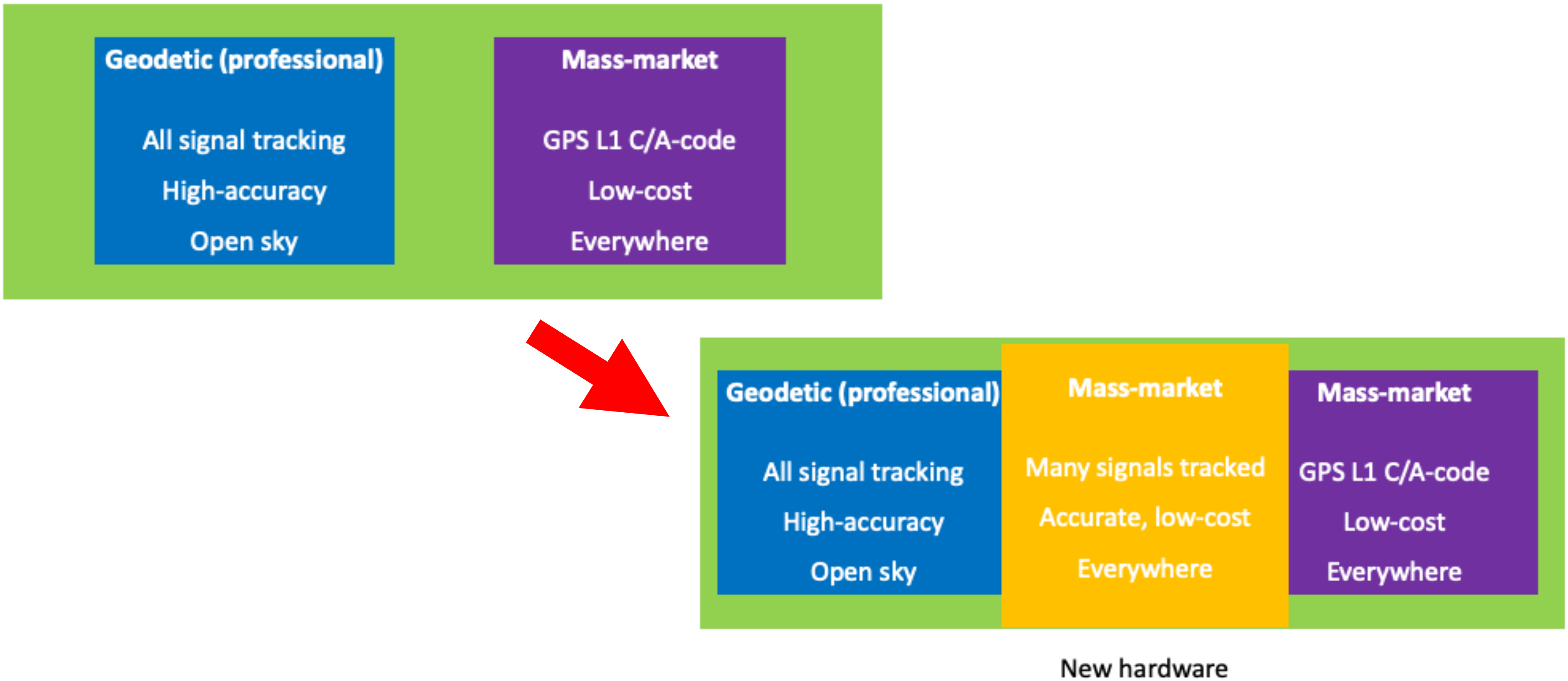
EXISTING AND CHANGING "DUALITY" OF GNSS USAGE



(Bisnath, 2020, *IEEE/ION PLANS*)

AUTONOMOUS AUTOMOBILE PREDICTIONS ...

June 1940 issue of Popular Science

https://clickamericana.com/topics/science-technology/future-predictions-from-mid-20th-century-retro-futurism

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Self-driving cars

This article is more than **8 years old**

Twelve things you need to know about driverless cars

By 2025 most of today's drivers are unlikely to even want to own a car. But will we still have gridlock? Will you need to pass a test? We asked the experts

James Silver

Sun 15 Jan 2017 07.30 GMT

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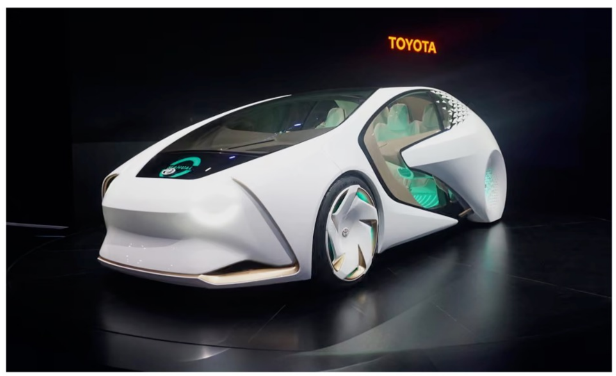

The Toyota Concept-i vehicle at the 2017 International Consumer Electronics Show in Las Vegas, on 5 January 2017. Photograph: Mike Nelson/EPA

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- Four countries to boycott Eurovision 2026 as Israel cleared to compete
- Student describes 'horror show' ICE deportation to Honduras at Thanksgiving

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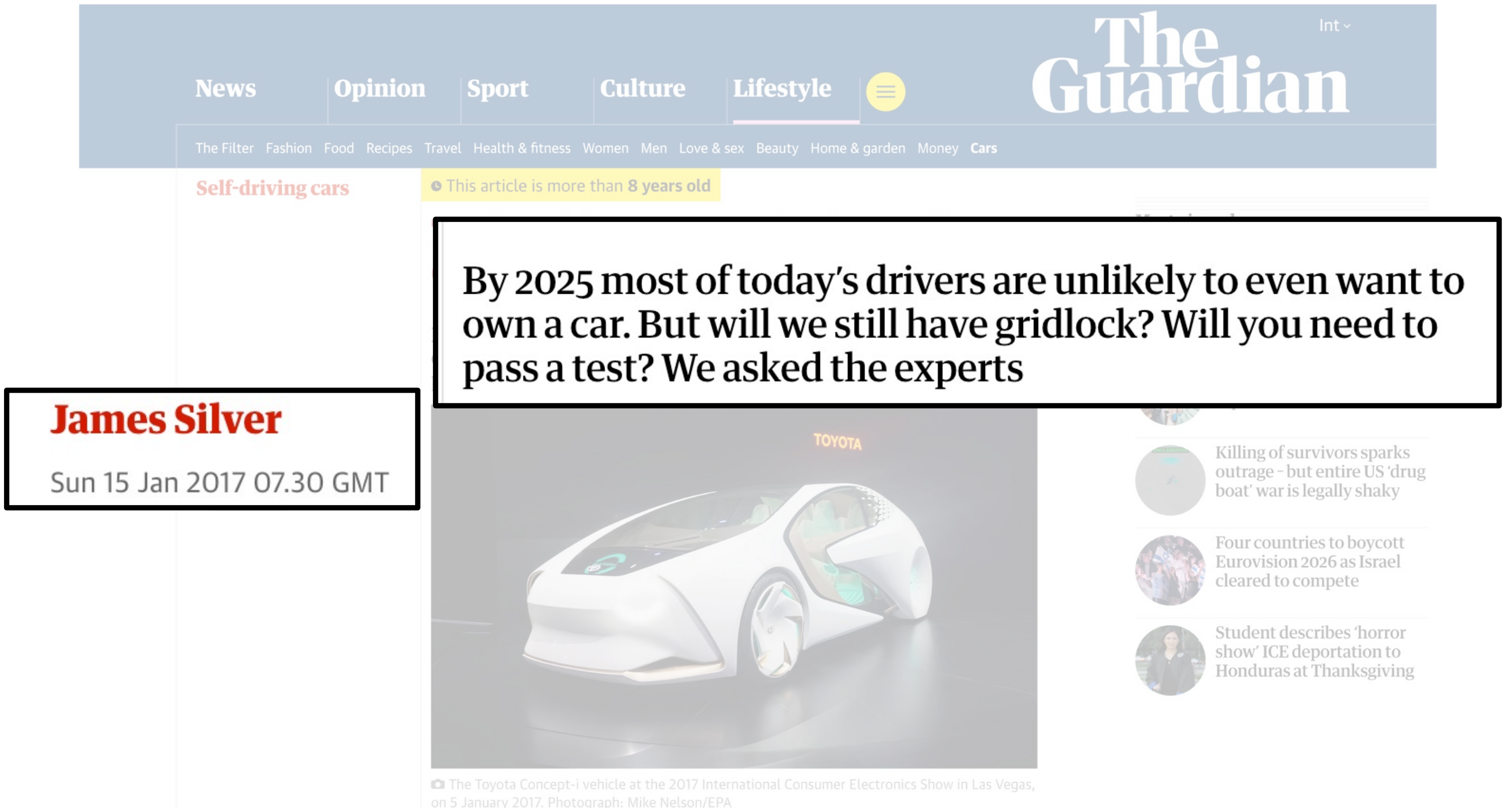
AUTONOMOUS AUTOMOBILE PREDICTIONS …



