On Toward the Realization of Artificial Scientists:
Progress and Concerns

Ryohei Sasano, Nagoya University

The awarding of the 2024 Nobel Prize in Chemistry to the developers of AlphaFold, a groundbreaking system that predicts the three-dimensional structures of proteins using artificial intelligence (AI), highlights the growing importance of AI in scientific discovery. In recent years, this trend has further evolved through initiatives such as self-driving labs, which aim to integrate automated experimentation with AI-driven decision-making, and projects leveraging large language models (LLMs) to assist or automate the entire research cycle from hypothesis generation and experimental design to result interpretation and scientific writing (Fig. 1). Among these developments, the automatic generation of scientific papers by AI is raising important questions about its impact on scientific communication, considering reports that AI-generated papers have passed peer-review processes. This talk focuses on AI-driven scientific writing as part of broader efforts toward realizing artificial scientists and provides an overview of the progress and concerns, with particular attention to potential citation biases and the ongoing debates about submitting AI-generated papers to peer-reviewed conferences.

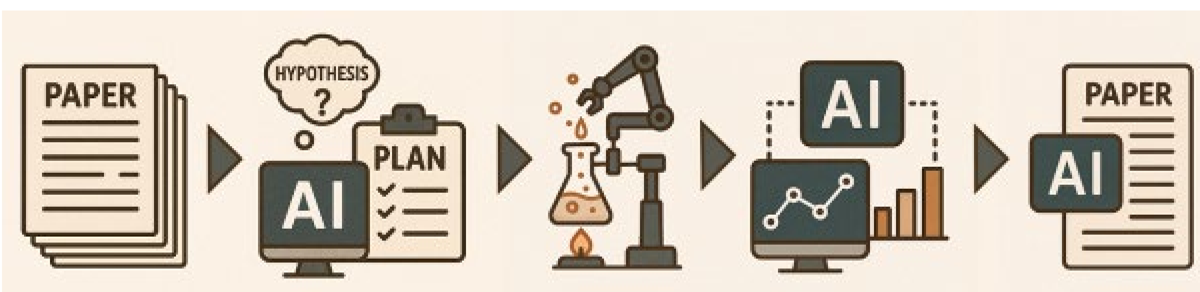

Fig. 1 Conceptual illustration of AI automating the entire research cycle.

Refences:

[1] Gottweis et al. “Towards an AI co-scientist.” arXiv preprint arXiv:2502.18864 (2025). https://arxiv.org/abs/2502.18864

[2] Lu et al. “The AI Scientist: Towards Fully Automated Open-Ended Scientific Discovery.” arXiv:2408.06292 (2024). https://arxiv.org/abs/2408.06292

Peer review in the Age of AI

Ilia Kuznetsov, TU Darmstadt, Germany

Peer review is the cornerstone of academic quality control. It helps us validate and prioritise research, decide who gets the funding, and determine which findings are worth public attention. Yet, submission numbers are rising, and the experts are lacking. Exhausted reviewers, low-quality reviews, publication delays and perceived randomness of the process are commonplace. LLMs and AI are poised to revolutionize knowledge work, and promise to help us write more clearly, read more thoroughly, review more efficiently – and maybe, one day, AI systems can produce research on their own. But AI can also do a lot of harm by enabling unethical behavior, reinforcing bias, leaking confidential information, and inducing undue trust. How can we use AI to help science, without breaking science?

My talk will introduce current challenges on the path towards responsible AI for reviewing assistance and scientific work. I will describe a systemic approach to reviewing assistance, that sees peer review as a complex process where different parties perform different tasks, which allow different degrees of automation. I will talk about capability measurement as a key scientific challenge in developing AI for peer review, and share key insights from my work in this domain. Finally, I will talk about AI ethics and safety, highlighting the issues of bias, confidentiality, authorship and accountability: some tasks are better left to humans, not because LLMs can't, but because they shouldn't. So far, AI for peer review has been limited to the computer science community. To move forward, we need dialogue and productive collaboration between computer science and researchers from other fields.

