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Invited Talk
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Secrets of Semantic Communications in the Era of 6G Networked Intelligence

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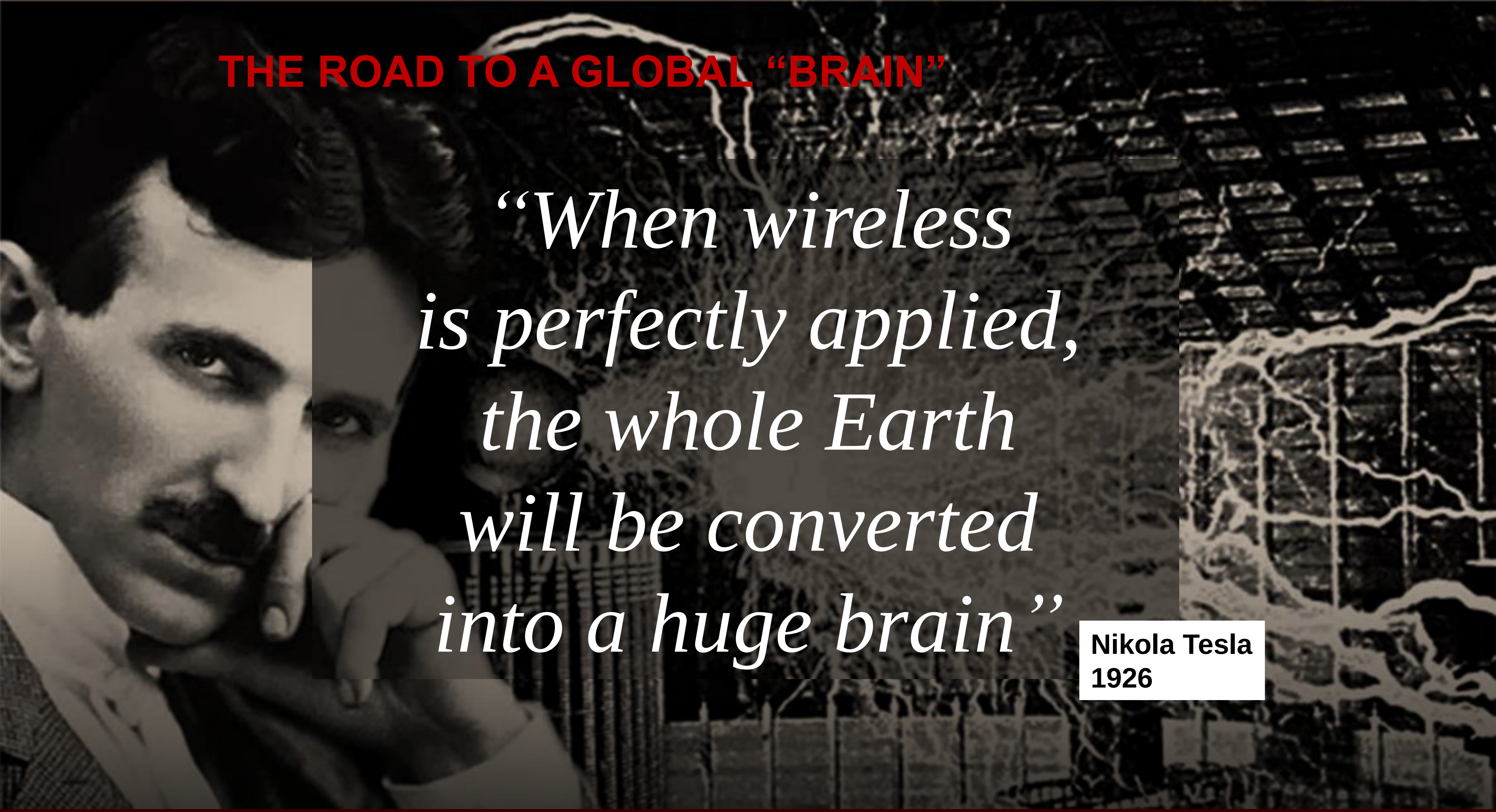
THE ROAD TO A GLOBAL "BRAIN"



"When wireless
is perfectly applied,
the whole Earth
will be converted
into a huge brain"

Nikola Tesla
1926

GENERATIONS OF CONTENT BLIND COMMUNICATIONS

Current *content-blind transmit-without-understanding* approach:
Data is transmitted without any prior **understanding** of how informative it is (**semantic**) to the receiver or useful (**pragmatic**) for the end-goal of communications

x1000 x10 x10 x10

$$C = BW \times n \times \log_2(1+SNIR)$$

Capacity (bits/seconds)

Radio channel Bandwidth (Hz)

- Spectrum Management
- Carrier aggregation
- New mmW Spectrum

Number of uncorrelated signal paths

- (Ultra Massive) MIMO
- Network densification
- Small cells
- RIS

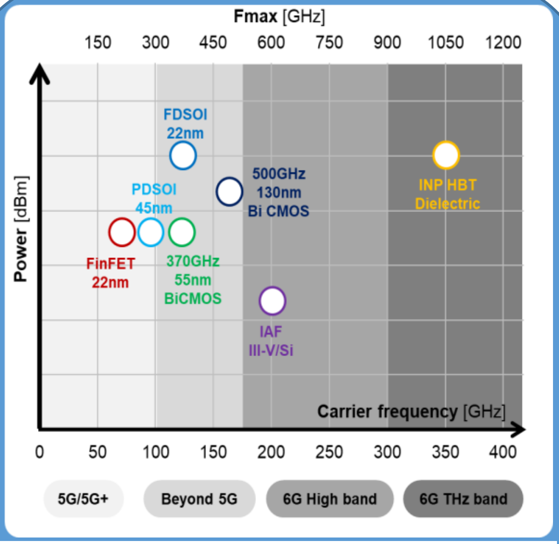
Signal to Noise + Interference Ratio

Spectral efficiency:
- Beamforming & high dBi antennas
- new modulations & coding schemes
- new waveforms, full-duplex
- RIS

Note that this is the Shannon **capacity for an idealized single user AWGN channel** under **infinite code lengths** assumption. Noise is statistically independent of the signal, with **constant power spectral density.** This formulation is not valid with other types of channels.

ULTRA-RELIABLE CONTENT BLIND 6G TECHNOLOGY PILLARS

Sub-THz Communications



Calvanese Strinati, E., et al. "Toward 6G: From New Hardware Design to Wireless Semantic and Goal-Oriented Communication Paradigms". *ESSCIRC 2021*

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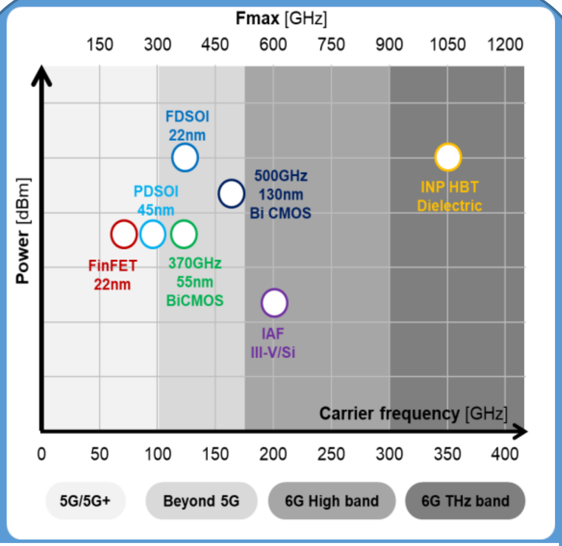

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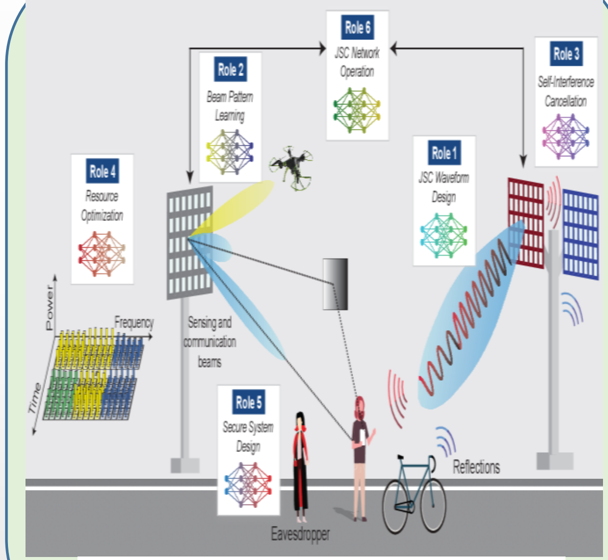
Integrated Communication & Sensing



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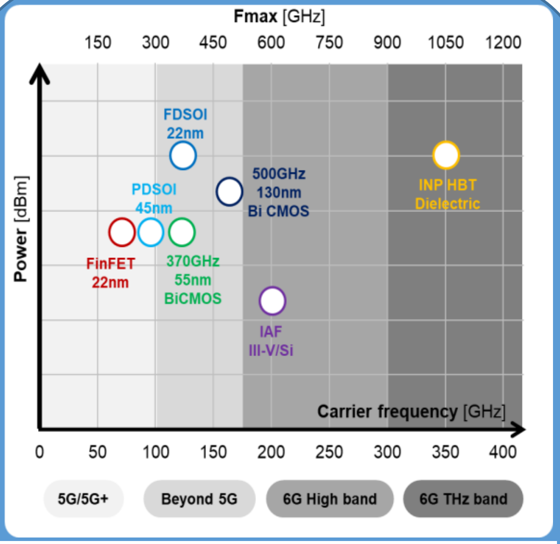

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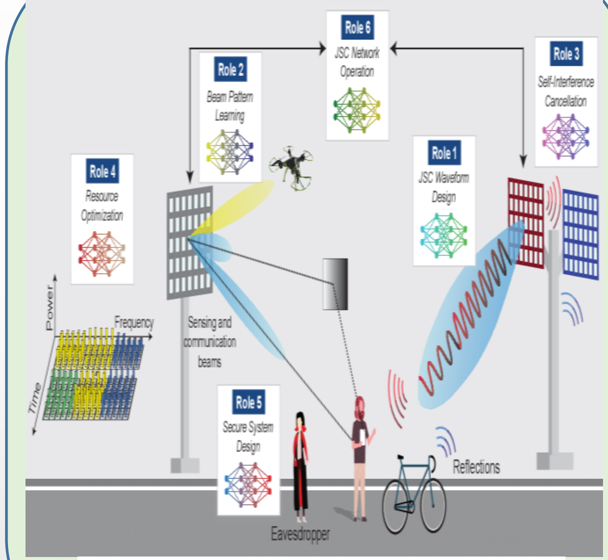

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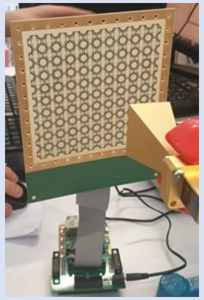
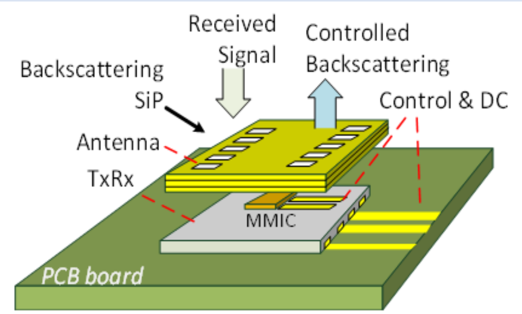
New materials & Intelligent antennas





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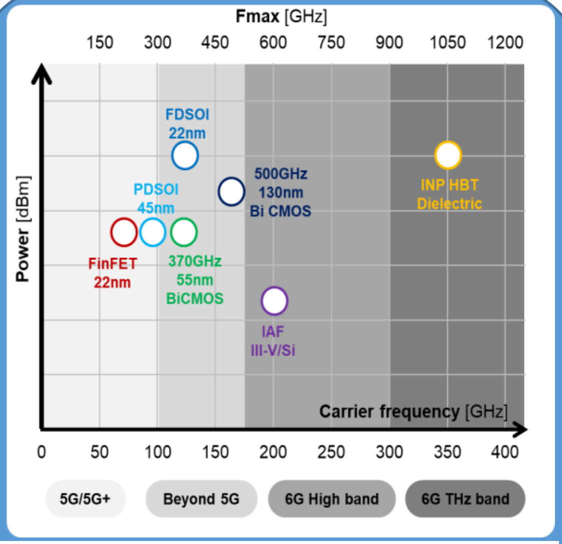

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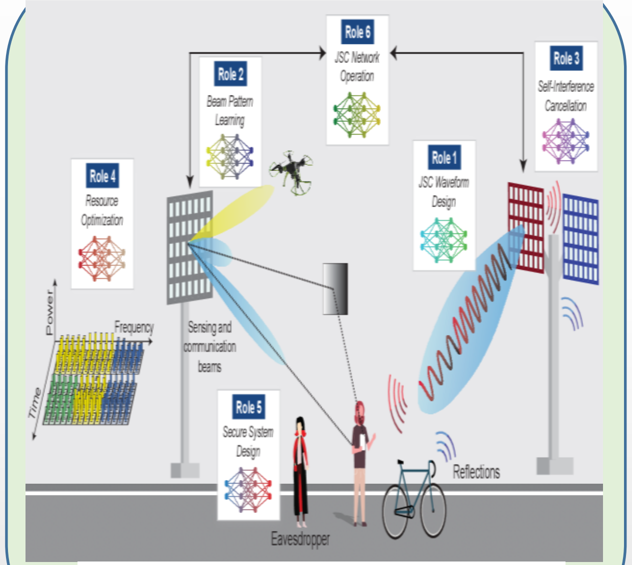
AI/ML technologies to design the next gen air interface & new compensation techniques for HW limitations

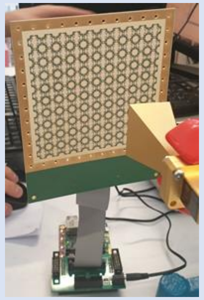
Integrated Communication & Sensing

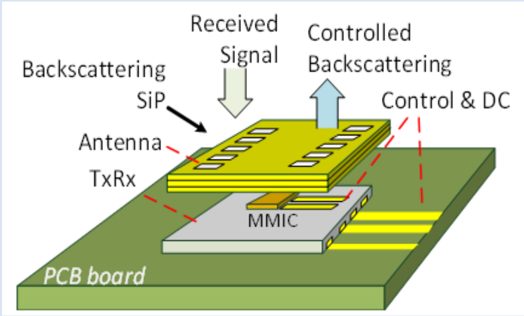


Source: "Integrated Sensing and Communication for 6G: Ten Key Machine Learning Roles", Umut Demirhan and A. Alkhateeb, in IEEE Communications Magazine, 2022.