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AUTONOMOUS AUTOMOBILE AND AI PREDICTIONS

The current state of the AI debate:

On-line meme, Why Tech Predictions Always Miss the Mark | Ignacio Ramirez Moreno

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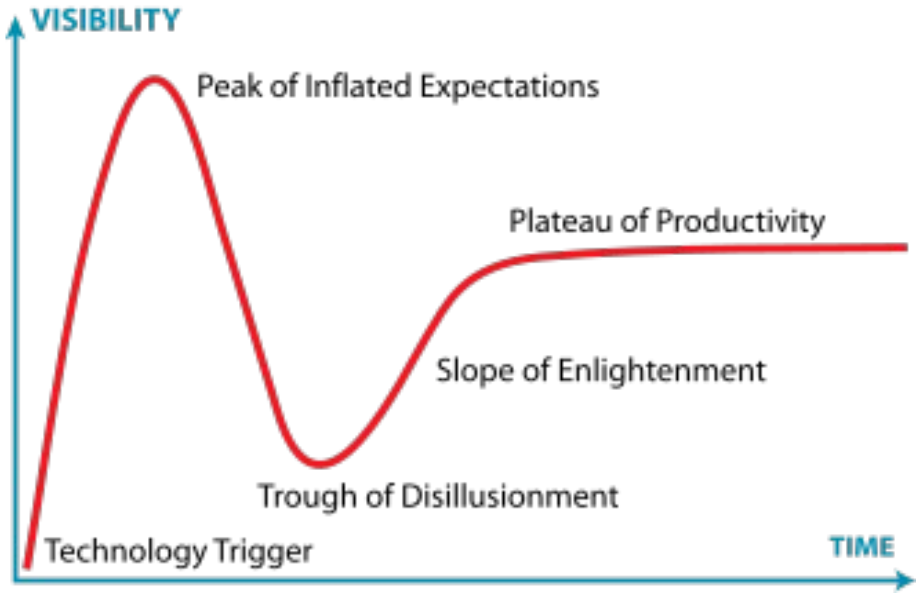
NEW TECHNOLOGY DEVELOPMENT CURVE



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

Gartner hype cycle: graphical representation of maturity, adoption and social application of specific technologies

Hype cycle's veracity disputed, with studies pointing to it being inconsistently true at best

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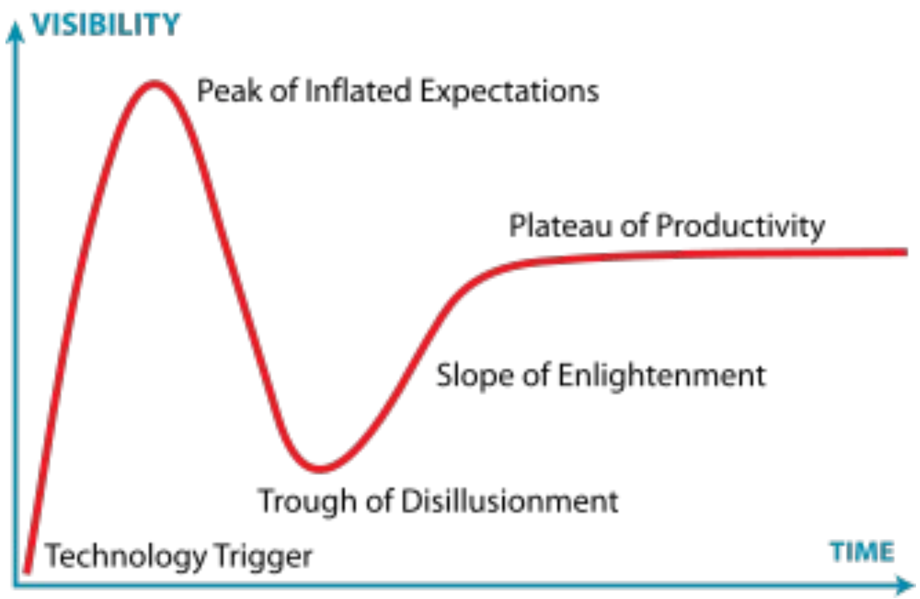
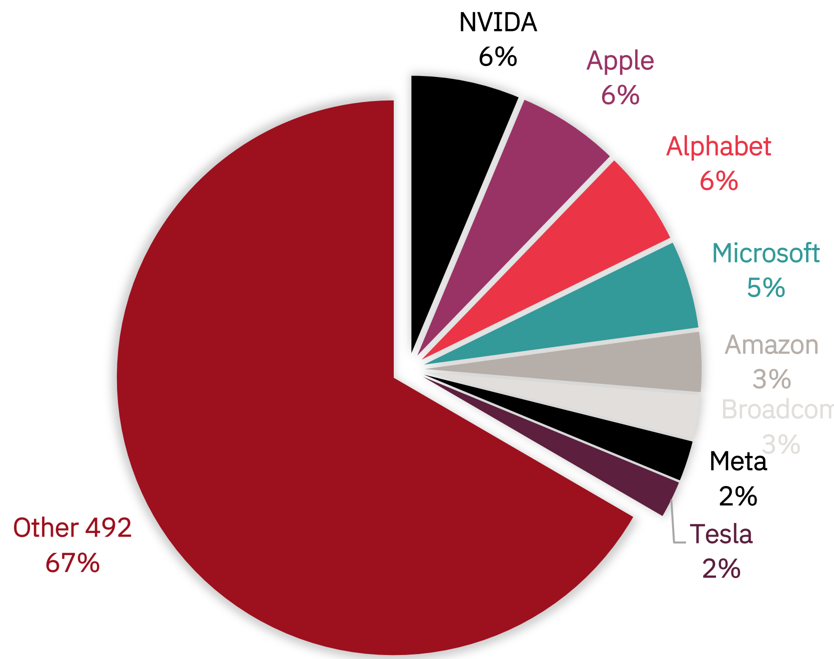


https://en.wikipedia.org/wiki/Gartner_hype_cycle

https://techcrunch.com/2012/04/01/the-market-curve-the-life-cycle/

TOP OF THE STOCK MARKET

Company	Market capitalization (Trillions USD)
NVIDA	6.2
Apple	5.8
Alphabet	5.4
Microsoft	5.0
Amazon	3.4
Broadcom	2.5
Meta	2.3
Tesla	2.1
Other 492	***65.3***
TOTAL	**98**