Glossary:

LLMs (large language models): general-purpose language-centric AI systems like ChatGPT, GPT-4, Claude, Gemini and LLaMa. LLMs are predominantly studied in Natural Language Processing – a subfield on the intersection of machine learning, computational linguistics and AI research. Many types of reviewing assistance do not require an LLM per se and are not limited to language, so I often use AI systems as a general term.

Task: in machine learning, a task is a formal description of a desired system behavior, often specified in terms of input, expected output and a metric that measures the system's success rate (or **performance**) on the task. Tasks vary widely in terms of complexity, inputs, outputs and success criteria. Some examples of tasks include machine translation, image recognition, question answering, and information retrieval.

Bias: a systematic deviation in model's behavior due to an external factor that, by design, should not affect this behavior. Some examples of bias include gender bias in job application screening, harmful LLM behavior in low-resource languages, and social class bias where AI systems under-perform on texts produced by certain demographics.

Further materials:

- White paper "*What can Natural Language Processing do for Peer Review?*" https://arxiv.org/abs/2405.06563
- Website of the InterText initiative https://intertext.ukp-lab.de/

Can LLMs Generate Novel Research Ideas?

Diyi Yang, Stanford University

Can large language models (LLMs) generate novel and effective research ideas? In this talk, I present findings from two large-scale human studies involving over 100 NLP researchers that evaluate LLMs' research ideation capabilities. We first show that LLM-generated research ideas are rated as significantly more *novel* than those from human experts, though slightly less *feasible*. However, when these ideas are executed by researchers and turned into full projects, their perceived quality drops significantly more so than human ideas, often reversing their initial rankings across all evaluation metrics. These results reveal a critical ideation-execution gap, highlighting both LLMs' potential and limitations in advancing scientific discovery.

Background Review Articles:

Si, Chenglei, Diyi Yang, and Tatsunori Hashimoto. "Can LLMs Generate Novel Research Ideas? A Large-Scale Human Study with 100+ NLP Researchers." In The Thirteenth International Conference on Learning Representations.

Si, Chenglei, Tatsunori Hashimoto, and Diyi Yang. "The Ideation-Execution Gap: Execution Outcomes of LLM-Generated versus Human Research Ideas." arXiv preprint arXiv:2506.20803 (2025).

An Earth History Perspective on Climate

Christian Zeeden, LIAG Institute for Applied Geophysics, Germany

Climate has been changing throughout in Earth history, with warm and cold episodes. Yet, the recent rapid increase in global CO_2 concentrations and temperatures is rather unique. This talk bridges an Earth-history viewpoint with the ongoing climate change. Special emphasis will be laid on the last ~60 million years in which Earth's climate dynamically devolved and underwent warm- and cold-phases. Drivers of natural climate variability will be discussed. The last decades have seen a clear warming in global mean temperatures, yet local effects are varying considerably. While mean temperatures are mostly assessed, also the precipitation and availability of water are of high relevance for society and biota.

While a warming per se is naturally expected to lead to a higher biodiversity, Earth is intensively occupied and utilized by humans. Higher mean temperatures lead to higher evapotranspiration, and drought is in many places not only a natural phenomenon, but amplified by the extensive and often non-sustainable use of groundwater. Biota react to climate and to seasonality particularly sensitively, and for example an earlier blossoming in spring occurs. While for a long time, natural climate change has been the driver of evolution and ecosystems, humans are forming landscapes efficiently nowadays, with clear effects on ecosystems.

Invisible Nutrient Cycle in Coral Reefs

Atsuko YAMAZAKI, Nagoya University

Tropical and subtropical coastal areas are home to many creatures with crystal-clear seas. The high transparency of the water means that there are almost no nutrients necessary for living creatures. We are trying to clarify the invisible nutrient cycle.

Coral reefs are distributed at the boundary between the hydrosphere, lithosphere, and atmosphere. Despite facing various environmental changes, coral reefs maintain a high level of biodiversity. However, due to high solar radiation, producers quickly consume and deplete nutrients. This results in few continuous and quantitative nutrient observation records, and the nutrient cycle has not been fully clarified.