Edge AI/ML to offer processing and data fusion capability close to applications requirements

New materials & Intelligent antennas





ML to optimize the use of RIS and enable on demand selective KPIs optimization (EE, secrecy, resources reuse factors, EMF …)

AI RAN to optimize

- data processing & transmission
- network operation & orchestration
- Agile trade-off C^3 resources
- Prediction
- Self-Configuration
- Interoperability

THE BIG CHANGES WITH 6G: WITH WHOM TO COMMUNICATE

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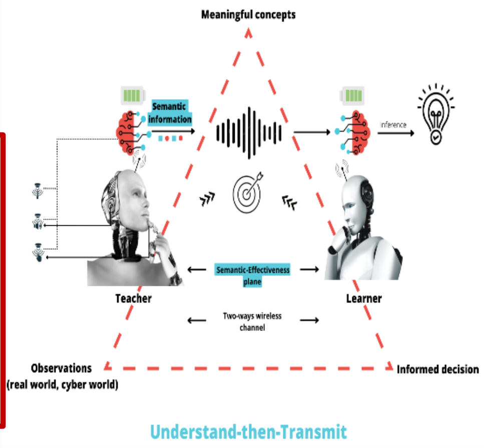
WHAT THE SEMANTIC COMMUNICATION PROBLEM



Beyond Bit Accuracy: Ensuring shared understanding, not just shared data

Meaning ≠ Message delivery

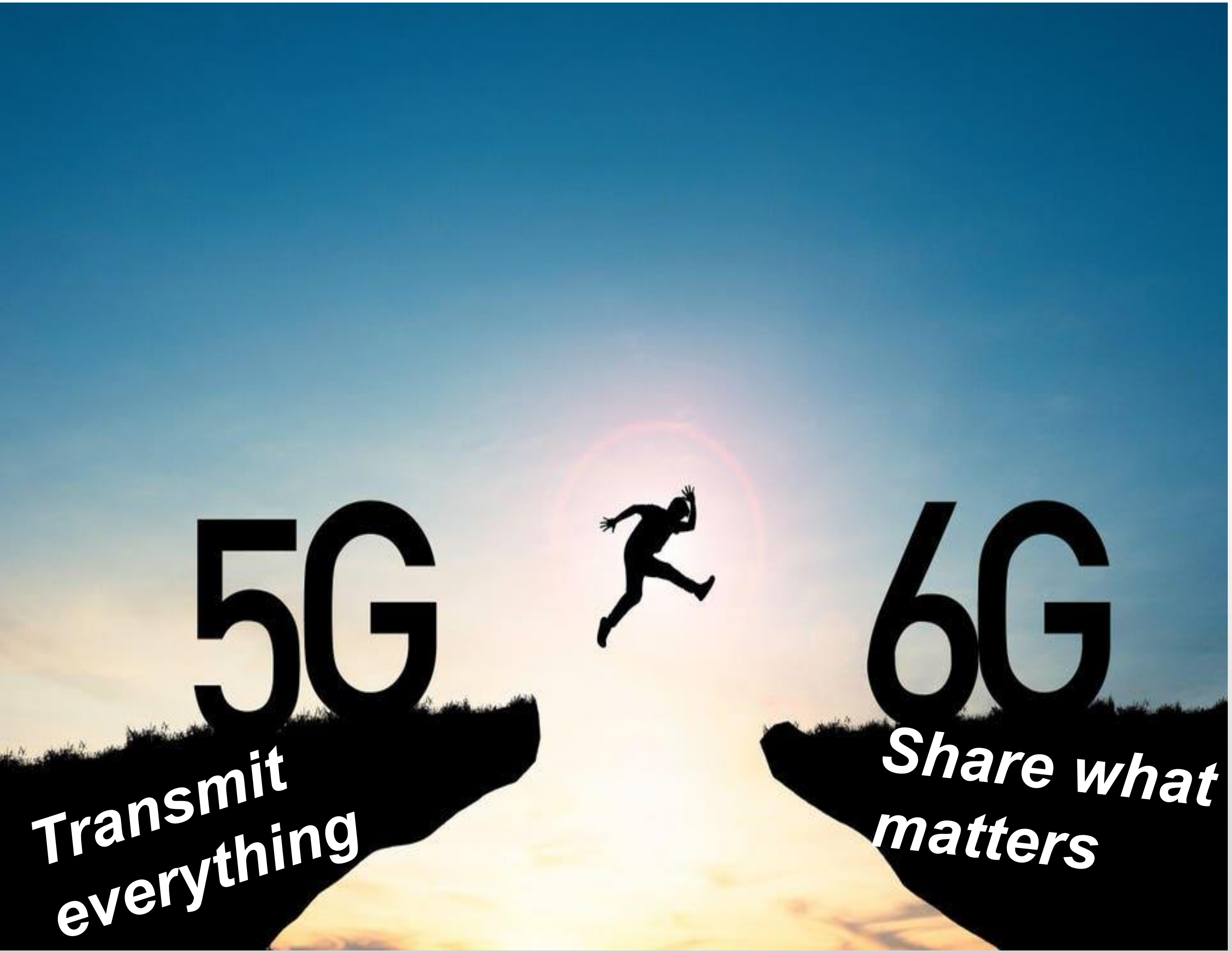
- Classical systems aim to **transmit symbols perfectly** (bit-level fidelity).
- Semantic communication seeks to ensure the **meaning is understood**

… … even if some data is lost!

Understand first:

share only what cannot be deduced or inferred by (Generative)AI

THE BIG CHANGES WITH 6G: SHARING "JUST" WHAT MATTERS



- **Data carries meaning for decisions and Intelligence**
  - Not just bits to be delivered with non sense high precision (10^{-8}).
- **Data traffic growth: x2000⁺**
- 140–360 GB per mobile connection per month by 2040
  - Not just sensor dumps, raw data or user content
- **New class of AI-centric data**:
  - For AI & **between intelligent AI agents**
  - **Up to 50%** of total traffic

THE BIG CHANGES WITH 6G: MULTIPLE PERCEPTION OF TIME

[Popovski22] P. Popovski, et al. "A perspective on time toward wireless 6G." Proceedings of the IEEE, vol. 110.8 (2022): pp. 1116-1146

[Calvanese24] E. Calvanese Strinati "6G: the catalyst for artificial general intelligence“, Nature Reviews Electrical Engineering 1 (9), 561-562 (2024)

From “*how fast*” to “*when* information *is informative* for action” [Popovski22] [Calvanese24]

From Latency-Centric Time to Intelligence-Centric Time

- **Time** = context + causality + prediction (even negative latency)
- **Synchronization** :for communication → for reasoning & intelligence
- **Dynamic temporal logic**
- Data delivery delay → goal-oriented effective information use

Context-dependent temporal granularity

- “**Real-time**” depends on Agents, reasoning capability, semantic causality, application context, …

HOW HUMANS UNDERSTAND & COMMUNICATE

Communication goes beyond data transmission:

- It requires **modeling the receiver**
  - **How the world is perceived**
  - **Information is interpreted**
  - **The implicit relation of data** (dark matter in AI)
- **Humans attribute to others:**
  - **Beliefs, intentions, knowledge**
  - **Adapt** our message to the audience
  - **Anticipate** reactions using **inferred mental states**
  - **Sensitivity to the context**

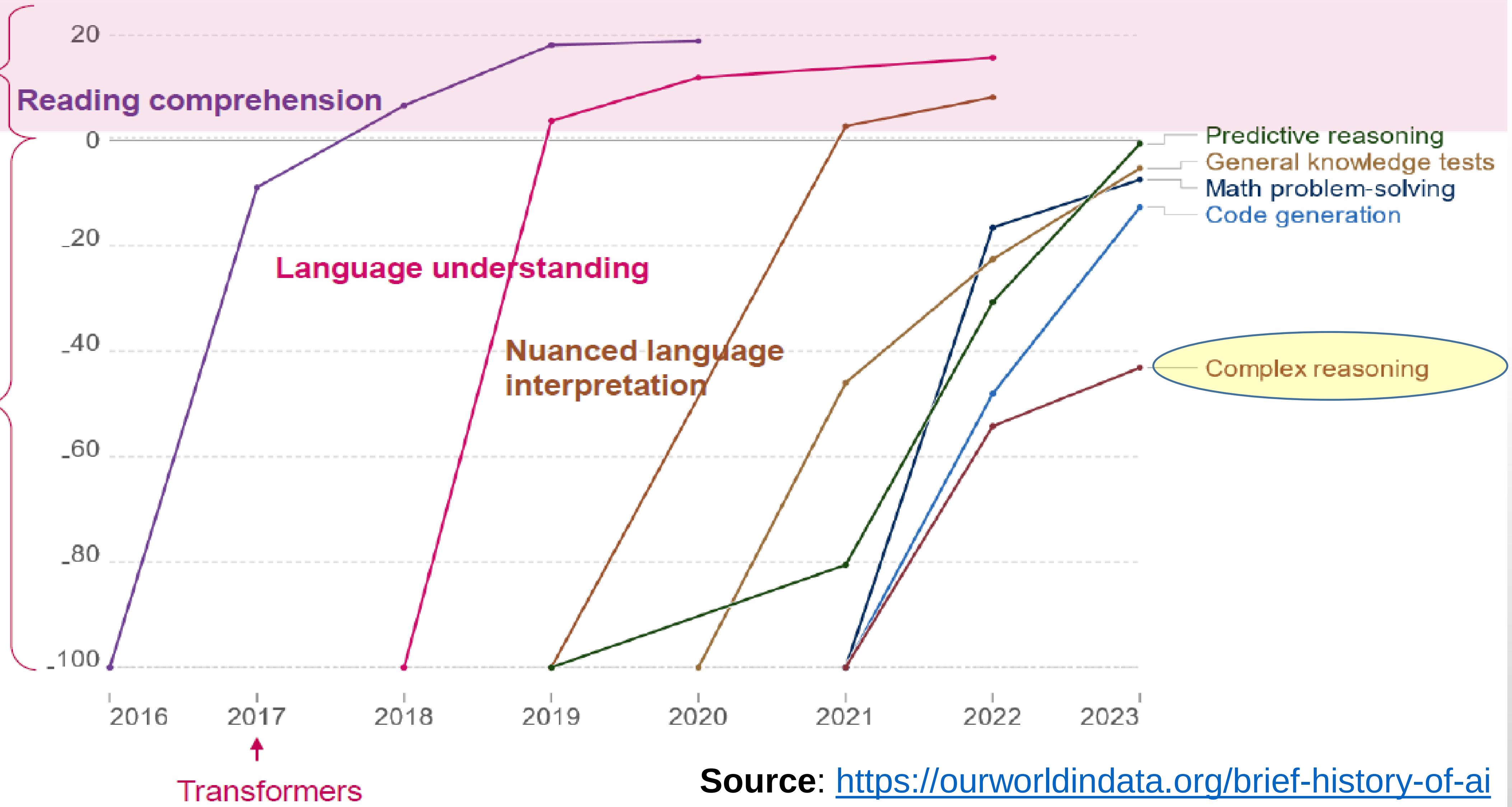
The theory of minds

HOW

THE EVOLUTION OF A NEW INTELLECTUAL SPECIES : AI

AI performs better

Humans perform better



Source: https://ourworldindata.org/brief-history-of-ai

HOW

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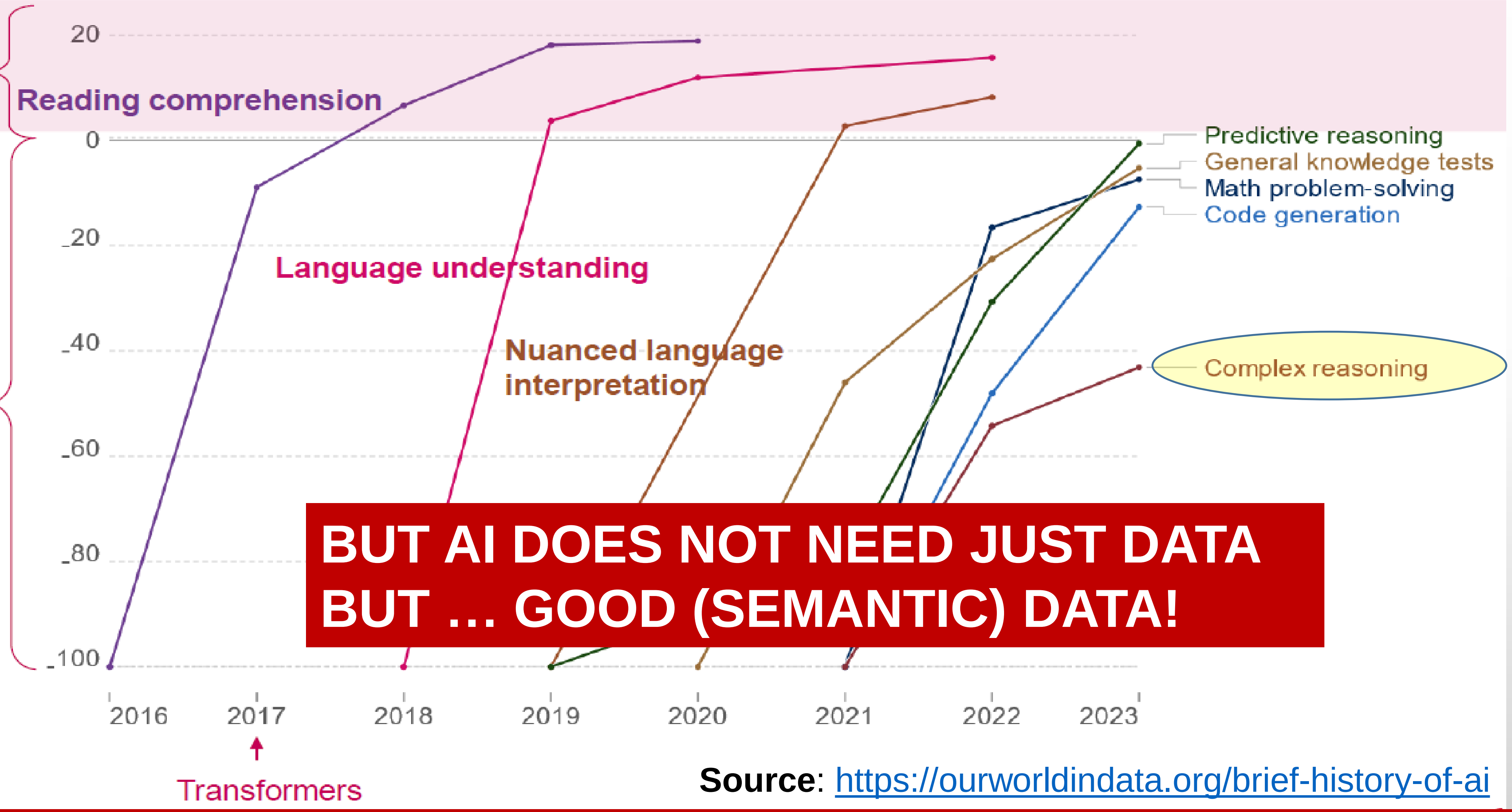
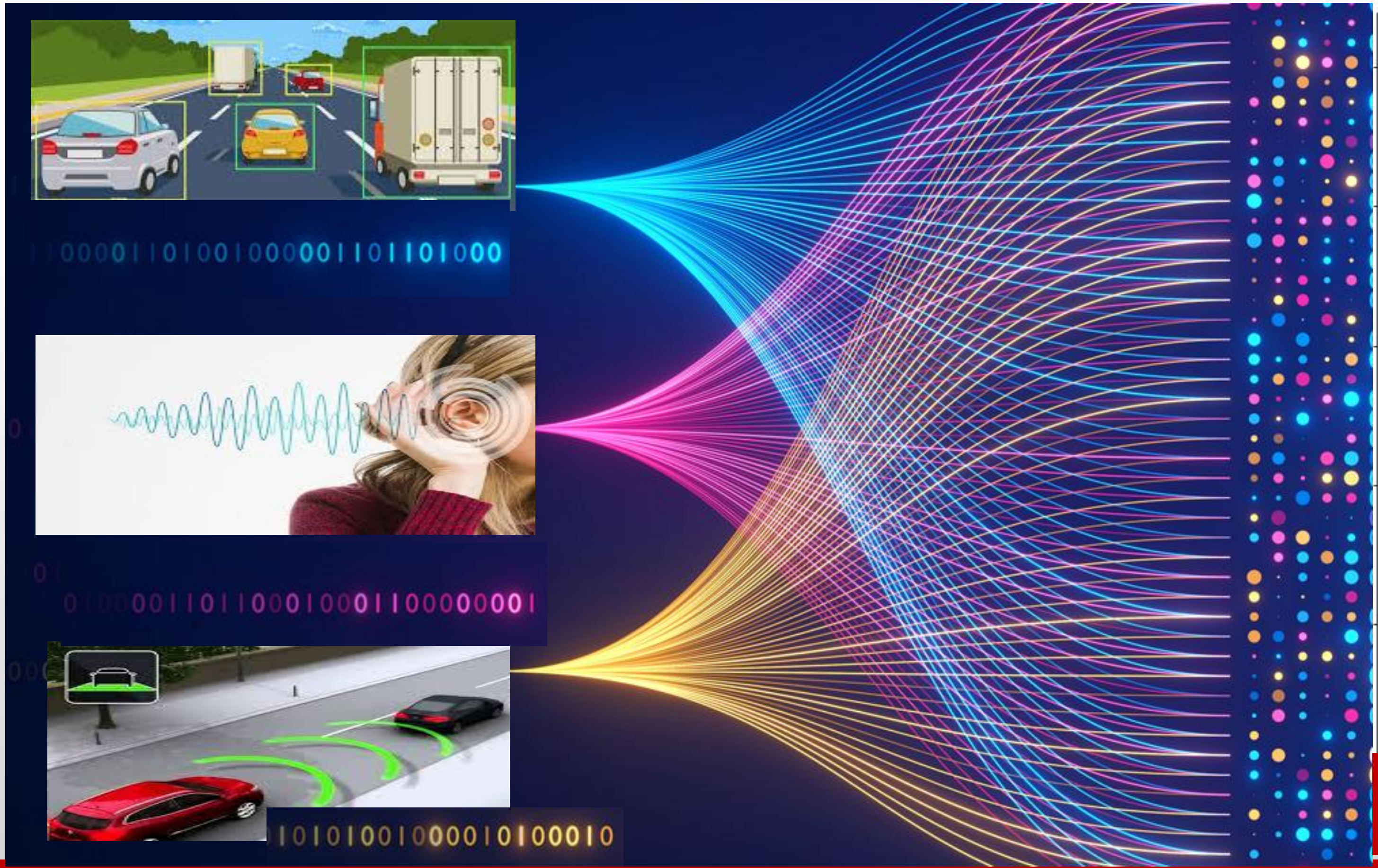