Largest companies by market capitalization S&P 500 - Dec 4th, 2025

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llustration by Peter Crowther for TIME

Painting by Jason Seiler for TIME

OMINOUS PREDICTIONS FOR AI

https://www.unite.ai/has-ai-taken-over-the-world-it-already-has/

NEGATIVE AI EFFECTS IN RESEARCH


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Artificial intelligence (AI)

Artificial intelligence research has a slop problem, academics say: 'It's a mess'

AI research in question as author claims to have written over 100 papers on AI that one expert calls a 'disaster'

Aisha Down
Sat 6 Dec 2025 15.00 GMT
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The author, Kevin Zhu, now runs Algoverse, an AI research and mentoring company for high schoolers. Photograph: Cavan Images/Alamy

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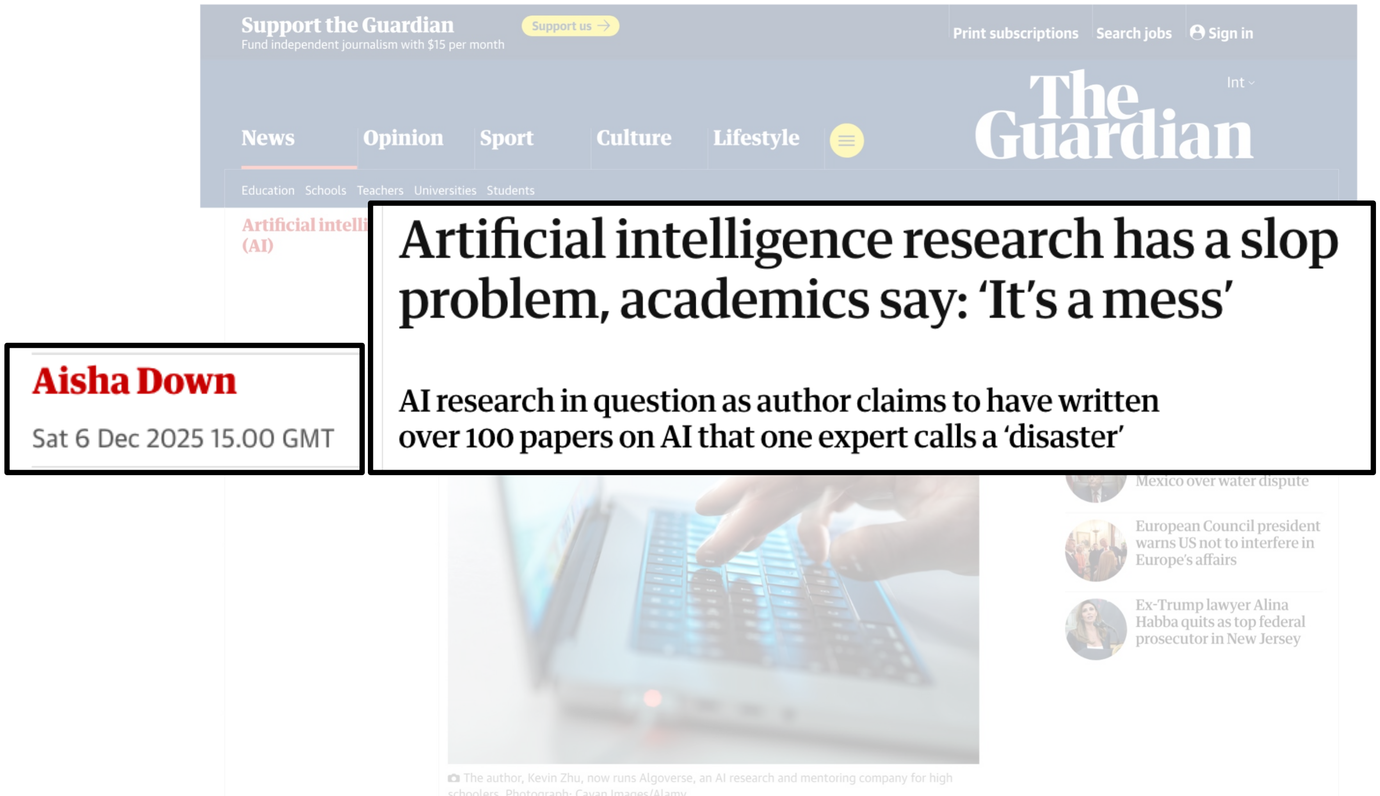
NEGATIVE AI EFFECTS IN RESEARCH



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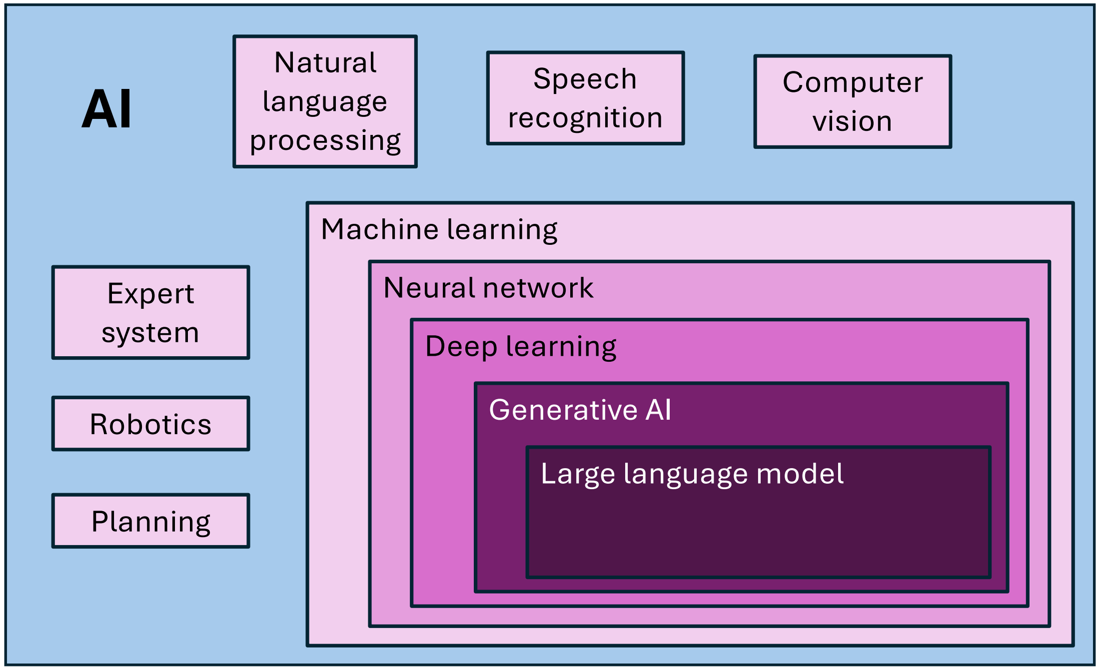
The author, Kevin Zhu, now runs Algoverse, an AI research and mentoring company for high schoolers. Photograph: Cavan Images/Alamy

Mexico over water dispute

European Council president warns US not to interfere in Europe's affairs

Ex-Trump lawyer Alina Habba quits as top federal prosecutor in New Jersey

CONCEPTS WITHIN / SUBSETS OF AI



(Bisnath, 2025, *GPS World*)

TYPES OF MACHINE LEARNING MODELS AND TRAINING ALGORITHMS

Supervised learning

Data scientists provide input, output and feedback to build model (as the definition).