Therefore, we focused on coral skeletons. Like trees, coral skeletons form annual rings, and geochemical analysis along their growth direction enables us to quantitatively understand environmental changes in coral reefs, such as water temperature, salinity, and the concentration of substances flowing into the reef. We successfully analyzed the nitrogen isotope ratios used as major nutrient tracers in coral skeletons [1]. The nitrogen isotope proxy enabled us to determine the origin of nutrients in coral reefs, and their seasonal and annual variations over the past few centuries, and even further back in time using fossils.

It has become clear that coral reefs are exposed to ocean currents and upwellings and sometimes utilize nitrogen fixation. They maintain their ecosystems by utilizing various nutrients, depending on the sea area. It has also become clear that the origin of nutrients has changed significantly due to climate change [2]. Human activities have also begun to affect the nutrient cycle in recent years. Our goal is to understand the marine environment that nurtures coral reef ecosystems, the effects of climate change, and our role within that system. We aim to work with people in coral reef regions to promote sustainable practices.

References:

[1] Yamazaki, A., T. Watanabe, and U. Tsunogai (2011), Nitrogen isotopes of organic nitrogen in reef coral skeletons as a proxy of tropical nutrient dynamics, *Geophys. Res. Lett.*, 38, L19605, doi:10.1029/2011GL049053.

[2] Yamazaki, A., T. Watanabe, U. Tsunogai, F. Iwase, and H. Yamano (2016), A 150-year variation of the Kuroshio transport inferred from coral nitrogen isotope signature, *Paleoceanography*, 31, 838–846, doi:10.1002/2015PA002880.

Glossary:

- nitrogen isotope ratios: The ratio of stable nitrogen isotopes 14N and 15N. By analyzing the nitrogen isotope ratio in nitrogen compounds, the origin and mixing ratio of the compounds can be determined, making it useful as an environmental tracer.

Locusts, Monsoons, and Livelihoods: A Climate-Induced Crisis Hidden in Plain Sight

Daniel Gebregiorgis, Georgia State University

Eastern Africa faces an increasingly severe, climate-induced locust risk that remains under-prioritized in global climate discourse despite its disproportionate impacts on smallholder food security. The latest Intergovernmental Panel on Climate Change (IPCC) report documents that both weather extremes—events rare for a particular place and time of year—and climate extremes—persistent patterns of extreme weather—have increased markedly in intensity and frequency worldwide (Seneviratne et al., 2021). These shifts create ideal breeding conditions—moist soils, greening vegetation, and warm temperatures—that enable rapid locust population growth and long-range swarm movements. During the 2019–2021 crisis, more than 20 million people in six countries were pushed toward acute food insecurity, with losses reaching billions of dollars, while operational surveillance struggled to ground-truth remote breeding areas. Future projections indicate that insect-driven crop losses could rise by up to ~50% under +2 °C warming, underscoring the need for climate-aware, community-centered monitoring that complements the FAO's global Desert Locust Information Service (DLIS) with stronger local verification and ethical, environmentally safer control options (Gebregiorgis et al., 2025).

In this talk, I stress that urgent attention and better-designed mitigation strategies are essential to address the dire and underreported crisis of recurring locust outbreaks. The increasing frequency and wide geographic spread of recent events underscore the pivotal role of anthropogenic climate change in amplifying their severity and intensity. While the United Nations Food and Agriculture Organization (FAO) plays a central role in global locust management—operating a 24/7 surveillance system through its Desert Locust Information Service (DLIS) to provide forecasts, early warnings, and alerts on the timing, scale, and location of invasions and breeding areas—critical gaps persist in local verification, community engagement, and timely, targeted response. Strategies for mitigating and managing future locust outbreaks focus on integrating community perspectives, needs, and insights with emerging technologies to enable effective large-scale monitoring, early detection, reporting, verification, and control.