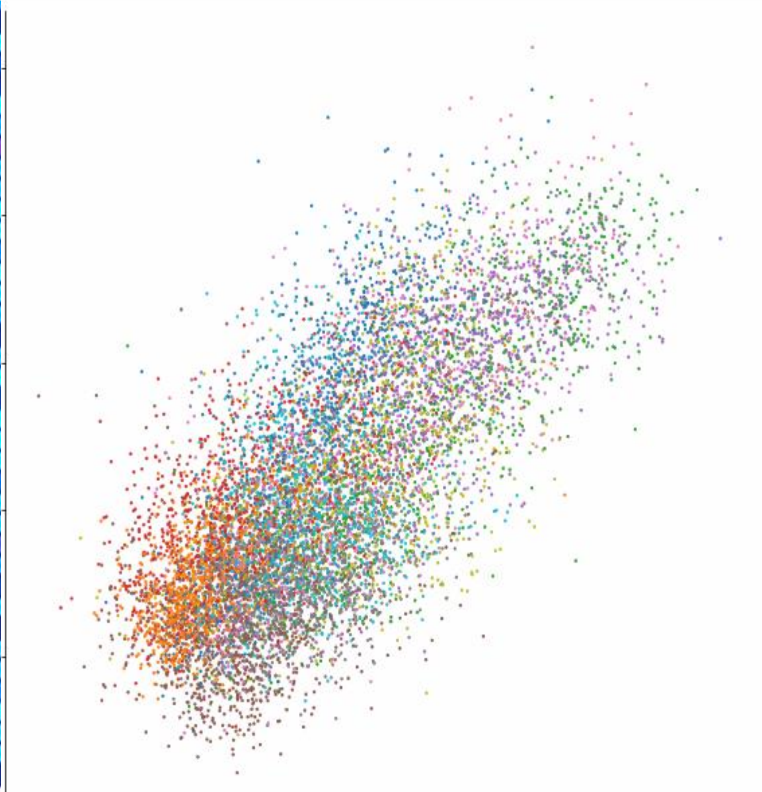
BUT AI DOES NOT NEED JUST DATA BUT … GOOD (SEMANTIC) DATA!

Source: https://ourworldindata.org/brief-history-of-ai

WHAT SEMANTIC 101: GIVING RELEVANT MEANING TO DATA

Semantic is about meaning, it prioritizes relevance over volume, enabling efficient and meaningful communication





AI latent spaces representation (multi-dimensional vector)

Informed Decision

HOW TO MEASURE SEMCOMS GAINS & EFFECTIVENESS?

Semantic communications metrics

20+ metrics and KPIs in 6 different areas: Information theoretic, text, image/video, timing-related, goal-oriented, secrecy **[D2.2 6G-GOALS]**

$$\begin{cases} R(D,P) \overset{\text{def}}{=} \min_{p_{\hat{X}|X}} I(X,\hat{X}) \\ E[\Delta(X,\hat{X})] \le D \\ d(p_X, p_{\hat{X}}) \le P \end{cases}$$

Rate-distorsion-perception: low distortion alone is not enough — perception (semantic fidelity) is essential

$$\text{FID} = ||\mu_{\text{real}} - \mu_{\text{generated}}||^2 + \text{Tr}\left(\Sigma_{\text{real}} + \Sigma_{\text{generated}} - 2\left(\Sigma_{\text{real}}\Sigma_{\text{generated}}\right)^{1/2}\right)$$

Frechet-Information Distance: Captures **semantic similarity** measuring on a learned feature space

$$\Theta(f(A), f(B)) = ||f(A) - f(B)||_2^2$$

Semantic similarity among embeddings

$$\text{AoE} = \{\mathcal{S} \mid \mathcal{E}_{go}(\mathcal{S}) \ge q_{\text{th}}\}$$

Area of Effectiveness

$$\text{LPIPS}(x,y) = \sum_l \frac{1}{H_l W_l} \sum_{h,w} ||\widehat{y_{hw}^l} - \widehat{x_{hw}^l}||_2^2$$

Perceptual Image similarity (DL, GO, Heuristics)

It measures meaningful features preservation

$$s(t) = sup\{g_i \in S: g_i + \delta_i \le t\}$$

$$\Delta_L(t) = t - s(t)$$

Age of Loop: freshness of information when used

HOW TO MEASURE SEMCOMS GAINS & EFFECTIVENESS?

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20+ metrics and KPIs in 6 different areas: Information theoretic, text, image/video, timing-related, goal-oriented, secrecy **[D2.2 6G-GOALS]**

Semantic metrics focus on

- **Semantic Similarity and equivalence**
- **Task Success Rate/Cost**
- **Contextual Relevance**
- **Goal Achievement**
- **Semantic alignment**
- **Semantic temporal consistency**

$R(D,P)$ … $E[\Delta($ … $d(p$

Rate-disto…

…ated$)^{1/2})$

…$S) \geq q_{\mathrm{th}}\}$

…eness

LPIPS…

Perceptual Image similarity

Age of Loop

WHAT

SEMANTIC COMMUNICATION GAINS: ROBUSTNESS

Semantic robustness (Comm, Inference, Task accomplishment)

Trade-offs:

- Robustness versus ambiguity
- Robustness versus resource use (energy, processing, …)

fi yuo cna raed tihs, yuo hvae a sgtrane mnid too. Cna yuo raed tihs? Olny smoe plepoe can. i cdnuolt blveiee taht I cluod aulaclty uesdnatnrd waht I was rdanieg. The phaonmneal pweor of the hmuan mnid, aoccdrnig to a rscheearch at Cmabrigde Uinervtisy, it dseno't mtaetr in waht oerdr the ltteres in a wrod are, the olny iproamtnt tihng is taht the frsit and lsat ltteer be in the rghit pclae. The rset can be a taotl mses and you can sitll raed it whotuit a pboerlm. Tihs is bcuseae the huamn mniddeos not raed ervey lteter by istlef, but the wrod as a wlohe. Azanmig huh? yaeh and I awlyas tghuhot slpeling was ipmorantt!

WHAT

SEMANTIC COMMUNICATION GAINS: ROBUSTNESS

When the order of words or characters changes,

your brain still **correctly interpret** sentences.

Semantic robustness depends on transmitters-receivers alignment (both ends "speak the same semantic language") & on reasoning (to recover meaning under uncertainty or noise)

7H15 M3554G3
53RV35 70 PR0V3
H0W 0UR M1ND5 C4N
D0 4M4Z1NG 7H1NG5!
1MPR3551V3 7H1NG3!
1N 7H3 B3G1NN1NG
17 WA5 H4RD BU7
Y0UR M1ND 1S
R34D1NG 17
4U70M471C4LLY
W17H 0U7 3V3N
7H1NK1NG 4B0U7 17,
B3 PROUD! 0NLY
C3R741N P39PL3 C4N
R3AD 7H15.
PL3453 F0RW4RD 1F
U C4N R34D 7H15.

WHAT

SEMANTIC COMMUNICATION GAINS: ROBUSTNESS

研表究明，漢字的序順並不定
一能影閱響讀，
比如當你看完這句話後，
才發這現裡的字全是都亂的

SEMANTIC + AI-RAN

SemComs in the AI on RAN

AI on RAN = AI hosted in the RAN & used to optimize RAN functions

SemComs in the AI for RAN

AI for RAN =
AI used to optimize RAN functions

Secret advantages of semantic communications in/for/on AI-RAN:

- **Make easier to run AI workloads on constrained RAN nodes** by reducing communication overhead, accelerating re-training & effectively feeding AI reasoning engines
- **Bridges AI and Communication**: Enabling joint adaptation & reasoning between AI models and communication layers
- **Resilience & Efficiency:** Errors in bits don't matter if the **semantic intent is preserved:** allowing adaptation on what to protect & what to drop for tasks & applications
- **Compressing** high-dimensional features exchanged between RUs & edge servers
- **Reducing** fronthaul/backhaul **load** for AI-supported tasks (beam prediction, CSI feedback, anomaly detection)
- **Enforce multi-agents cooperation**

SEMANTIC + AI-RAN

SemComs in the AI on RAN

AI on RAN = AI hosted in the RAN & used to optimize RAN functions

Saves bandwidth for AI model data exchange
Save spectrum use
Reduces overhead (data, signalling, (re)training)
New effective trade-offs communication–computation–caching paradigm for AI functions hosting & execution
Enhance robustness of communication against noise and interference
Coexistence & alignment of AI models

SemComs in the AI for RAN

AI for RAN =
AI used to optimize RAN functions

SEMANTIC + AI-RAN

SemComs in the AI on RAN

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- **Saves bandwidth** for AI model data exchange
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- **New effective** communication–computation–caching **trade-offs** paradigm for AI functions hosting & execution

SemComs in the AI for RAN

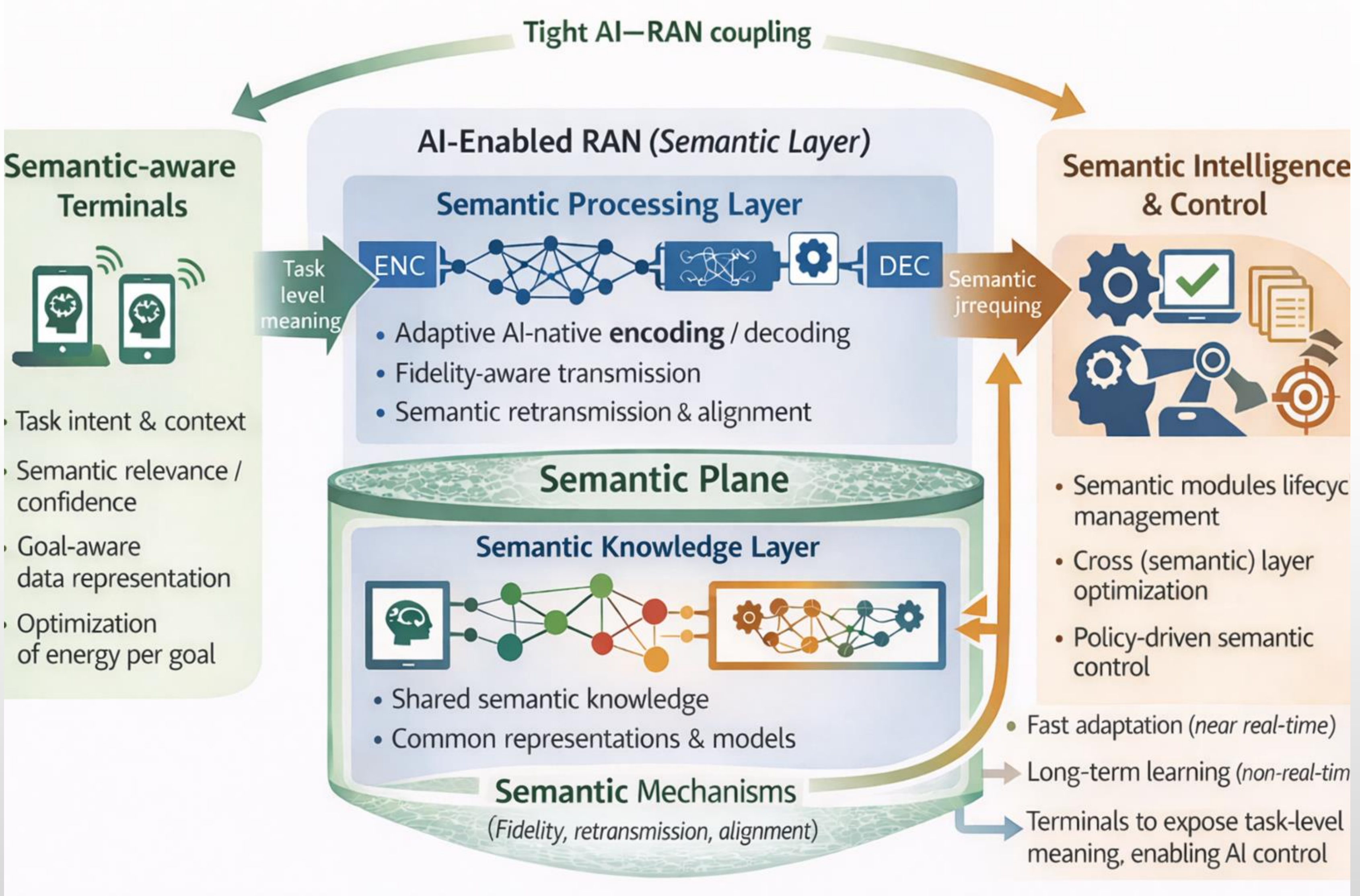
AI for RAN =
AI used to optimize RAN functions