EXAMPLE ALGORITHMS:

Linear regressions
- Sales forecasting.
- Risk assessment.

Support vector machines
- Image classification.
- Financial performance comparison.

Decision trees
- Predictive analytics.
- Pricing.

Unsupervised learning

Use deep learning to arrive at conclusions and patterns through unlabeled training data.

EXAMPLE ALGORITHMS:

Apriori
- Sales functions.
- Word associations.
- Searcher.

K-means clustering
- Performance monitoring.
- Searcher intent.

Artificial neural networks
- Generate new, synthetic data.
- Data mining and pattern recognition.

Semi-supervised learning

Builds a model through a mix of labeled and unlabeled data, a set of categories, suggestions and exampled labels.

EXAMPLE ALGORITHMS:

Generative adversarial networks
- Audio and video manipulation.
- Data creation.

Self-trained Naïve Bayes classifier
- Natural language processing.

Reinforcement learning

Self-interpreting but based on a system of rewards and punishments learned through trial and error, seeking maximum reward.

EXAMPLE ALGORITHMS:

Q-learning
- Policy creation.
- Consumption reduction.

Model-based value estimation
- Linear tasks.
- Estimating parameters.

Ensemble learning

Combination of other models.

https://www.techtarget.com/searchenterpriseai/tip/Types-of-learning-in-machine-learning-explained

WHY THE SLOW ADOPTION OF AI IN GNSS?

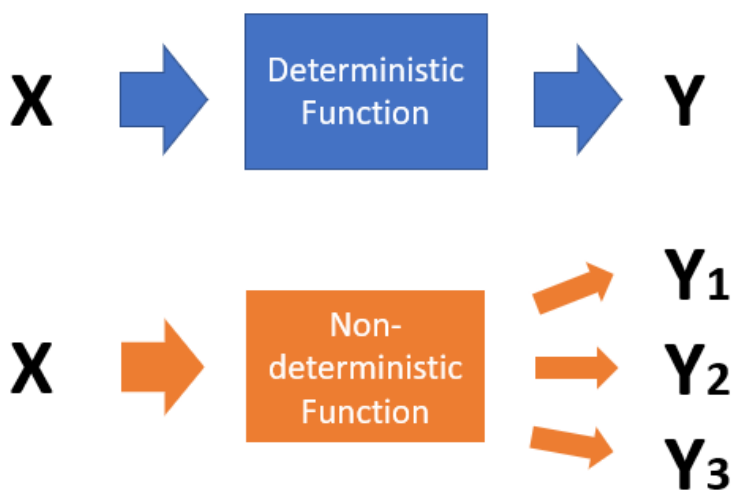
- Over past decade:
  - ML has been adopted in, and has transformed, many areas of Geomatics
  - e.g., photogrammetry, remote sensing, GIS
  - And merged with computer science approaches, e.g., computer vision, SLAM, geospatial data analytics

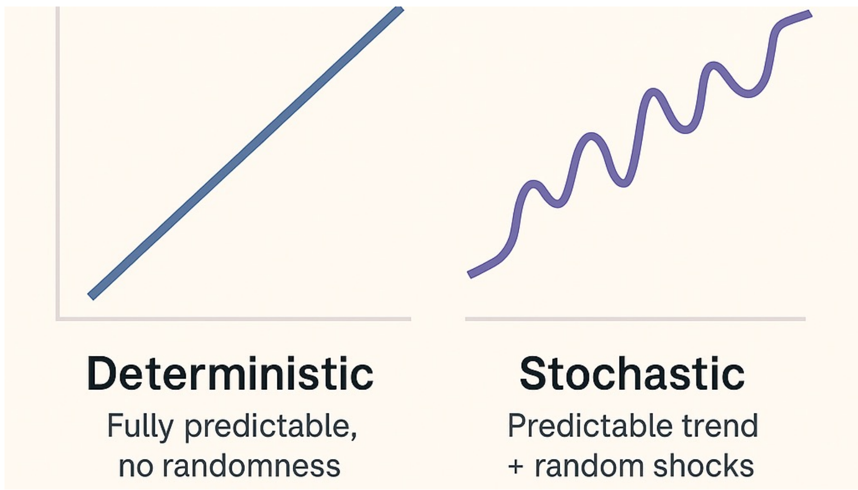
- **Classical PNT optimal estimation techniques have served GNSS community well**

- **GNSS problems tend to be “well-defined” and “well-behaved” compared to other Geomatics problems**

- **Geodesists have long history of physics-based solutions – resistance to AI**

DETERMINISTIC VERSUS NON-DETERMINISTIC VERSUS STOCHASTIC





https://www.statisticshowto.com/deterministic-function-nondeterministic/

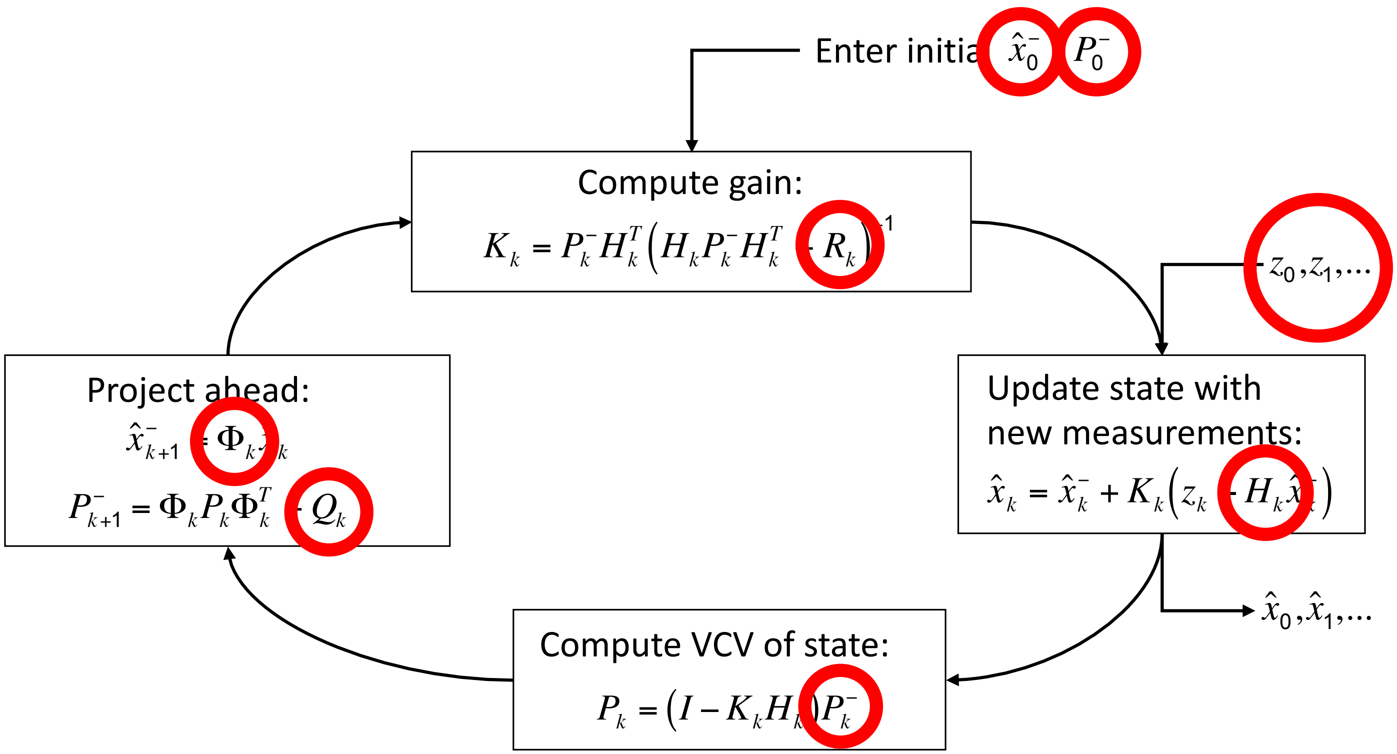
https://www.linkedin.com/pulse/why-arima-models-always-carry-error-term-vs-explained-krish-naidu--sgtuc