Background Review Article:

Salih, A.A., Baraibar, M., Mwangi, K.K. and Artan, G., 2020. [Climate change and locust outbreak in East Africa](). Nature Climate Change, 10(7), pp.584-585.

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Gebregiorgis, D., Asrat, A., Birhane, E., Tiwari, C., Kiage, L.M., Ramisetty-Mikler, S., Kallam, S., Kabengi, N., Gebrekirstos, A., Wanjiru, S. and Mariam, H.G., 2025. Critical gaps in the global fight against locust outbreaks and addressing emerging challenges. npj Sustainable Agriculture, 3(1), p.29.

Seneviratne, S.I., Zhang, X., Adnan, M., Badi, W., Dereczynski, C., Luca, A.D., Ghosh, S., Iskandar, I., Kossin, J., Lewis, S. and Otto, F., 2021. Weather and climate extreme events in a changing climate.

From Taxonomy to Conservation: Mapping Extreme Life in the Ocean

Torben Riehl, Senckenberg Research Institute and
Natural History Museum Frankfurt, Germany

The ocean's depths represent one of Earth's last great frontiers, harboring life forms that thrive under conditions once thought impossible—crushing pressures, perpetual darkness, and frigid temperatures. These "extreme" environments are not barren; instead, they teem with a diversity of organisms whose extraordinary adaptations challenge our understanding of biology and resilience. As we explore these realms, we uncover not only new species but also novel ways life can persist, offering insights relevant far beyond marine science.

Today, the deep ocean is increasingly recognized as a critical player in the planet's climate system. It absorbs vast amounts of heat and carbon dioxide, helping to buffer the impacts of climate change on the surface. Yet, this vital role also makes it vulnerable: warming, acidification, and oxygen loss are altering deep-sea habitats, threatening both their unique biodiversity and the essential services they provide to humanity.

The deep ocean's fate is intertwined with global challenges—climate change, resource extraction, and the need for sustainable stewardship—making its study relevant to all scientific disciplines.

This session invites scientists from across fields to engage with the mysteries and urgencies of extreme ocean life. Connections abound: the flows and patterns shaping deep-sea currents mirror those in physics and materials science; the chemistry of two-dimensional materials echoes the molecular innovations of deep-sea organisms; and the impacts of climate change on the biosphere are nowhere more acute than in these hidden depths. Even the rise of artificial intelligence in data analysis opens new possibilities for unraveling deep-sea complexity.

By bridging disciplines, we can better understand, protect, and learn from the ocean's most extreme inhabitants—a task that is both an intellectual adventure and a planetary necessity.

The Unseen Life in the Deep Sea Reshaping Our View of Evolution

Masaru K. NOBU, Japan Agency for Marine-Earth Science and Technology

Life began with simple cells—**prokaryotes**—possibly in the deep ocean, and studying their biology is essential to understanding the essence of life on Earth. Yet the minuscule size of microbes puts them beyond the reach of our eyes. Under the microscope, we can see a diversity of microbial cells, but shape alone rarely reveals identity, and most microbes remain biologically anonymous. Among the roughly 200 major branches (phyla) of prokaryotic life, only about 20% have ever been grown and observed in the lab. This leaves fundamental questions about cell structure, function, and evolution largely unanswered.

What separates simple from complex life, and how did complexity evolve? Life is often divided into **prokaryotes**, like bacteria and archaea, which have relatively simple cells, and **eukaryotes**, like animals, plants, and fungi, whose cells are internally structured. For decades, this distinction defined biological complexity.

Recent discoveries are now blurring that line. One comes from our success in growing a bacterium that surrounds its DNA with a membrane—a feature once thought unique to eukaryotes. Yet even this level of complexity is far from what we see in eukaryotic cells, prompting the need to dig deeper to find the source of our cellular architecture.

A deeper clue emerged when we cultured an archaeon from deep-sea sediments closely related to the ancestor of all eukaryotes, ***Promethearchaeati***. This organism grows extremely slowly, depends on symbiotic partners, and lives without oxygen. Most unexpectedly, it forms elaborate membrane-based structures outside the cell—suggesting that cellular complexity may have first evolved at the surface.