- **Massive efficiency gains** CSI/feedback exchange (semantic CSI)
- **Semantic sensing** and radio environment maps
- **Reduced signaling** overhead for ML coordination across sites
- **Reduced deployment**/network nodes use
- **Reduced** RAN functions **complexity** and duty cycle (ex. CSI)
- **Coverage extension**
- **Semantic aware** PHY design (waveforms)

SECRET #1 THE SEMANTIC PLANE IN AI-NATIVE 6G ARCHITECTURES

Semantic plane

- New **logical layer** to processing meaning
- To **“semantically” enhances** both the user & control planes
- **Facilitate** the delivery of **semantic services**, enable **knowledge-driven reasoning**



[D2.5 6G-GOALS]: 6G-GOALS Project, **Initial 6G-GOALS architecture and operation analysis** June 2025. https://sites.google.com/view/6ggoals/results/deliverable?authuser=0

SECRET #1 THE SEMANTIC PLANE IN AI-NATIVE 6G ARCHITECTURES

Advantages

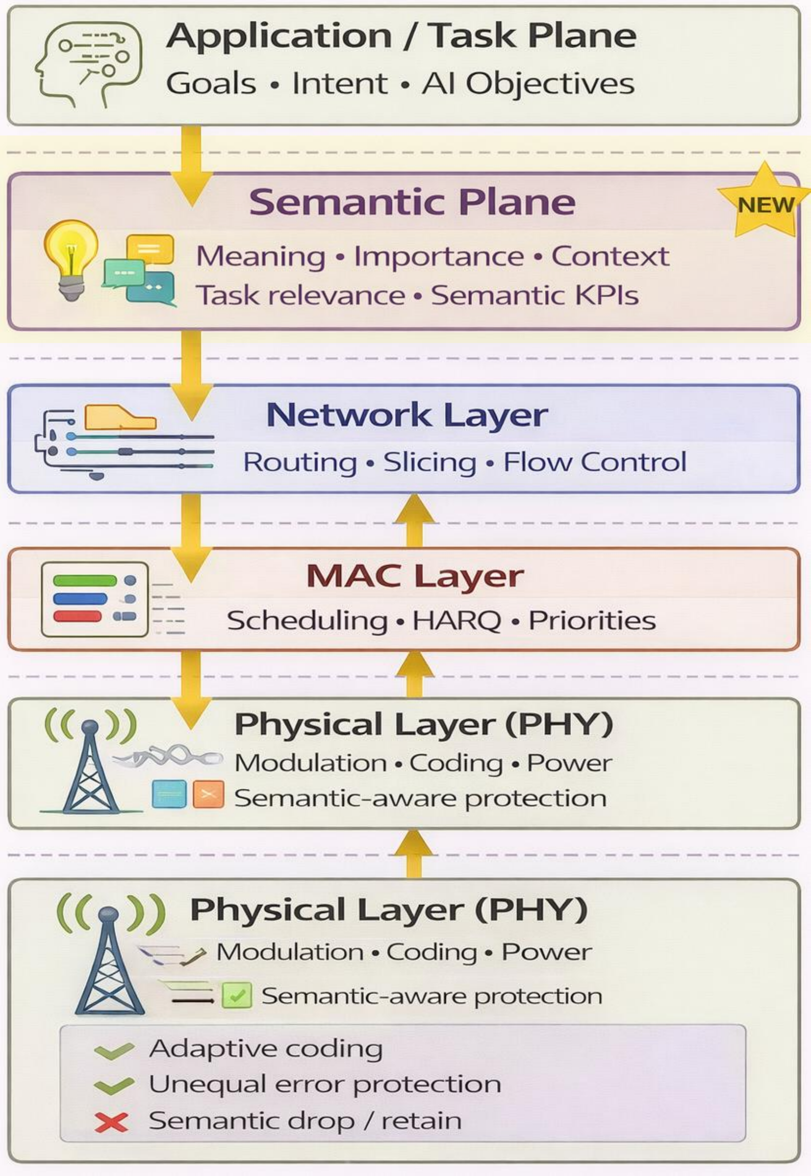
AI–Communication Convergence: Enables joint reasoning and adaptation across AI models and communication layers

Semantic Cross-Layer Optimization: Injects meaning into PHY/MAC/Network decisions → new metrics, new information-communication–computation trade-offs

Resilience & Efficiency: Preserves semantic intent rather than bits, enabling importance-aware protection, drop, and resource allocation

Issues (Potential)

- **Extra latency** and **signaling** overhead
- Possible **higher energy per bit** (extra semantic processing & signaling) **but lower CUMULATIVE energy per goal** (send less bits – large semantic compression)



SECRET #2 THERE EXISTS AN INVISIBLE SEMANTIC LOGIC CHANNEL

Even with successful syntactic transmission, reconstructed meaning might differ from the intended one.

- The **semantic logic channel** carries concepts, intent, and task-relevant meaning.
- **Logic is transmitted implicitly** and receivers do not interpret what has been received but what "**make sense**"
- But "**common sense**" depends on shared semantic space & knowledge
- But … Commonly SemComs assume common ground between agents

Semantic channel modelling challenge:

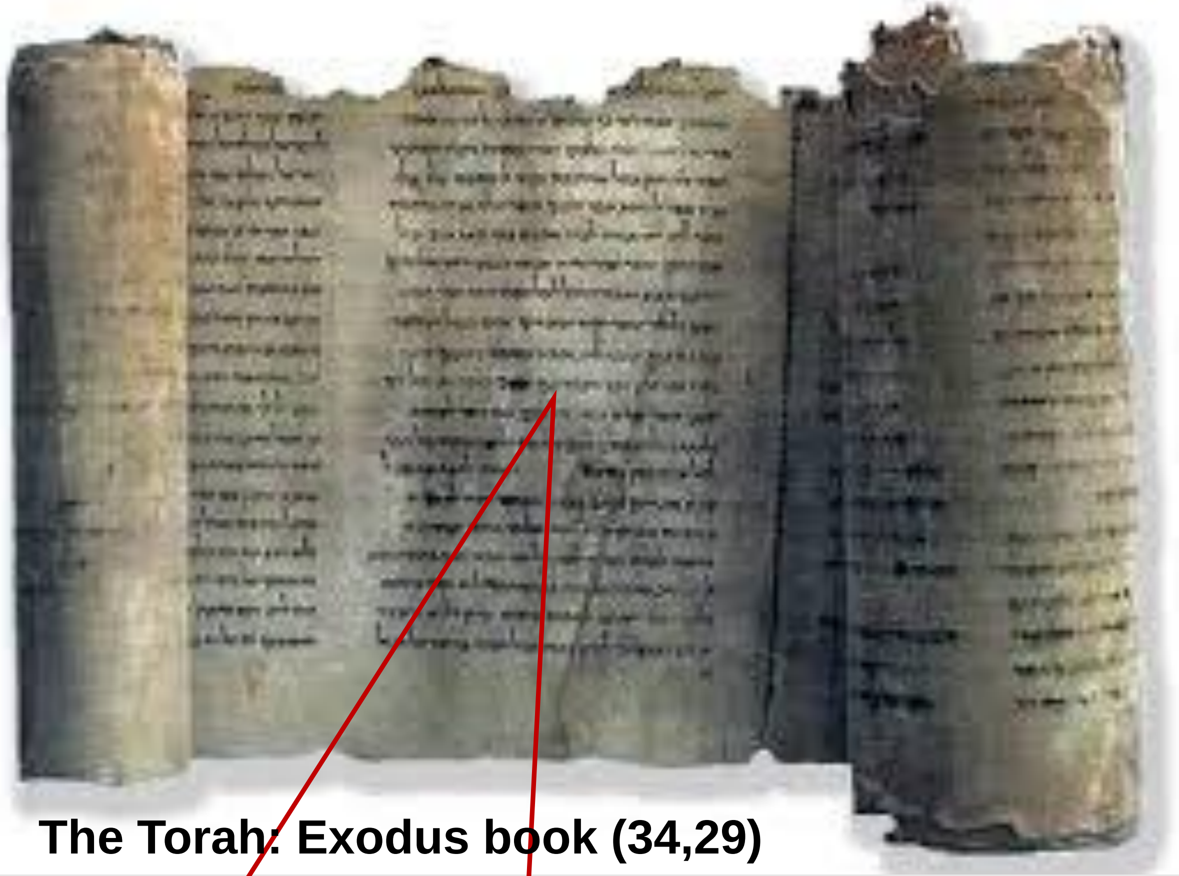
- Representing how the meaning and content of semantic messages can change as they pass through various stages or transformations
- Counteract or avoid semantic channel errors

MOSES IN ROME: THE “RAYS OR HORNS?” AMBIGUITY

The Torah: Exodus book (34,29)

וַיְהִי בְּרֶדֶת מֹשֶׁה מֵהַר סִינַי וּשְׁנֵי לֻחֹת הָעֵדֻת בְּיַד־מֹשֶׁה
בְּרִדְתּוֹ מִן־הָהָר וּמֹשֶׁה לֹא־יָדַע כִּי **קָרַן** עוֹר פָּנָיו בְּדַבְּרוֹ אִתּוֹ

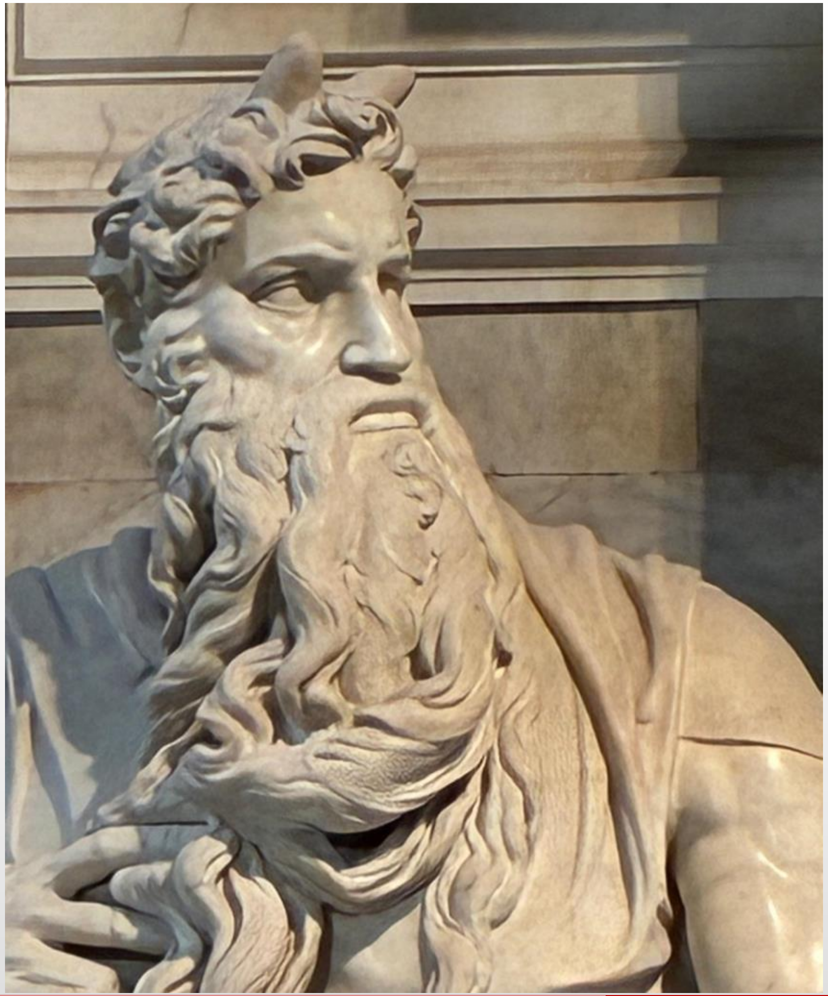
MOSES IN ROME: THE "RAYS OR HORNS?" AMBIGUITY



The Torah: Exodus book (34,29)

*As Moses came down from Mount Sinai, the skin of his face **shone** (radiant)*

MOSES IN ROME: THE “RAYS OR HORNS?” SEMANTIC AMBIGUITY



In Biblical Hebrew, the root **Q-R-N (קרן)** can refer to both:
- **horns** (*qeren*)
- **radiance / rays of light** (*qaran*)

In Bible, Moses’ face after Sinai may mean:
“radiated light”
or be interpreted as
“horned”

- Greek translations favored **radiance**, while the Latin Vulgate rendered it as **“horned.”**

A shift in interpretation transformed **divine luminosity into physical horns**.

Lost in translation: **Long-term semantic misalignment consequence:** The ambiguity propagated into centuries of iconography, including Moses by Michelangelo ☹

WHY SEMANTIC MISALIGNMENT

Representation misalignment : Tx & Rx represent knowledge differently

Semantic language mismatch between agents (extraction & interpretation) :

- Not compatible or unambiguously interoperable **training / NN models**
- Languages induce **different partitions over the semantic space**

➔ Common in **heterogeneous AI agents** trained with different architectures or datasets.

Semantic expressiveness misalignment :

- **Limited semantic extractor** (Tx): language limits concepts representation for Rx
- **Limited semantic interpreter** (Rx) : language limits interpretation of received symbols

Background knowledge mismatch :

- Different prior beliefs or semantic models
- Divergence in Semantic Domain: Terms or signals carry different implications

Pragmatic misunderstanding : Differences in intent or goal, of the message.

HW Implementation : limits performance or imposes low energy consumption at the device

HOW ABORIGINAL COMMUNITY IN AUSTRALIA TALK?
[BORODITSKY2001]

- In their language the do not use ***left*** or ***right***
- Everything is in **Cardinal directions** (North, South, East, West)
- Ex. *there is a banana at your South-South-West leg, so move your body to the north-east-east*

[Boroditsky2001] Lera Boroditsky, Does Language Shape Thought?: Mandarin and English Speakers' Conceptions of Time, Cognitive Psychology, Volume 43, Issue 1, 2001, Pages 1-22.

HOW ABORIGINAL COMMUNITY IN AUSTRALIA TALK?