HOW ARE WE MODELLING MEASUREMENTS IN GNSS?

$$P_{r,1}^{s}\left(t_r\right) = \rho_r^s\left(\hat{t}^{\,s}\right) + c\left(dt^s - dt_r\right) + dT_r^s\left(t_r\right) + dI_{r,1,P}^s\left(t_r\right) + dm_{r,1,P}^s + dh_{1,P}^s + dh_{r,1,P} + \varepsilon_{1,P}$$

$$\Phi_{r,1}^{s}\left(t_r\right) = \rho_r^s\left(\hat{t}^{\,s}\right) + c\left(dt^s - dt_r\right) + dT_r^s\left(t_r\right) - dI_{r,1,\Phi}^s\left(t_r\right) + \lambda_1 N_r^s$$
$$+ dm_{r,1,\Phi}^s + dh_{1,\Phi}^s + dh_{r,1,\Phi} + \varepsilon_{1,\Phi}$$

HOW ARE WE ESTIMATING UNKNOWN STATES IN GNSS?



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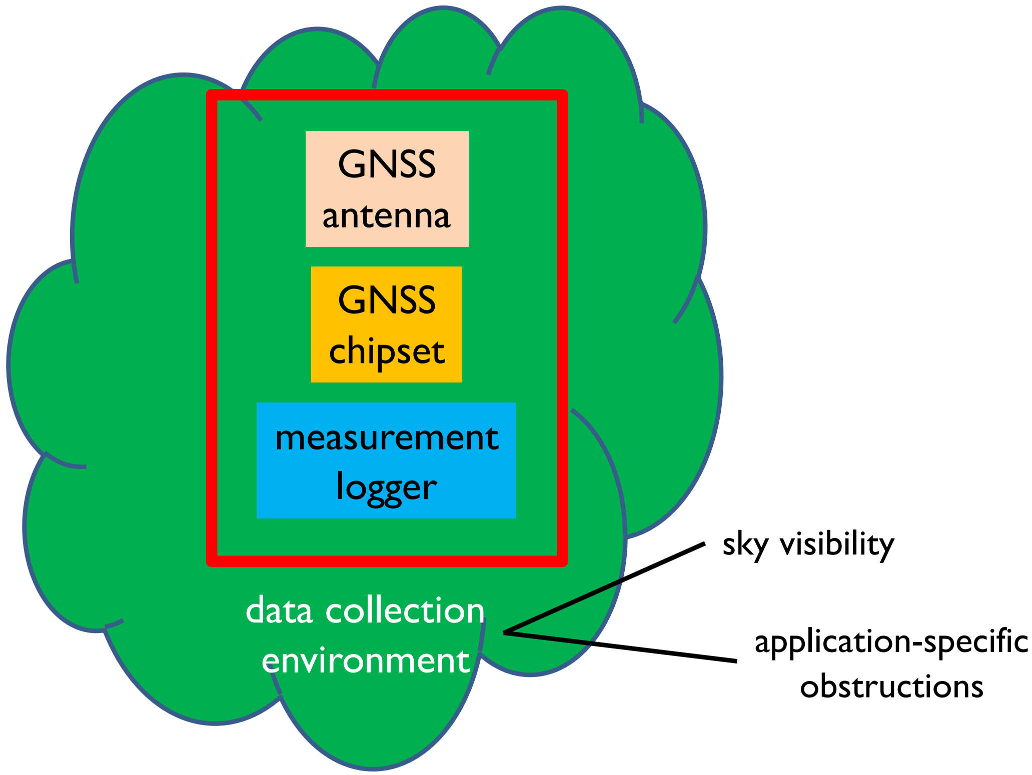
OVERALL PROBLEM STATEMENT FOR SMARTPHONE GNSS MEASUREMENTS



(Bisnath and Aggrey, 2024, *ION ITM*)