Together, these findings reshape our understanding of what cells are capable of and where complexity begins, offering the first experimental glimpse into the evolutionary roots of all organisms we can see with the naked eye.

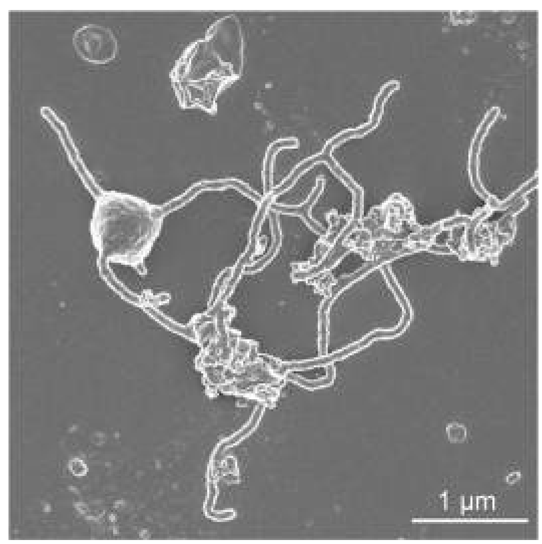

Figure 2. Microscopy image of a close relative of our ancestor.

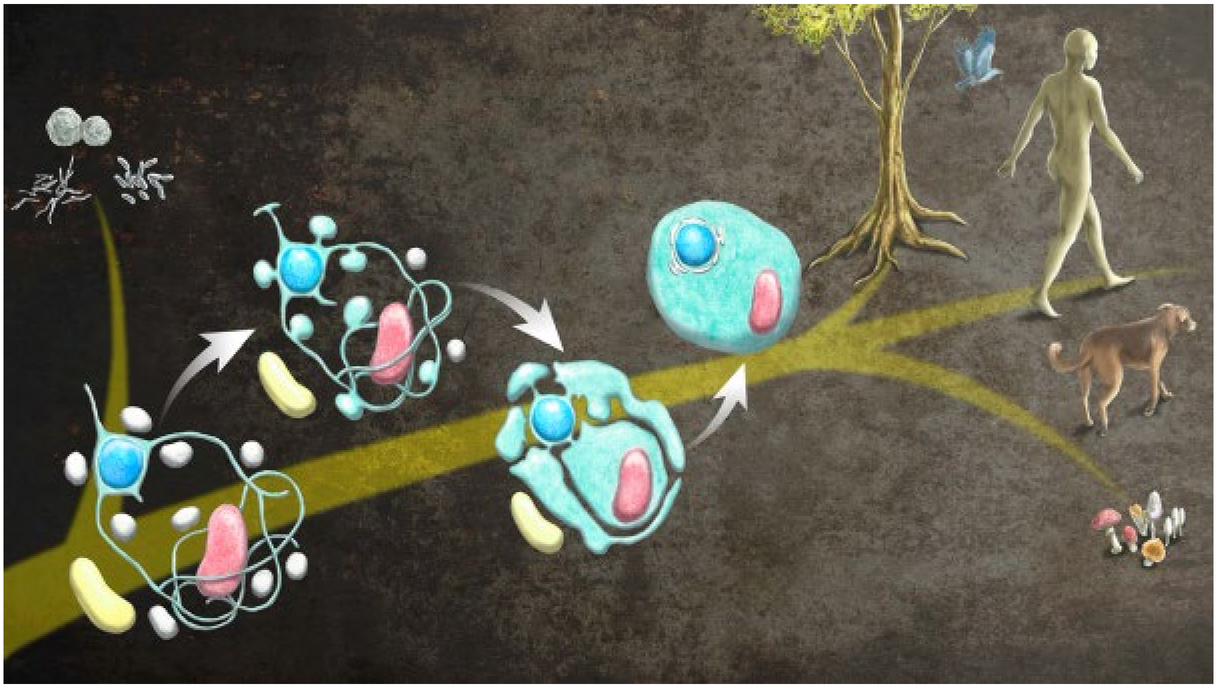

Figure 2. Newly proposed schematic for the origin of complex life—eukaryotes—through interaction between our ancestor archaeon (blue), an ancient bacterium (red), and symbiotic partner (yellow). Illustration by Misaki Ouchida.