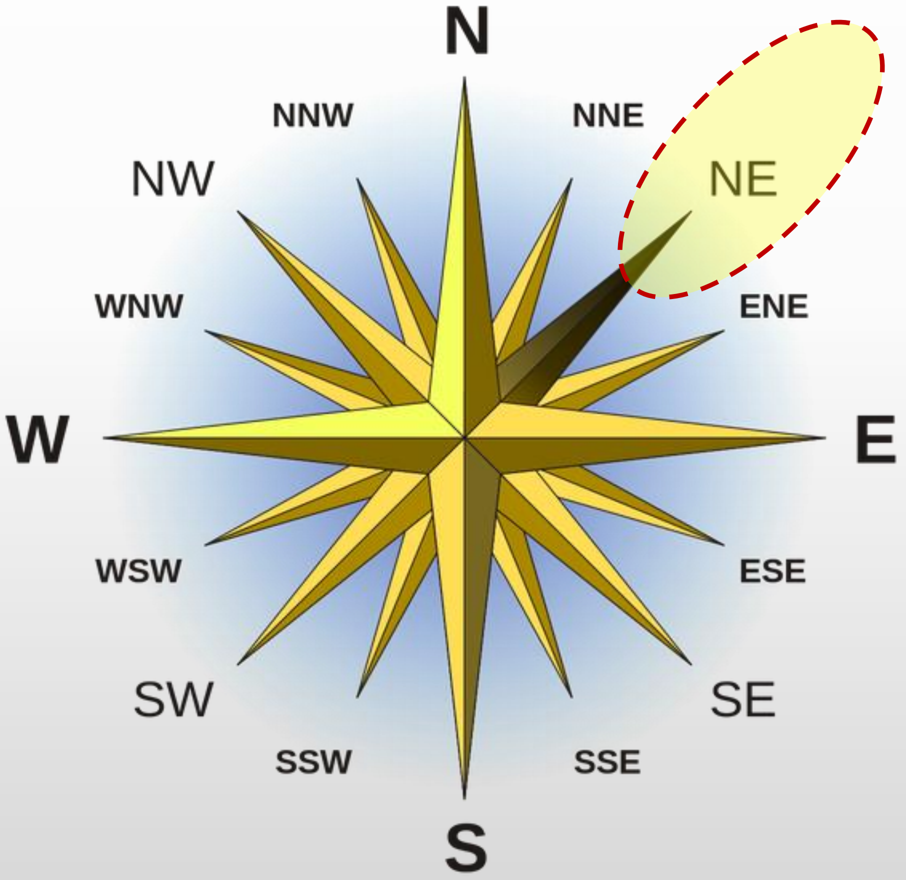
- Everything is in **Cardinal directions** (North, South, East, West)

- *“Hallo”* is expressed as: *which way you go?*
- Answer: *South-South-East in a far distance*, what about you?
- Literally you cannot pass « hallo » if you ignore where you go!
- People in this community are excellent in orientation!

Thanks to the language, they have a continuous training on how to be oriented

HOW DIFFERENT IS FROM THE WAY WE DO IT?

Close your eyes for few seconds and point North-East



HOW DIFFERENT IS FROM THE WAY WE DO IT?

A 5 years old Pormpuraaw Aboriginal boy would it know exactly!

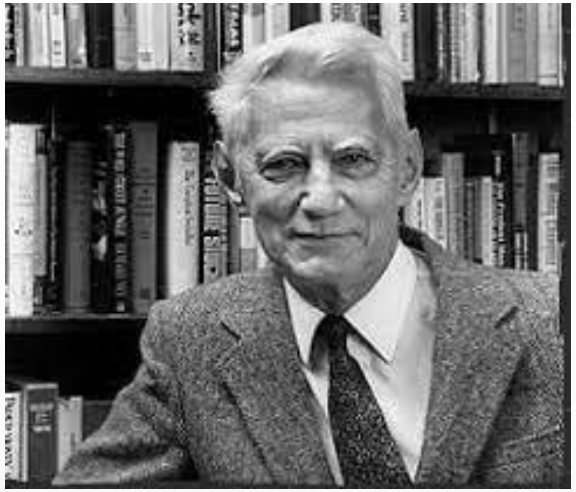
Thanks to **their language,** they have a **continuous training** on how to be oriented **(reasoning in different contexts)**

Different Languages train different cognitive human capabilities!

Agents reasoning with different languages understand & think differently

ISSUE

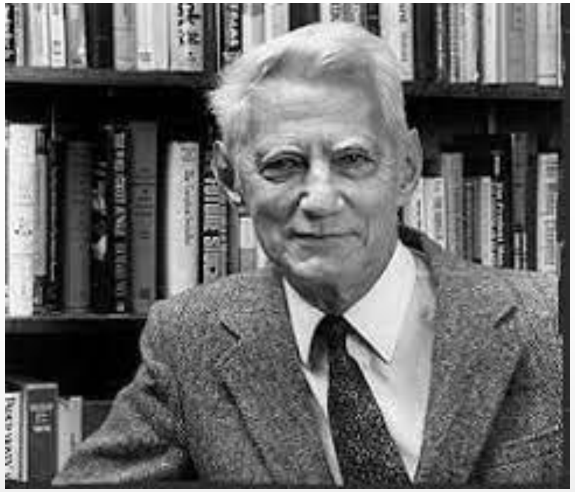
INFER DIFFERENTLY (*OR CONTROL OR ACTUATE*)
EX. THE PICTURE OF C. E. SHANNON AT DIFFERENT AGES



THE PICTURE OF C. E. SHANNON AT DIFFERENT AGES

How an English speaker would organize time?

THE PICTURE OF C. E. SHANNON AT DIFFERENT AGES

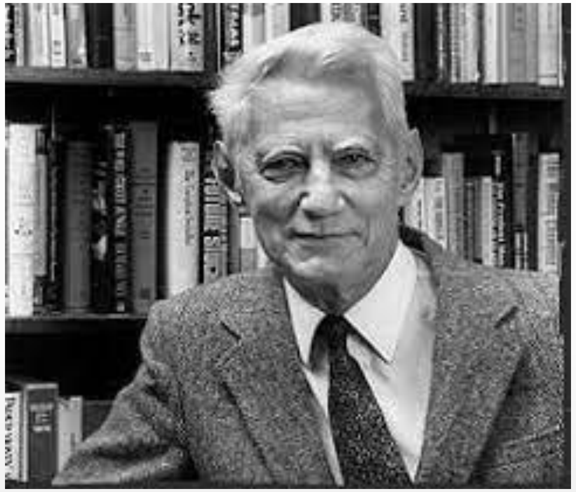


Most probably from left to right

THE PICTURE OF C. E. SHANNON AT DIFFERENT AGES

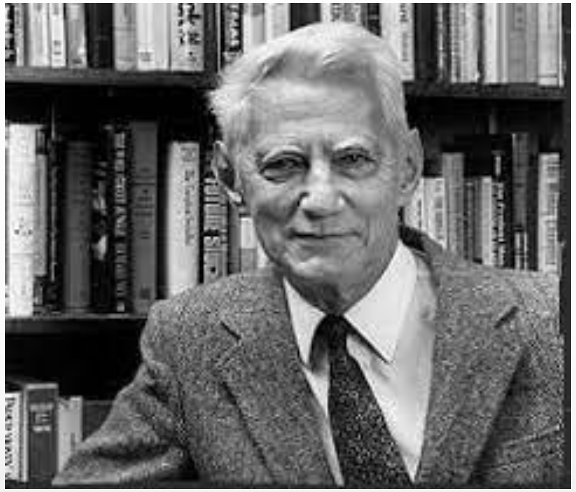
How an Arabic speaker would organize time?

THE PICTURE OF C. E. SHANNON AT DIFFERENT AGES




Most probably in the opposite direction: from right to left

THE PICTURE OF C. E. SHANNON AT DIFFERENT AGES



Most probably in the opposite direction: from right to left

… this has to do with *language specific* writing directions …

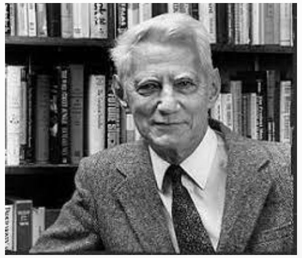
THE PICTURE OF C. E. SHANNON AT DIFFERENT AGES

How an Pormpuraaw Aborigian would organize time?

THE PICTURE OF C. E. SHANNON AT DIFFERENT AGES

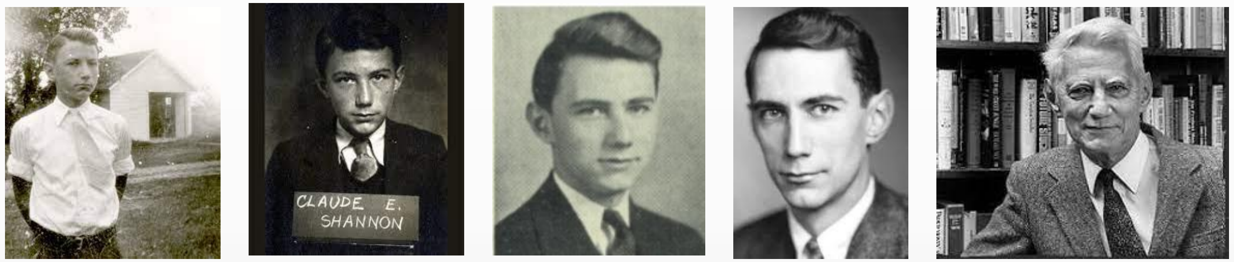
Sitting or standing <u>facing south</u>: from left to right



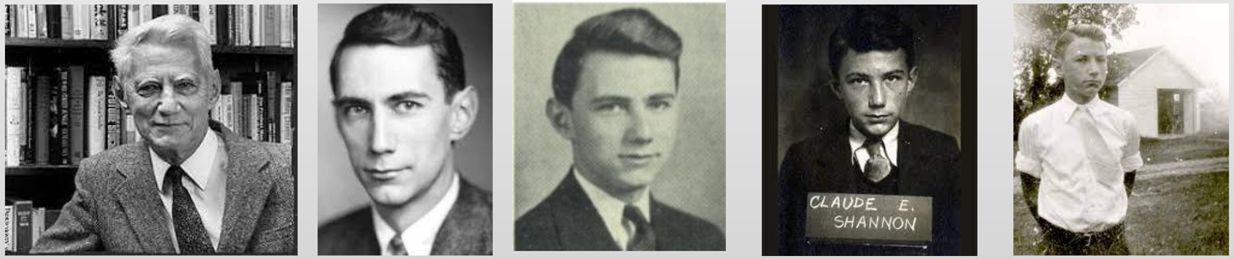



THE PICTURE OF C. E. SHANNON AT DIFFERENT AGES

Sitting or standing facing south: from left to right

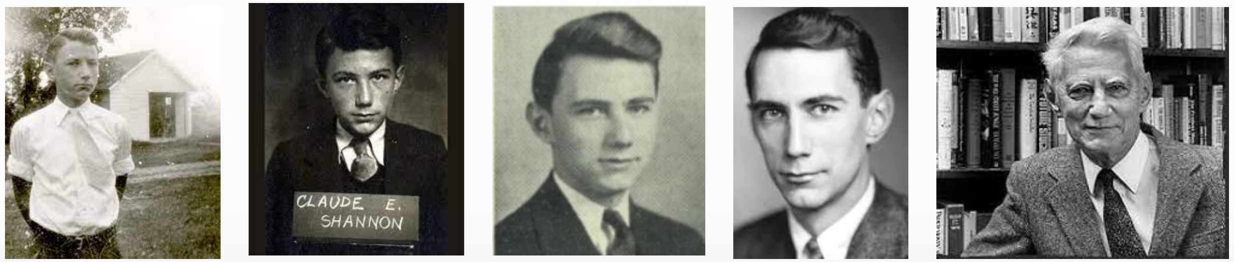


Sitting or standing facing north: from right to left



THE PICTURE OF C. E. SHANNON AT DIFFERENT AGES

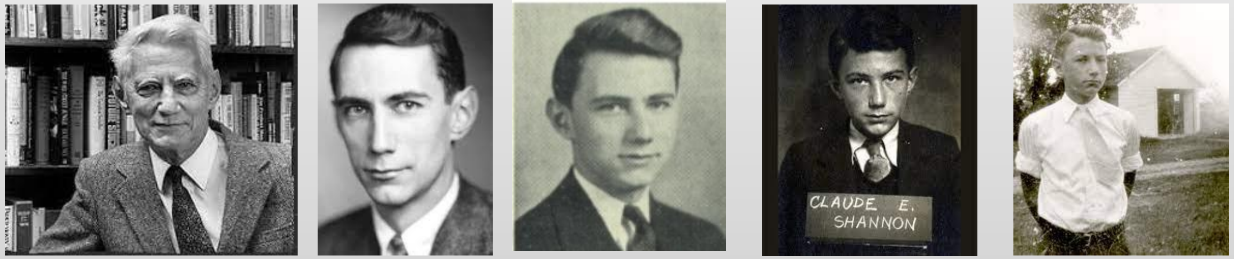
Sitting or standing facing south: from left to right



Sitting or standing facing east: time came toward the body

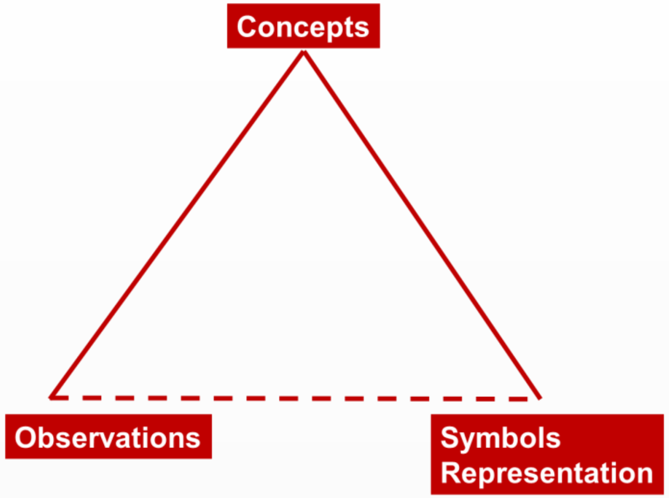
Time is locked on the environment

Sitting or standing facing north: from right to left



The language dramatically change the way to reason completely about space, time, attributes, relations, etc.

THE LANGUAGE GUIDES OUR UNDERSTANDING & REASONING ABOUT EVENTS!



- **Languages shape the way to think** (associate concepts to data)
- The way to communicate **depends on how intelligence is trained to reason**
- The language dramatically change the way to reason about space, time, attributes, etc.
- Agents trained on different languages will **pay attention to different things**
- Severe **Semantic Ambiguity** might arise !!

ISSUE

REASONING DIFFERENTLY: THE LANGUAGE GUIDES OUR REASONING ABOUT EVENTS!