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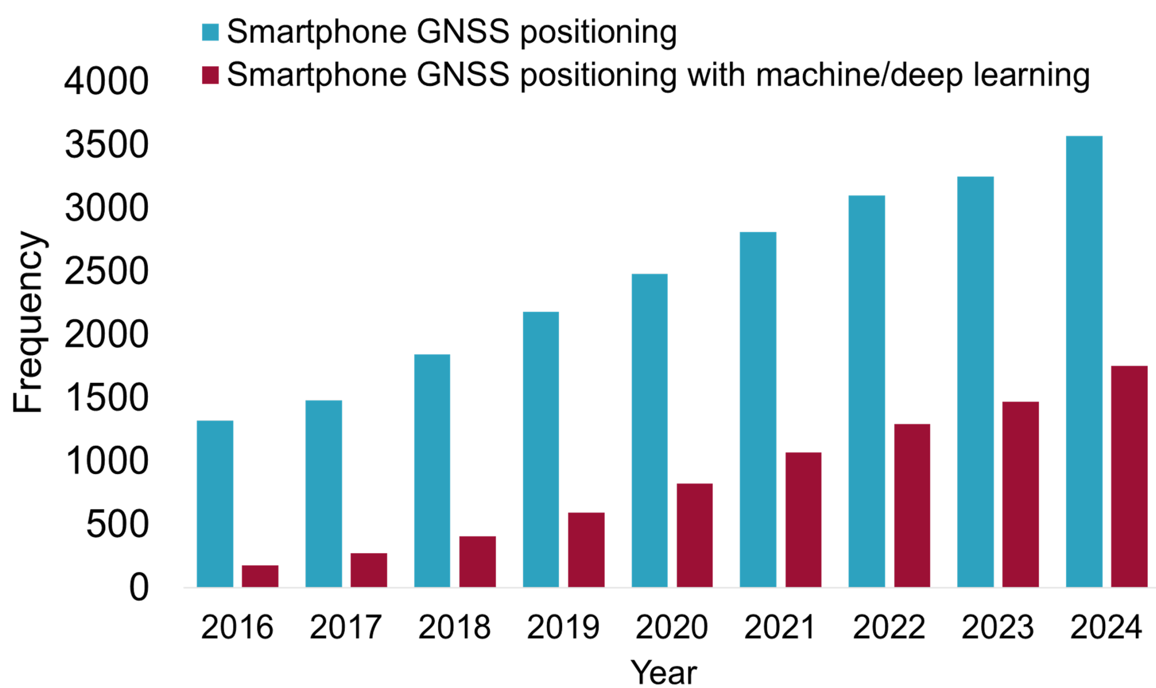
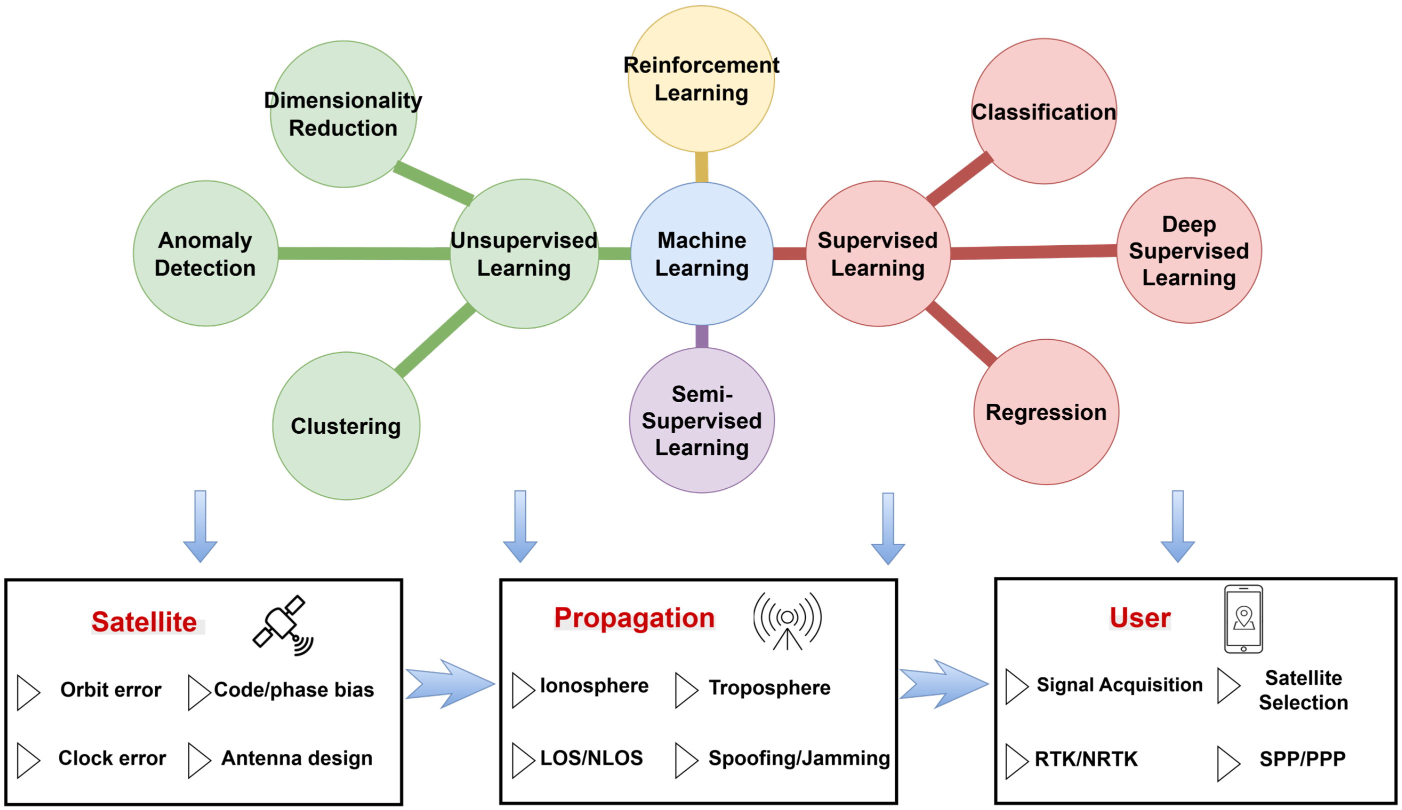
GROWTH OF SMARTPHONE GNSS ML PUBLICATIONS