References:

[1] T. Katayama, M. K. Nobu, H. Kusada, X. Y. Meng, N. Hosogi, K. Uematsu, H. Yoshioka, Y. Kamagata and H. Tamaki (2020). "Isolation of a member of the candidate phylum 'Atribacteria' reveals a unique cell membrane structure." *Nature Communications* 11(1): 6381.

[2] H. Imachi, M. K. Nobu, N. Nakahara, Y. Morono, M. Ogawara, Y. Takaki, Y. Takano, K. Uematsu, T. Ikuta, M. Ito, Y. Matsui, M. Miyazaki, K. Murata, Y. Saito, S. Sakai, C. Song, E. Tasumi, Y. Yamanaka, T. Yamaguchi, Y. Kamagata, H. Tamaki and K. Takai (2020). "Isolation of an archaeon at the prokaryote-eukaryote interface." *Nature* 577(7791): 519-525.

Glossary:

- Prokaryote:a single-celled organism without a nucleus or internal compartments. Includes bacteria and archaea, often considered "simple" cells.

- Eukaryote: an organism whose cells contain a nucleus and internal structures (organelles). Includes us, animals, plants, and fungi.

- *Promethearchaeati* : a group of archaea, commonly also called “Asgard archaea”, considered the closest known prokaryotic relatives of eukaryotes. Studying them offers clues to how complex life evolved.

Deep Hypersaline Anoxic Basins and Other Hypersaline Environments as Windows to Microbial Life on Other Worlds

Jeff Bowman, University of California, San Diego

The last few decades have revealed an abundance of potential habitats for microbial life in our solar system including subsurface aquifers on Mars and vast oceans below the ice shells of Europa and Enceladus. However, until we can directly access these environments the best approach to studying their ecology is to study analogous environments on Earth. In our research we have focused on the availability of water, described by water activity, as a key limit for life in analog and extraterrestrial environments. Where water interacts with rocks hygroscopic salts can drive water activity, and the resulting hypersaline systems host rich microbial communities that are unlike those found anywhere else on Earth. With support from NASA and the US National Science Foundation we have undertaken broad investigations of microbial life in hypersaline systems in the deep ocean, sea ice, and terrestrial settings, selected for their geochemical or physical similarity to anticipated extraterrestrial ecosystems.

Deep hypersaline anoxic basins (DHABs) are particularly provocative analogs for extraterrestrial environments. DHABs occur along continental margins where geological salt deposits interact with seawater, forming pools of dense, stable brine that lead to a strong vertical zonation of microbial communities and metabolisms based on available sources of energy. While oxygen is quickly depleted, alternate electron acceptors including iron, manganese, and nitrate support dense and activity communities of microbes.

In this presentation I'll provide an overview of different analog environments including sea ice, acid brine lakes in Western Australia, and DHABs. I will provide a detailed overview of our 2023 expedition to Orca Basin, the largest DHAB in the Gulf of Mexico, where our interdisciplinary team undertook an intensive investigation of the physical, chemical, and biological setting. Using coupled metagenomic-metatranscriptomic-metabolomic approaches we developed the first high-resolution view of microbial metabolism across depth in Orca Basin, reaching into the extremely saline and energy limited "core brines." Observations of new taxa, along with surprising distributions of familiar taxa, have raised as many questions as the data have provided answers for.

Bacground Review Article:

Fisher, L.A., Pontefract, A., M Som, S., Carr, C.E., Klempay, B., E Schmidt, B., S Bowman, J. and Bartlett, D.H., 2021. Current state of athalassohaline deep-sea hypersaline anoxic basin research—recommendations for future work and relevance to astrobiology. Environmental Microbiology, 23(7), pp.3360-3369.