In Germanic like languages (ex. English) you would say "he broke the vase"

- Attention on who did it
- Relations to concepts are stronger on who more than on why it happened

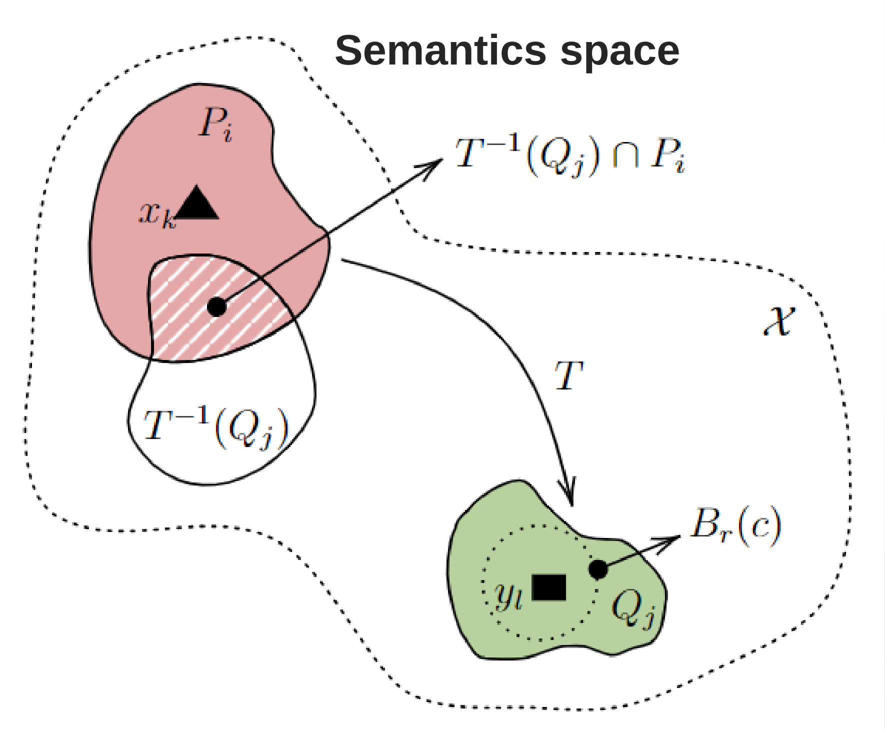
In romance like (ex. Spanish) you would say "the vase was broken (itself)

- Remember the intention (if it was an accident or not)

Agents observing the same event :

- **Extract** different concepts & differently **Interpret** concepts
- Associate different relations between concepts
- Actuation, control, decision making are potentially different

EXAMPLE SEMANTIC ALIGNMENT VIA SEMANTIC EQUALIZATION [GLOBECOM23]



Find T by solving the following problem [PCF+16]

Transport of source atoms — Kantorovich relaxation cost (*)

$$(\mathcal{P}'_1) \quad \underset{T\in\mathcal{T},\gamma\in\widehat{\Gamma}}{\operatorname{argmin}} \left|\left|T(\mathbf{X}_i) - N_X \boldsymbol{\gamma}\mathbf{B}_r(\mathbf{Y}_j)\right|\right|_{\mathcal{F}}^2 + \alpha\langle\gamma, D\rangle_{\mathcal{F}} + \beta h(T)$$

Alignment with target atoms — Regularization term

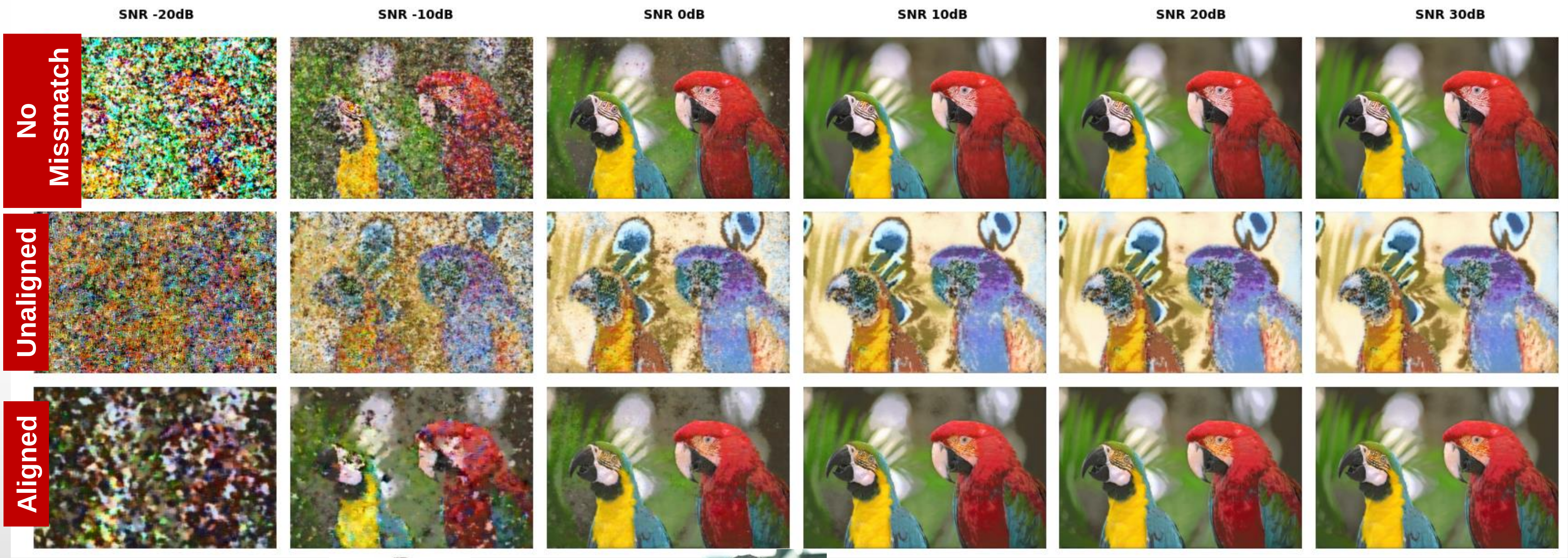
- $\mathbf{B}_r(\mathbf{Y}_j)$ is a barycentric mapping of the sample in $\mathbf{Y}_j$ into a ball of radius r center in c (e.g., atom centroid).
- Here, α and β are some hyper-parameters;
- $||\cdot||_f$ and $\langle\cdot,\cdot\rangle_{\mathcal{F}}$ are the Frobenius norm and dot product.
- D is the (Euclidean) distance matrix between sample in $\mathbf{X}_i$ and $\mathbf{Y}_j$
- Γ is the set of all probabilistic couplings in the space of all joint distributions with marginal μ and ν.

[PCF+16] M. Perrot, N. Courty, R. Flamary, and A. Habrard, “Mapping Estimation for Discrete Optimal Transport,” Advances in Neural Information Processing Systems, vol. 29, 2016.

[Globecom23] Sana, Mohamed, and **Emilio Calvanese Strinati. "Semantic channel equalizer: Modelling language mismatch in multi-user semantic communications."** IEEE GLOBECOM 2023.

EXAMPLE

THE MISALIGNMENT ISSUE



Prof. Paolo di Lorenzo

Dr. Emilio Calvanese Strinati

[Panacci25] L. Pannacci, S. Fiorellino, M. E. Pandolfo, **E. Calvanese Strinati**, and P. Di Lorenzo**. "Semantic Channel Equalization Strategies for Deep Joint Source-Channel Coding"** 2025.

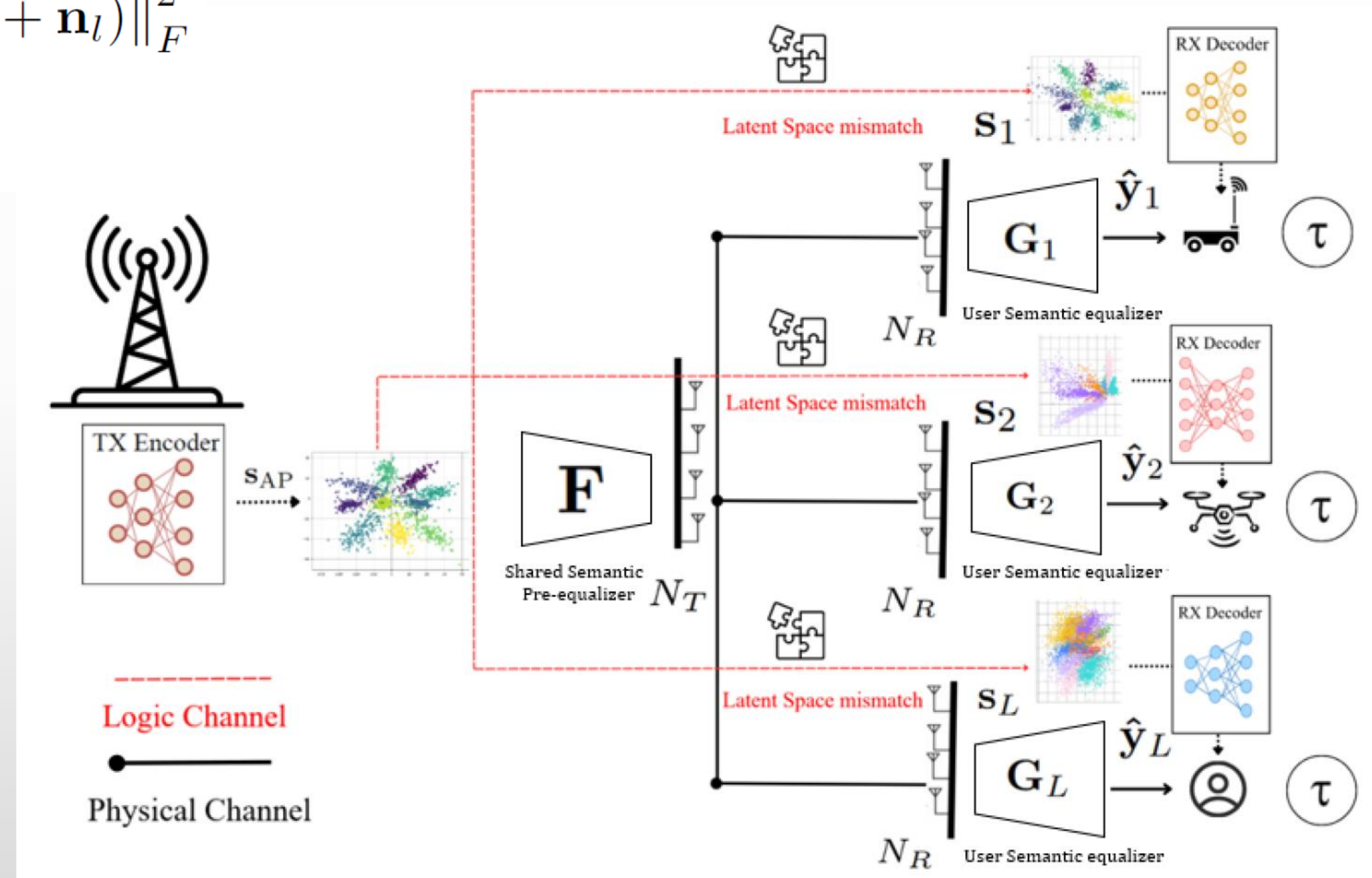
EXAMPLE SEMANTIC ALIGNMENT VIA MULTI USERS SEMANTIC EQUALIZATION [SPAWC25]

$$\min_{\mathbf{F},\{\mathbf{G}_l\}_{l=1}^{L}} \quad \frac{1}{Ln}\sum_{l=1}^{L}\sum_{i\in\mathcal{T}_r}\mathbb{E}\left\|\mathbf{y}_{i,l}-\mathbf{G}_l\left(\mathbf{H}_l\mathbf{F}\mathbf{x}_i+\mathbf{n}_l\right)\right\|_F^2$$

$$\text{s.t.} \quad \mathrm{tr}(\mathbf{F}\mathbf{F}^H) \le P_T$$

Algorithm 1 : Federated ADMM for Semantic Alignment

Input: $\mathbf{F}^{(0)} \sim \mathcal{CN}(0,1)$, $\{\mathbf{Z}^{(0)},\mathbf{U}^{(0)}\} = \mathbf{0}$, $\rho > 0$.
Output: Final values $\mathbf{F}^{(T)}, \mathbf{G}^{(T)}, \mathbf{Z}^{(T)}, \mathbf{U}^{(T)}$.
Perform *handshaking*;
for each iteration $t = \{1,\dots,T\}$ **do**
    The AP transmits $\mathbf{S}_l^{(t)}$ to all users $l = 1,\dots,L$;
    The users update locally $\mathbf{G}_l^{(t+1)}$ as in (7);
    Users send $\mathbf{A}_l$ and $\mathbf{P}_l$ to the AP;
    The AP updates $\mathbf{F}^{(t+1)}$ as in (8);
    The AP updates $\mathbf{Z}^{(t)}$ as in (17);
    The AP updates $\mathbf{U}^{(t)}$ as in (18).
end for

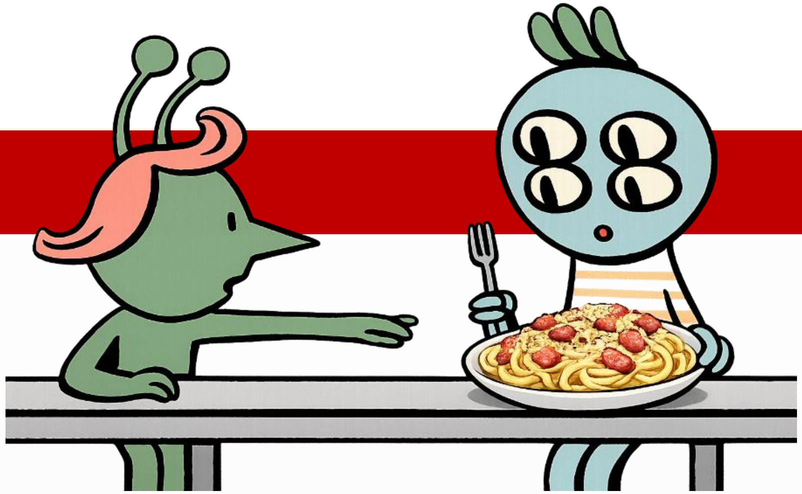


[SPAWC25] G. Di Poce, M. E. Pandolfo, E. Calvanese Strinati, P. Di Lorenzo, Federated Latent Space Alignment for Multi-User Semantic Communications, IEEE SPAWC 2025.