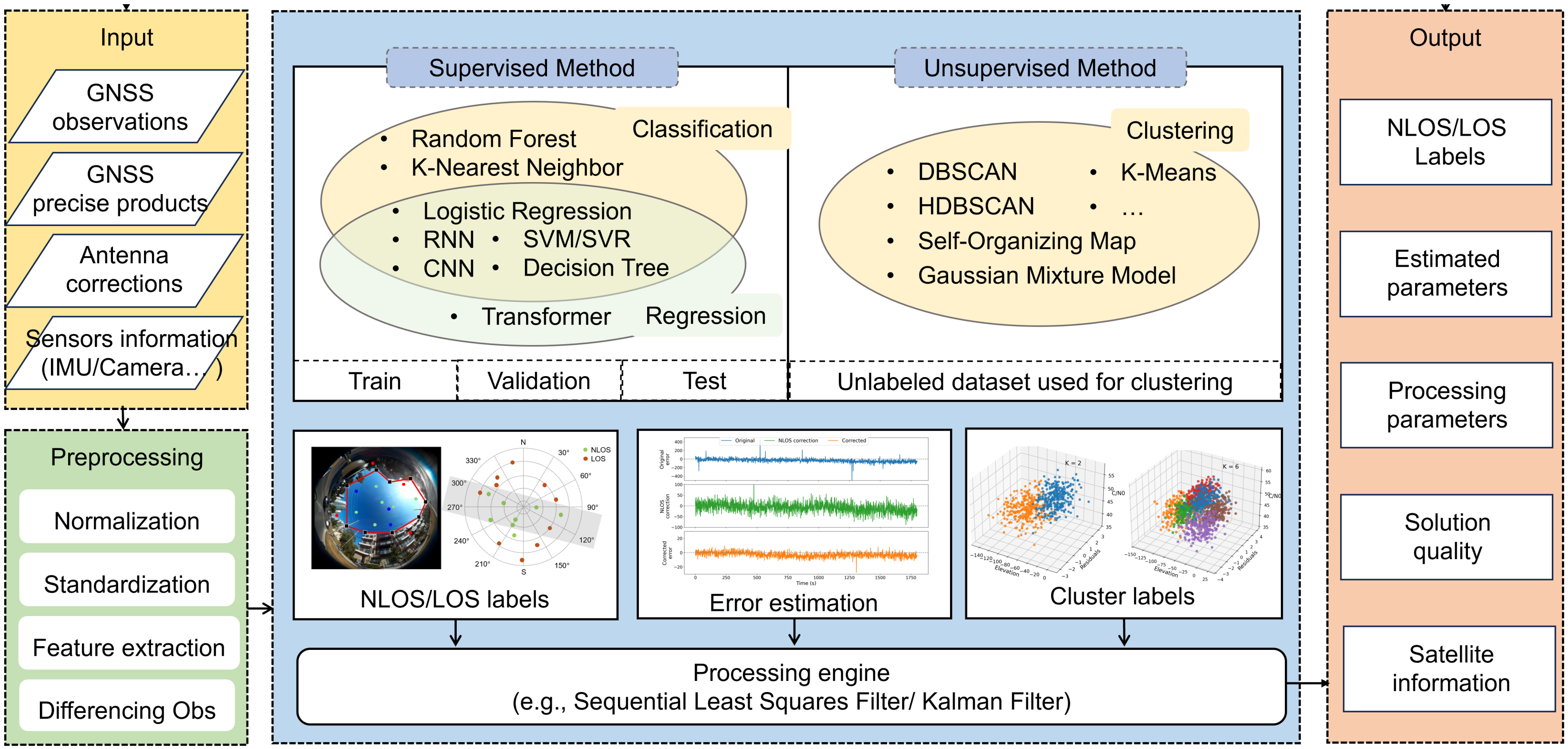


Keyword frequency on Google Scholar, 2016-2024
Data retrieved on: 9th Jun 2025

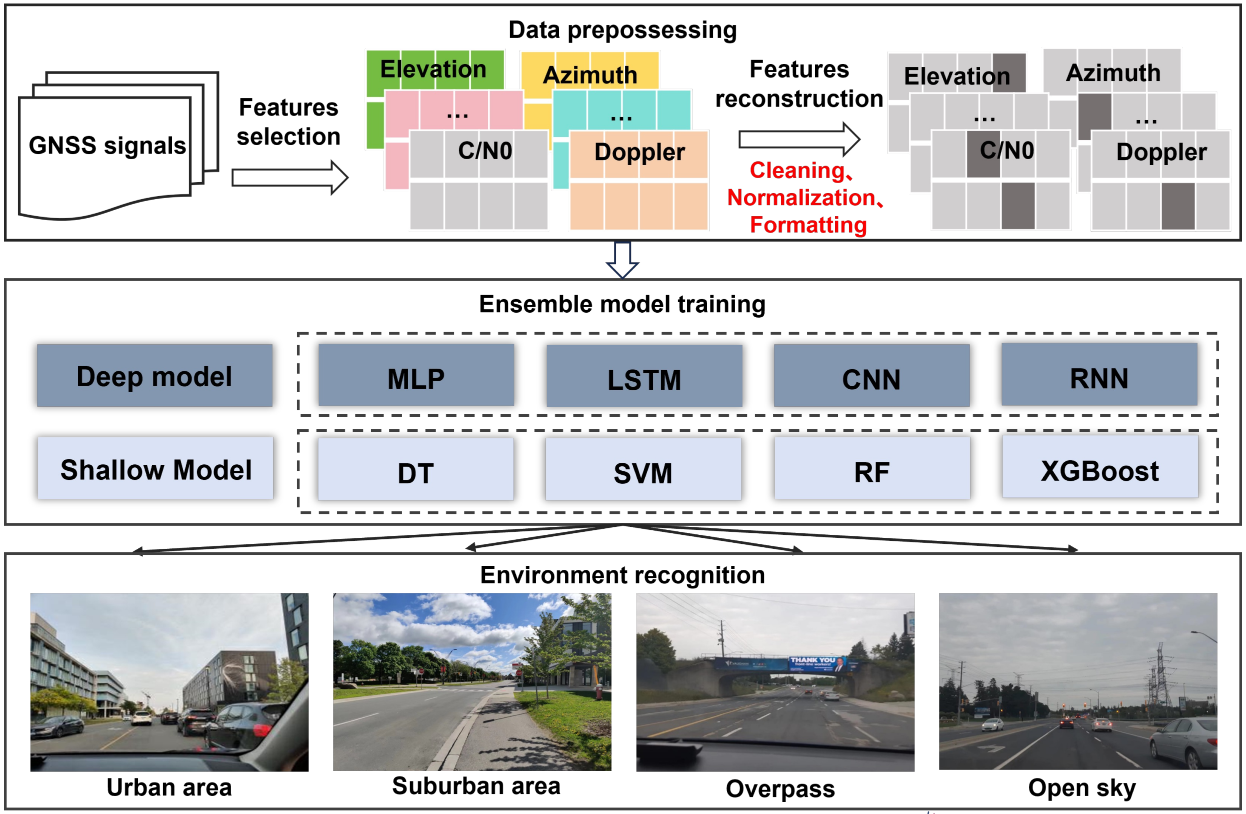
OVERVIEW OF ML METHODS AND USE CASES IN GNSS SMARTPHONE POSITIONING



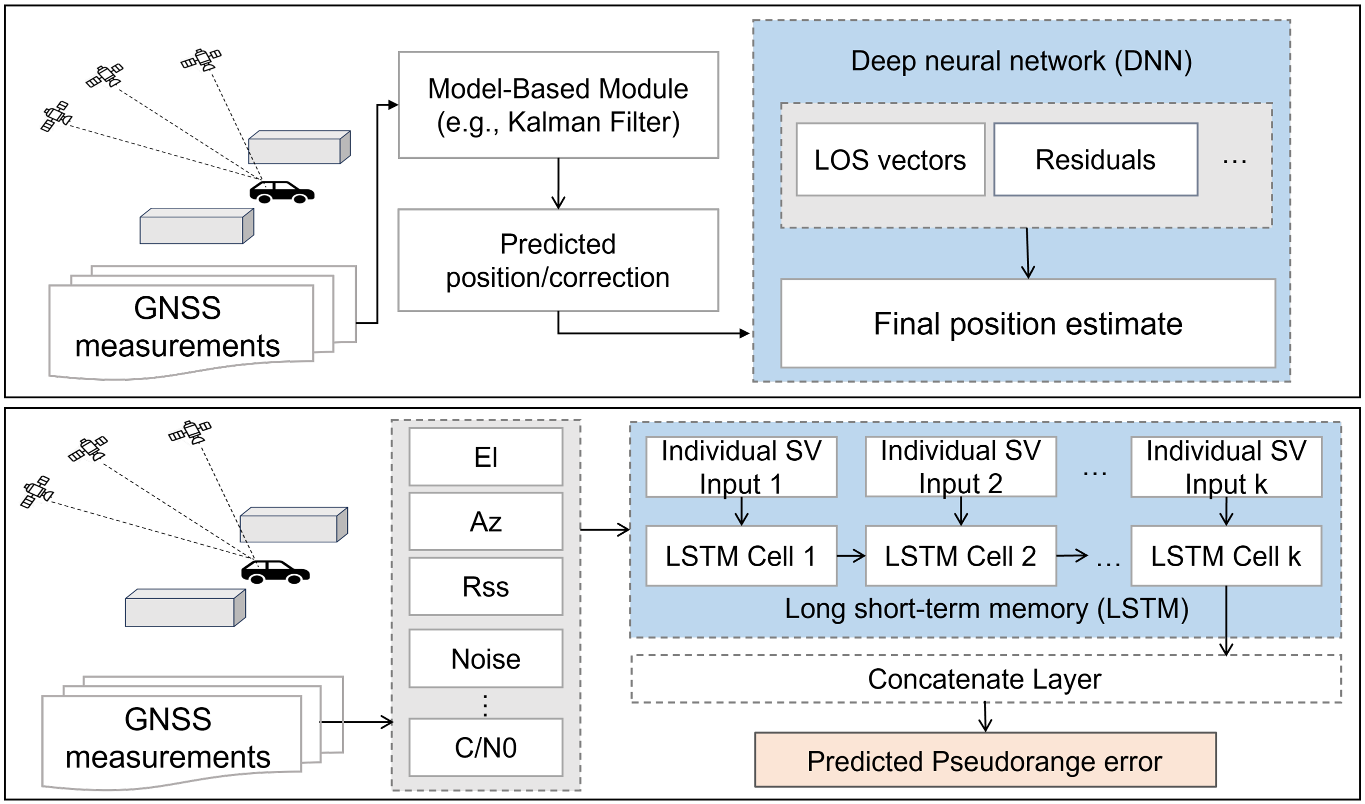
STRUCTURE OF DIFFERENT ML ALGORITHMS USED IN GNSS PPP NLOS/MULTIPATH CLASSIFICATION