Chemistry in Flatland

Alexandra Velian, University of Washington

In Edwin A. Abbott's 1884 novella *Flatland: A Romance of Many Dimensions*, readers are invited to imagine a world confined to two dimensions, where existence unfolds on flat planes and higher dimensions are inconceivable. More than a century later, chemists and physicists have realized their own version of "Flatland" through the discovery and exploration of atomically thin, two-dimensional (2D) materials. These van der Waals solids, exemplified by graphene, transition metal dichalcogenides, and a growing family of layered compounds, are defined by their reduction to a single atomic sheet and the striking departure of their properties from their bulk counterparts. In the past two decades, advances in synthesis, exfoliation, and chemical functionalization have unlocked unprecedented opportunities to tune structure and reactivity at the ultimate limit of thickness. Their electronic, optical, and catalytic properties—emerging from confinement, reduced dimensionality, and surface-dominated chemistry—have positioned 2D materials as model platforms for both fundamental science and transformative technologies. As we look ahead, the chemistry of 2D materials is expected to play a central role in enabling quantum devices, energy storage, catalysis, and novel modes of information processing. Just as Abbott's *Flatland* offered a way to rethink dimensions, the study of 2D van der Waals materials compels us to reimagine matter itself: not as static sheets, but as programmable, dynamic platforms for the next generation of scientific and technological breakthroughs.

Background Review Article:

Berman, Diana, et al. "Introduction to 2D materials and their applications." RSC advances 14.24 (2024): 17234-17235.

Engineering Flatness: Creating 2D Materials from Non-Layered Compounds

Yamamoto EISUKE, Nagoya University

Two-dimensional (2D) materials have garnered increasing attention in chemistry and physics, yet most known examples originate from layered compounds that are intrinsically predisposed to forming 2D structures. In contrast, many inorganic compounds adopt robust three-dimensional (3D) networks, making their transformation into nanosheets highly challenging. This raises a fundamental question: can we create atomically thin materials from compounds that were not meant to be flat? My research addresses this challenge by developing a novel approach to synthesizing 2D materials from non-layered compounds using surfactant templating.

In aqueous solution, surfactants self-assemble into lamellar structures that generate nanoscale 2D spaces, which can serve as soft templates for nanosheet formation (Figure 1a). While this method has enabled access to some non-layered 2D materials, it suffers from limited structural control due to molecular disorder, resulting in non-uniform thickness and aggregation. To overcome these limitations, we developed a solid-state surfactant templating approach, in which surfactant crystals, similar to solid soaps, serve as templates. Unlike liquid-phase self-assembly, solid surfactants form highly ordered, atomically flat lamellar structures that define uniform 2D reaction environments. Using these atomically flat spaces as both templates and confined reaction fields (Figure 1b), we synthesized nanosheets from various non-layered compounds with precise thickness control and excellent dispersibility. This solid-state templating strategy not only enables the production of structurally well-defined 2D materials but also allows the assembly of diverse nanosheets into complex architectures. It offers a new route for expanding the structural and functional landscape of 2D materials beyond naturally layered systems.