SEMANTIC COMMUNICATION OPTIMIZATION OVER TIME

- Transmitter-receiver is like a couple experiencing a relationship
- Communication improves over time
  - Building an optimal language
  - Mutual learning and shared knowledge

Communication to ask for Carbonara Pasta



First meeting

- Introduce each other
- Ask kindly with properly described request
- Thanks the other one

Shannon → **Weaver**

SEMANTIC COMMUNICATION OPTIMIZATION OVER TIME

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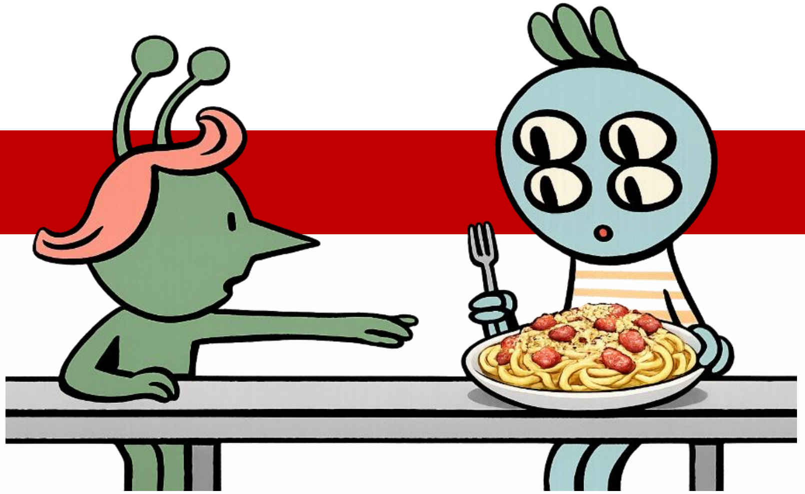

First meeting

- Introduce each other
- Ask kindly with properly described request
- Thanks the other one

Several months

- Know each other / brief introduction
- Ask with described request
- Brief thanks

Shannon → **Weaver**

SEMANTIC COMMUNICATION OPTIMIZATION OVER TIME

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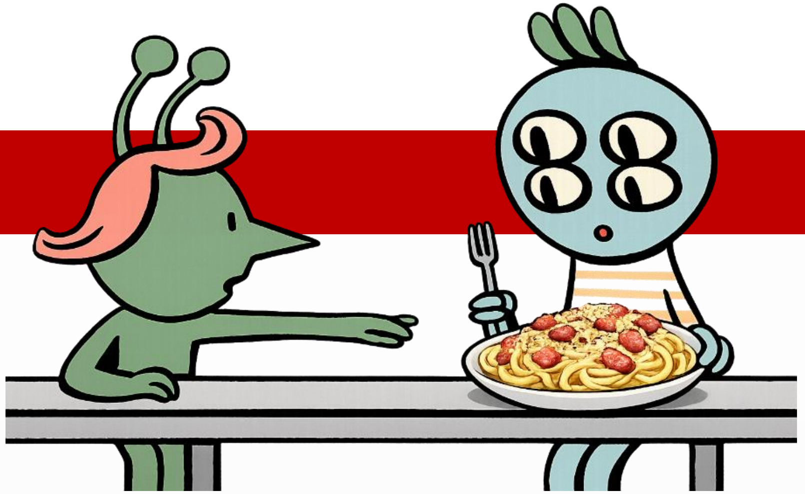

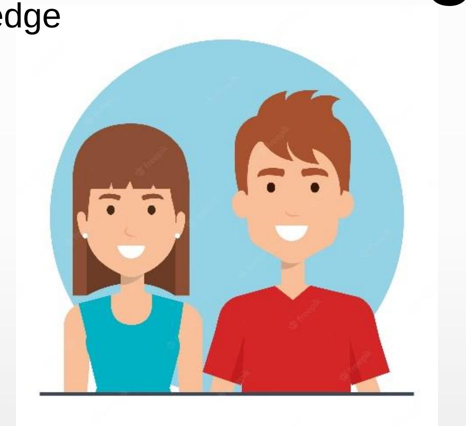

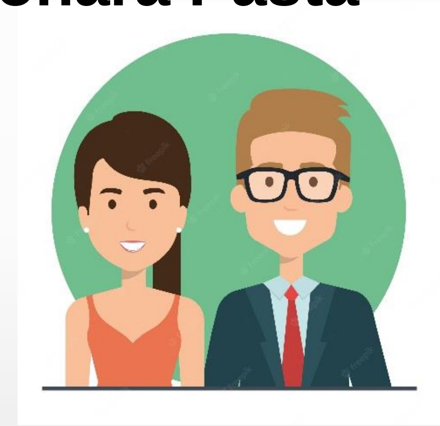

First meeting

- Introduce each other
- Ask kindly with properly described request
- Thanks the other one

Several months

- Know each other / brief introduction
- Ask with described request
- Brief thanks

Several years

- No introduction
- Expect the other one to do the action
- Ask with short request
- No thanks

Shannon → **Weaver**

SEMANTIC COMMUNICATION OPTIMIZATION OVER TIME

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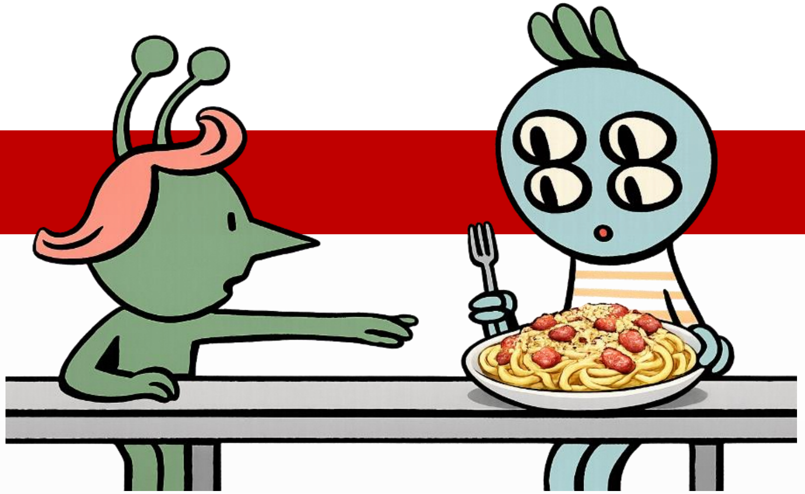
Communication to ask for Carbonara Pasta



First meeting

- Introduce each other
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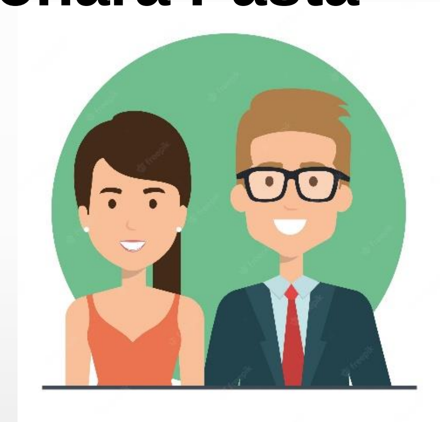
Several months

- Know each other / brief introduction
- Ask with described request
- Brief thanks



Several years

- No introduction
- Expect the other one to do the action
- Ask with short request
- No thanks

A whole life

- Just able to hear the other one
- Ask with a quick eye contact
- No thanks
- Wait for the next eye contact

Shannon → **Weaver**

5. TENTATIVE SCOPE FOR ETSI ISG ON SEMANTIC COMMUNICATIONS

Tentative Scope :

- Definition of a **list of key use cases** that benefit from Semantic Communications, with a roadmap for their study and evaluation.
- Derive **semantic information representation and models** (semantic encoding/decoding frameworks, knowledge representation, multimodal semantics, and AI/ML integration).
- Definition of an **architecture framework** for Semantic Communications, including inteterfaces, link-level and system-level mechanisms and protocols, and deployment considerations.
- Study how to leverage **AI/ML and Computing** assets in the Semantic Communications model and establish a framework for their effective integration.
- Study of the **end-to-end privacy and security aspects** as part of the generation, transmission, detection, computation, and storage of semantic information.
- Derive a set of **KPIs and an evaluation methodology** building upon potential synergies with other ETSI TBs, like TC DATA, TC QT, “TC NET”, and ISG ISAC.
- Foster **proof-of-concept and prototyping initiatives** (reference implementations, experimental platforms, interoperability demonstrations, and trials).

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Contact me if you wish to join the ETSI Semantic Communication ISG

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6GARROW EU-KR HORIZON PROJECT

6GARROW

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Aalto University

University of Oulu

Fraunhofer HHI

intel

orange

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Grenoble Ecole de Management

Hewlett Packard Enterprise

LG

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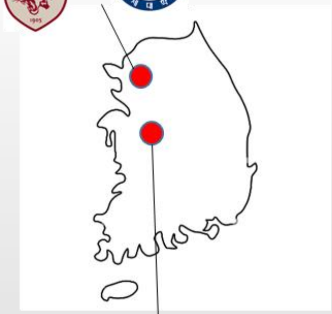
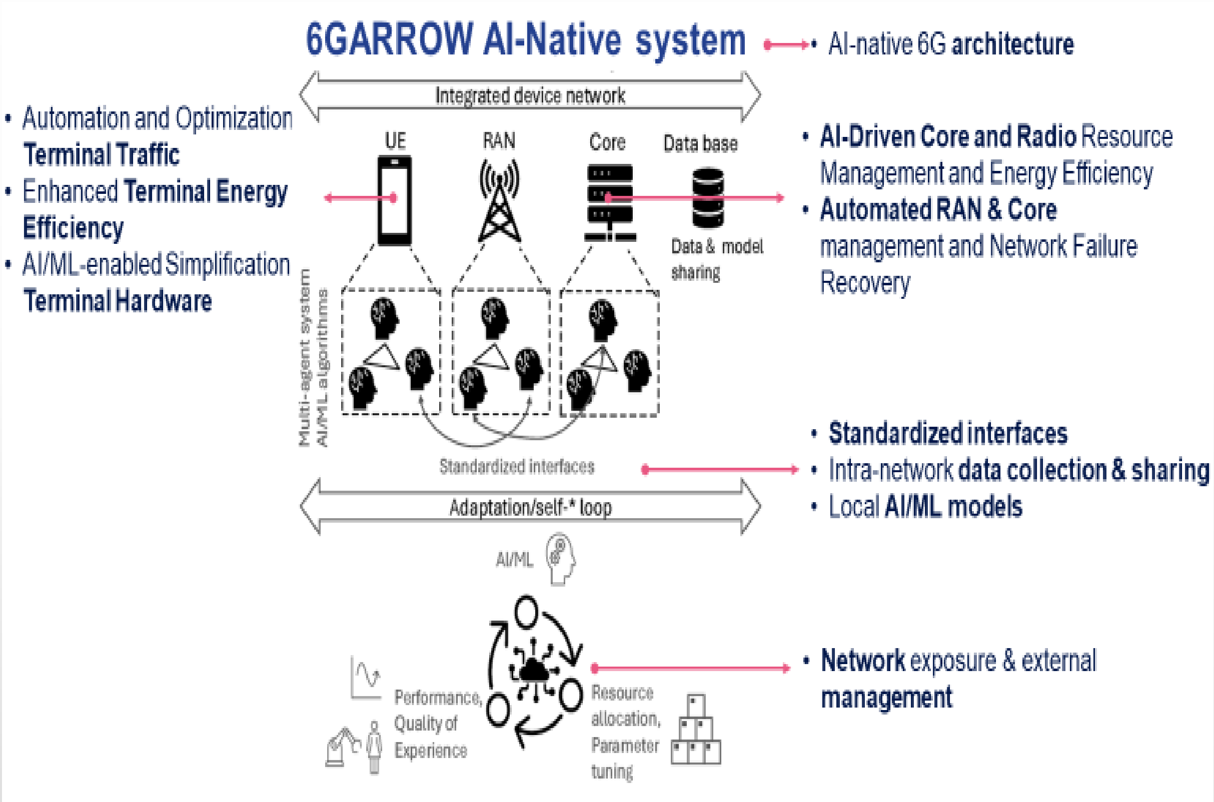


ETRI



5G PPP PUBLIC-PRIVATE PARTNERSHIP

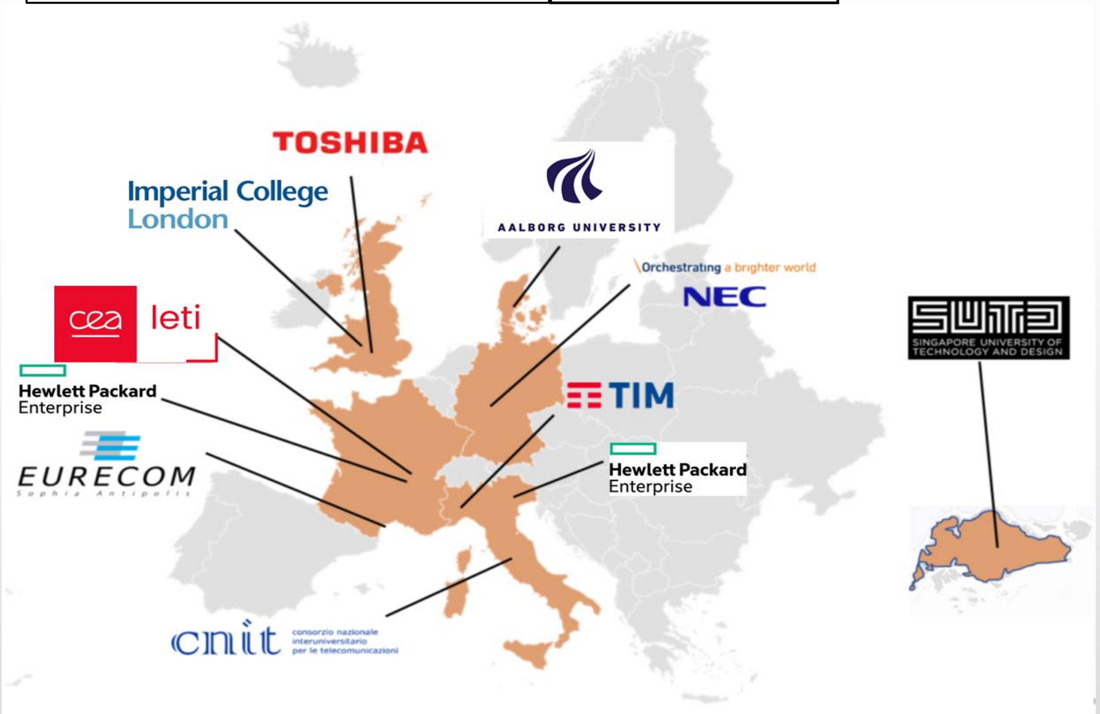
6G SNS

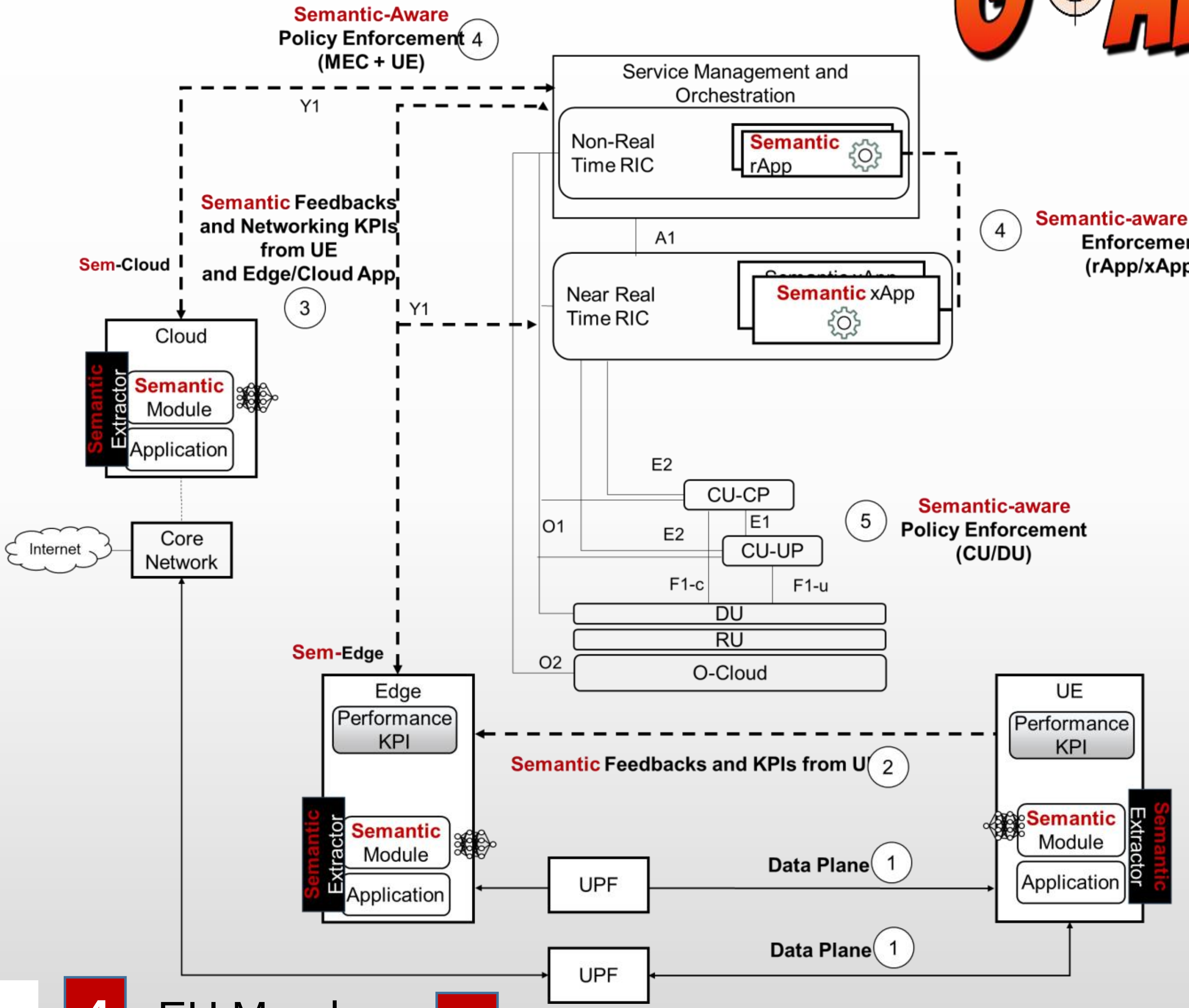
13	Consortium Partners	4	EU Member States + Korea