ML-BASED RECOGNITION OF GNSS RECEPTION ENVIRONMENTS: URBAN, SUBURBAN, OVERPASS, OPEN-SKY



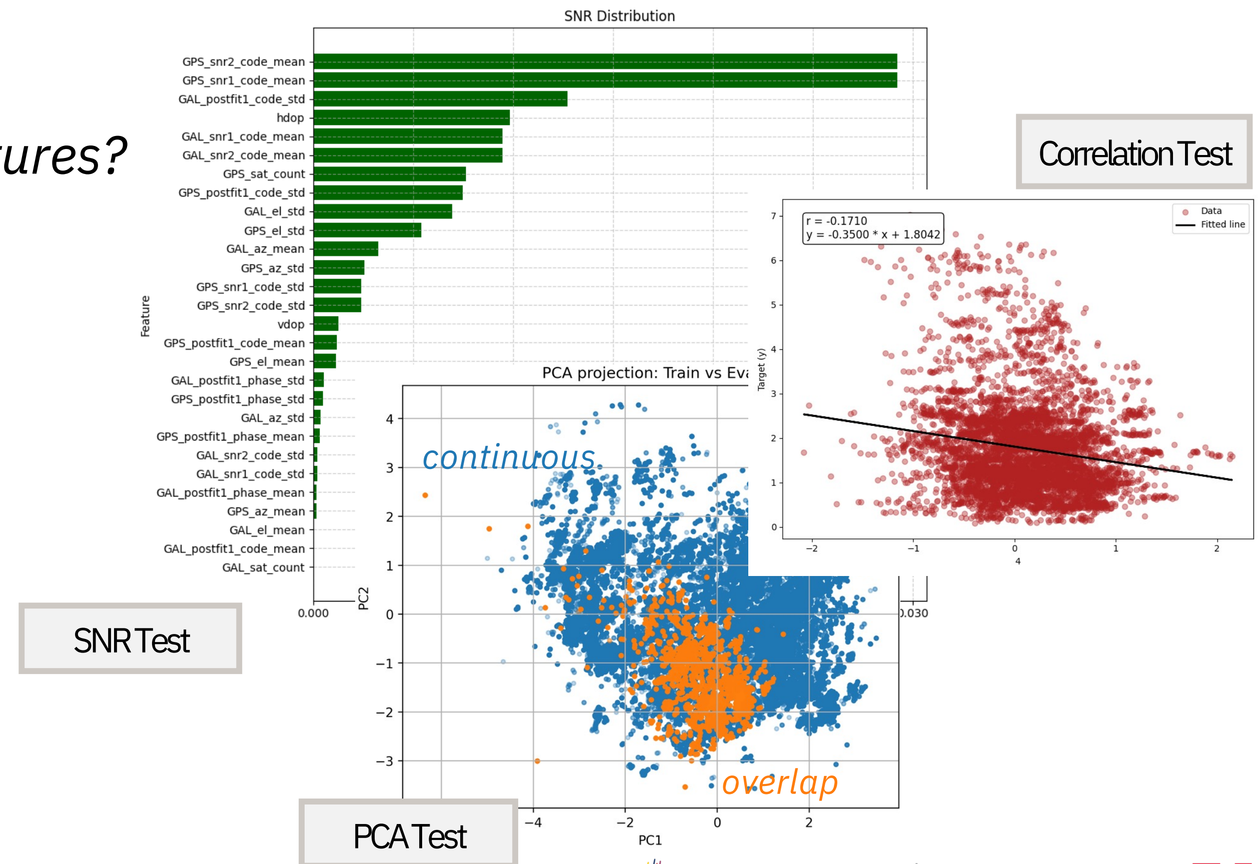
COMPARISON OF ML APPROACHES FOR POSITION AND OBSERVATION DOMAIN CORRECTION



FEATURE ENGINEERING

What makes good features?

- Correlated with targets
- Low redundancy
- Good stability
- Reasonable distribution
- Significant



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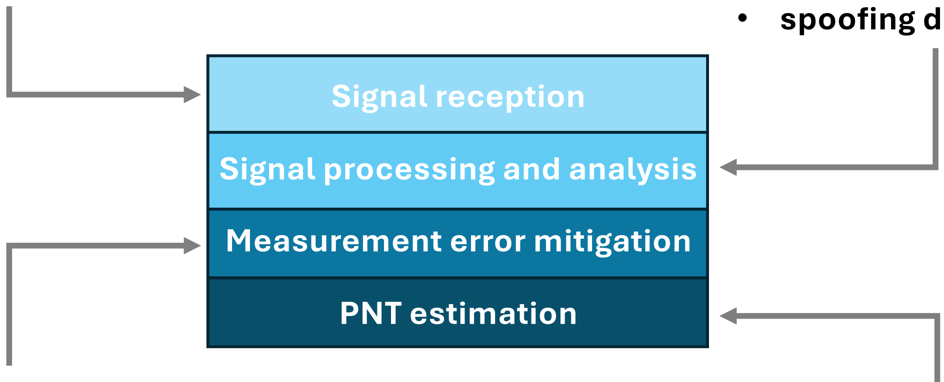
APPLICATION THEMES OF MACHINE LEARNING IN GNSS WITH INITIALLY STUDIED AND *POTENTIAL* RESEARCH AREAS

- **non-line-of-sight**
- **satellite selection**
- ***antenna design***

- **signal acquisition**
- ***signal tracking***
- **interference detection**
- **spoofing detection**



- **pseudorange multipath**
- **tropospheric refraction**
- **ionospheric refraction**
- ***orbit error***
- ***clock error***

- **point positioning**
- ***ambiguity resolution***
- ***RTK / network RTK***
- ***PPP / PPP-RTK***

(Bisnath, 2025, *GPS World*)

RESOURCE CONSIDERATIONS FOR MACHINE LEARNING USE IN GNSS

Resource consideration
Applicability / reliability
Significance of improvement
Data availability
Data storage
Computing power
Equipment and electrical power budgets
Hardware and software implementation

(Bisnath, 2025, *GPS World*)

SUMMARIZING AI IN GNSS TRENDS

- **Accelerating amount of research** applying ML approaches to enhance GNSS-based PNT
- **Great deal of ineffective research**
- We aren't developing AI algorithms, but we **need to well understand how to use these tools** – which requires significant insight
- **Specific, narrow improvements obtained**, especially in:
  - LOS / NLOS / multipath classification
  - Interference detection
  - Ionospheric refraction prediction

WHERE ARE WE GOING?

- **Much more experimentation** with ML algorithms and models
- Optimal balance between **specific measurement error mitigation and state estimation**
- Optimal **feature engineering**
- (Hopefully) **eventual convergence on "best" algorithms and models to use** for specific purposes
- **General adoption** of ML in specific applications

KEY CHALLENGES FOR ML USE IN GNSS

- **Finding "best" algorithms and models** for each GNSS performance issue
- Performance **improvement versus costs** (computational, power, complexity, etc.)
- Estimating **integrity**
- **Certification** of ML-based system solutions for safe-of-life applications

WHERE MAY WE END UP?

- Perhaps significant adoption of ML in particular aspects of **GNSS measurement characterization**
- Perhaps significant adoption of ML in particular aspects of **GNSS measurement processing**
- Perhaps **hybrid SLS or EKF estimation with ML** used to model non-deterministic processes and deal with invalid optimization assumptions
- **More resilient, low-cost GNSS-based PNT**

Thank you

Our people are our strength

gnsslab.lassonde.yorku.ca

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