6G-GOALS HORIZON PROJECT

Project Coordinator:
Emilio CALVANESE STRINATI

Technical Manager:
Paolo DI LORENZO





5G PPP PUBLIC-PRIVATE PARTNERSHIP

6GSNS PHASE 2

11 Consortium Partners

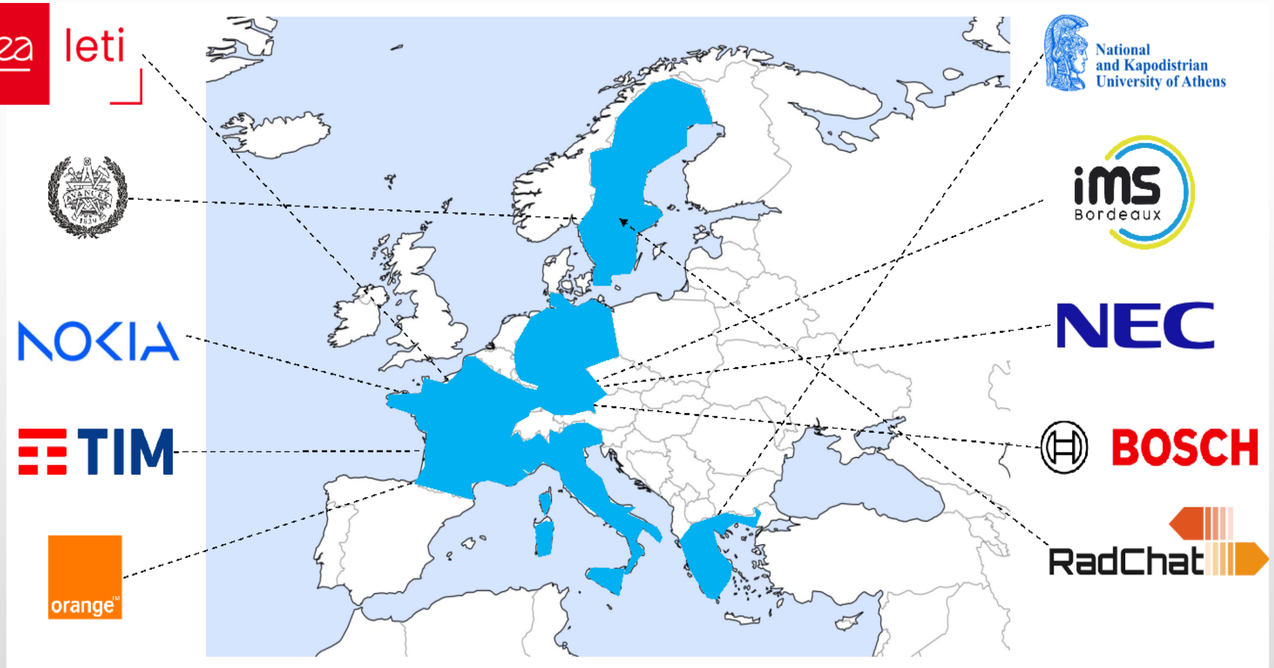
4 EU Member States

1 Asian Affiliated partner

6G-DISAC HORIZON PROJECT

Project Coordinator:
Emilio CALVANESE STRINATI

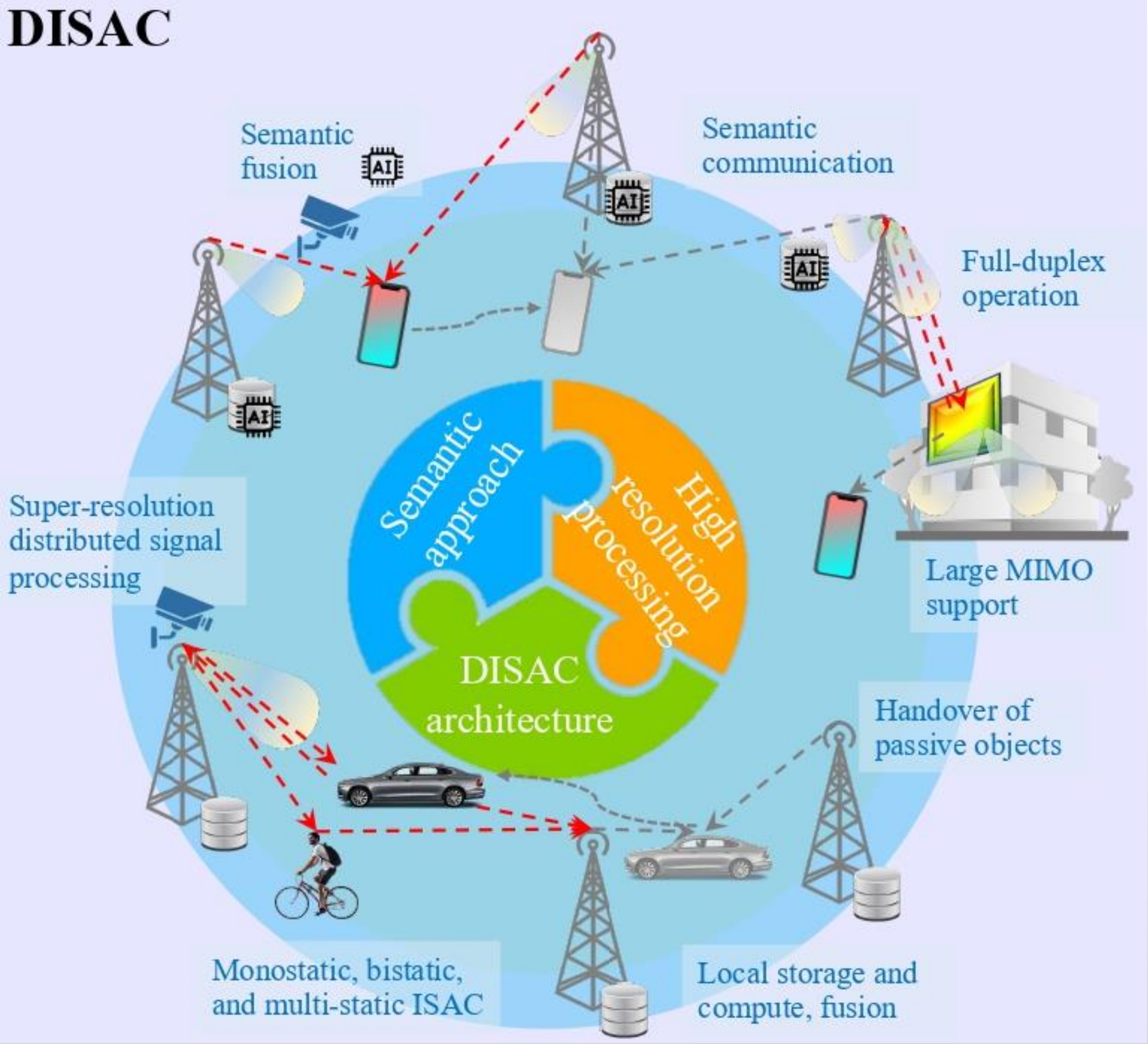
Technical Manager:
Henk Wymeersch



PHASE 2

10 Consortium Partners

5 EU Member States



Thank you!

MERCI!

謝謝

고맙습니다

ALOHA

Grazie!

https://doi.org/10.1038/s44287-024-00090-1

6G: the catalyst for artificial general intelligence

Nature reviews

Emilio Calvanese Strinati

Check for updates

6G might integrate 5G and AI to merge physical, cyber and sapience spaces, transforming network interactions and enhancing AI-driven decision-making and automation. The semantic approach to communication will train AI while selectively informing on goal achievement, moving towards artificial general intelligence, presenting new challenges and opportunities.

Although 5G is not yet fully deployed, there is already disagreement as to what 6G will be. The mainstream vision of 6G today is that it is a combination of 5G and artificial intelligence (AI), making it the main gateway to artificial general intelligence. However, even the link between AI and 6G is controversial. Existing AI systems are still stochastic parrots[1], mimicking or repeating sequences without any true understanding of the training data or their own output. Massive amounts of scattered data are capillary fed to AI by 5G networks with this 'content-blind transmission without understanding' approach. Thus, data are teleported without any prior understanding of how informative, valuable or timely the data are, and then the data are used to train and feed AI, with the aim of inducing reasoning and adaptation to various operational environments. As a result, AI algorithm outcomes remain limited to sophisticated pattern recognition and statistical correlations. Some algorithms generate responses on the basis of learned data, but without true understanding, interpretation or reasoning of the underlying meaning and nuances of the information processed. 6G needs more from AI and can offer more to AI. The hope is that 6G could make AI less artificial, connecting the biological world and AI, thus bridging the gaps between physical, cyber (digital) and sapience spaces. Meanwhile, AI is expected to hone reasoning skills, enabling reliable self-synthesizing networking and full automation of network management, thus eliminating the need for manual intervention (zero-touch networking).

6G can connect and entangle the physical, cyber and sapience spaces to radically change the system's perception of the foundational concepts of space, time, information and reliability.

Specifically, the shift from 5G to 6G marks a profound transformation in how networks and technologies interact with humans across physical and cyber spaces, creating intelligent environments that are responsive to the presence of both humans and machines. 5G is not AI native[2]: data are essential to feed AI reasoning engines; data are gathered, transferred and processed from scattered sources to update models, accumulate knowledge and attain goals. Still, 5G enhanced connectivity is designed to transport raw data rather than AI-understandable knowledge.

In contrast, 6G aims to create a deeply integrated, intelligent and immersive ecosystem. This ecosystem fus real-world interactions and events occur, tl interactions and activities take place, and humans and AI can combine their cognitive edge meaningfully. The Integrated comm advanced localization techniques of 6G and fusion of contextualized multimodal video, which can then be semantically anal communications will support AI by selecti representing knowledge to make continuo possible. AI will thus be able to make inforn underlying objective of the communicatio and to distinguish between correlation ar

As for time, chronological measurem nant in 5G. Instead, the focus is on the late sion and its reliable reception. 5G end-to managed mainly to limit and regulate da transmission latency within the wireless a the cumulative contributions of processing specific limitations. With 5G, this trans transfer speeds and guaranteed synchro applications and services. Nevertheless challenging. As of today, the physical limi munication are being reached, making it solutions at higher-spectrum bands. The s considered in 6G, targeting even smaller tii ing strictly controllable 'time jitters' to ser with similar physical and hardware limit for new spectra is increasingly difficult. T the conceptual understanding of time in different from that in 5G systems. Time is munication, processing, reasoning, mem use of information, such as inference, co 6G, time is not just about latency, nor is and ordering boundaries for the physical experienced differently, owing to disentar physical, cyber and sapience spaces. 6G the sapience space, where time is under within and between the physical and cyb ing reasoning, decision-making and the d and wisdom.

In the sapience space, time causality ceived, and digital synchrony differs simultaneity. Interactivity and the illusi the perceptible time granularity. This g spaces and agents (biological or artifici their methods of collecting, modeling, p external stimuli. Timing is governed by dy

nature reviews electrical engineering

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6G networks: Beyond Shannon towards semantic and goal-oriented communications

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Semantic learning
Goal oriented communications
Sustainability
Green communications

ABSTRACT

The goal of this paper is to promote the idea that including semantic and goal-oriented aspects in future 6G networks can produce a significant leap forward in terms of system effectiveness and sustainability. Semantic communication goes beyond the common Shannon paradigm of guaranteeing the correct reception of each single transmitted bit, irrespective of the meaning conveyed by the transmitted bits. The idea is that, whenever communication occurs to convey meaning or to accomplish a goal, what really matters is the impact that the received bits have on the interpretation of the meaning intended by the transmitter or on the accomplishment of a common goal. Focusing on semantic and goal-oriented aspects, and possibly combining them, helps to identify the *relevant information*, i.e. the information strictly necessary to recover the meaning intended by the transmitter or to accomplish a goal. Combining knowledge representation and reasoning tools with machine learning algorithms paves the way to build semantic learning strategies enabling current machine learning algorithms to achieve better interpretation capabilities and contrast adversarial attacks. 6G semantic networks can bring semantic learning mechanisms at the edge of the network and, at the same time, semantic learning can help 6G networks to improve their efficiency and sustainability.

Goal-Oriented and Semantic Communication in 6G AI-Native Networks: The 6G-GOALS Approach

Emilio Calvanese Strinati*, Paolo Di Lorenzo†, Vincenzo Sciancalepore‡, Adnan Aijaz,§, Marios Kountouris¶, Deniz Gündüz‖, Petar Popovski**, Mohamed Sana*, Photios A. Stavrou ¶, Beatriz Soret**, Nicola Cordeschi†, Simone Scardapane†, Mattia Merluzzi*, Lanfranco Zanzi‡, Mauro Boldi Renato ††, Tony Quek ‡‡, Nicola di Pietro*, Olivier Forceville*, Francesca Costanzo*, Peizheng Li§

Pragmatic Goal-Oriented Communications under Semantic-Effectiveness Channel Errors

Tomás Hüttebraucker, Mohamed Sana, Emilio Calvanese Strinati

Effective Goal-oriented 6G Communications: the Energy-aware Edge Inferencing Case

Mattia Merluzzi[1], Miltiadis C. Filippou[2], Leonardo Gomes Baltar[2], Emilio Calvanese Strinati[1]

Learning Semantics: An Opportunity for Effectiv 6G Communications

Mohamed Sana[1], Emilio Calvanese Strinati[1]

Goal-Oriented Communications for the IoT: System Design and Adaptive Resource Optimization

Paolo Di Lorenzo, Mattia Merluzzi, Francesco Binucci, Claudio Battiloro, Paolo Banelli, Emilio Calvanese Strinati, and Sergio Barbarossa

Semantic Channel Equalizer: Modelling Language Mismatch in Multi-User Semantic Communications

Mohamed Sana, Emilio Calvanese Strinati

6G Goal-Oriented Communications: How to Coexist with Legacy Systems?

Mattia Merluzzi [1,*], Miltiadis C. Filippou [2,†], Leonardo Gomes Baltar [2,‡], Markus Dominik Mueck [2] and Emilio Calvanese Strinati [1]


¡Por favor, haz solo preguntas fáciles y con mucho entusiasmo!