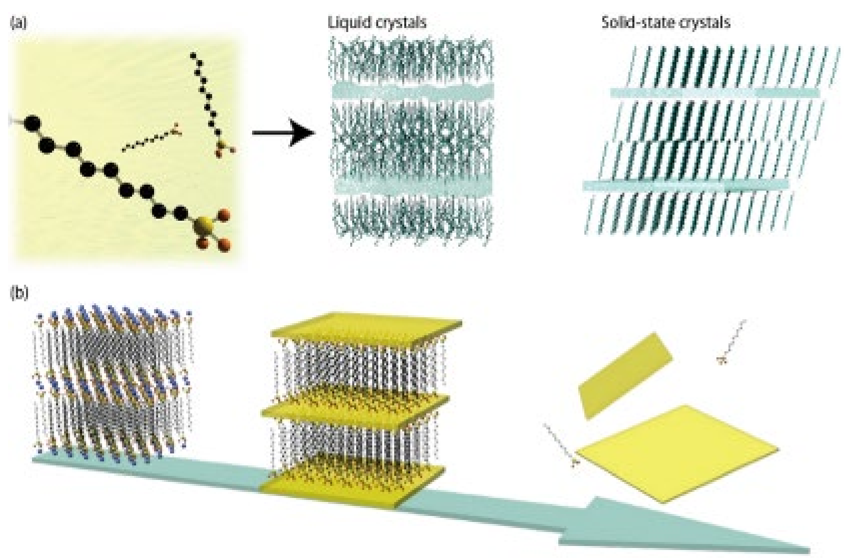

Figure1 (a) illustration of surfactants and (b) synthesis of the nanosheet using surfactants.

References:

[1] E. Yamamoto, A. Suzuki, M. Kobayashi, M. Osada, Tailored Synthesis of Molecularly Thin Platinum Nanosheets Using Designed 2D Surfactant Solids, *Nanoscale,* 2022, 14(32) 11561-11567.

[2] E. Yamamoto, K. Fujihara, Y. Takezaki, K. Ito, Y. Shi, M. Kobayashi, M. Osada, Free-Standing Molecularly Thin Amorphous Silica Nanosheets, *Small,* 2023, 19(22) 2300022.

[3] E. Yamamoto, D. Kurimoto, K. Ito, K. Hayashi, M. Kobayashi, M. Osada, Solid-state surfactant templating for controlled synthesis of amorphous 2D oxide/oxyhydroxide nanosheets, *Nat. Commun.* 2024,15 6612.

[4] E. Yamamoto et al., Molecularly Thin Nanosheet Films as Water Dissociation Reaction Catalysts Enhanced by Strong Electric Fields in Bipolar Membranes. J. *Am. Chem. Soc.* 2025, 147, 14270.

Glossary:

- Layered compounds: Materials with strong in-plane bonding and weak interlayer interactions (e.g., van der Waals forces), making them easy to exfoliate into 2D layers. Examples include graphite and MoS_2.
- Surfactant: A molecule that contains both hydrophilic (water-attracting) and hydrophobic (water-repelling) parts. In water, surfactants self-assemble into supramolecular structures such as micelles and lamellae.
- Templating method: A synthesis approach where a structured material (template) guides the formation of a desired product. In this context, surfactant assemblies act as “soft templates” for 2D material growth.

2D materials for low temperature integrated complementary electronics

Alwin Daus, University of Stuttgart, Germany

Advancements in modern electronics and their even more widespread employment in our daily lives require the integration of new materials with a low thermal budget. For instance, stacking electronic devices in the third dimension can enable more energy-efficient microchips. This is only possible if the integration temperature remains below a certain limit to avoid the alteration or even destruction of the components below. This becomes even more crucial thinking of unconventional platforms for our electronics such as flexible polymer substrates, which can typically only withstand temperatures of 100-200 °C. But the realization of flexible electronics would allow for implementation of electronic circuits and sensors in domains not accessible with conventional rigid silicon such as on-skin medical or health patches, ubiquitous environmental monitoring or low-cost food packaging.

Thus, I would like to address this in my research by developing growth and integration processes for 2D materials which allow for both n-type and p-type conductivity. This is a prerequisite for complementary electronics offering low power consumption and high performance in electronic circuits. 2D materials represent here a unique opportunity, because they do not chemically bind to their growth substrates and thus they can be integrated on arbitrary platforms, typically via transfer techniques. Furthermore, 2D semiconductors can be grown as monolayers with thicknesses of only 3 atoms while maintaining good electronic properties, which allows for ultimate scaling in all dimensions in e.g., transistors.

Based on these aspects, I will talk about the challenges and opportunities we have with 2D materials in terms of materials growth as well as device integration and show some examples from my own research activities (Fig. 1).

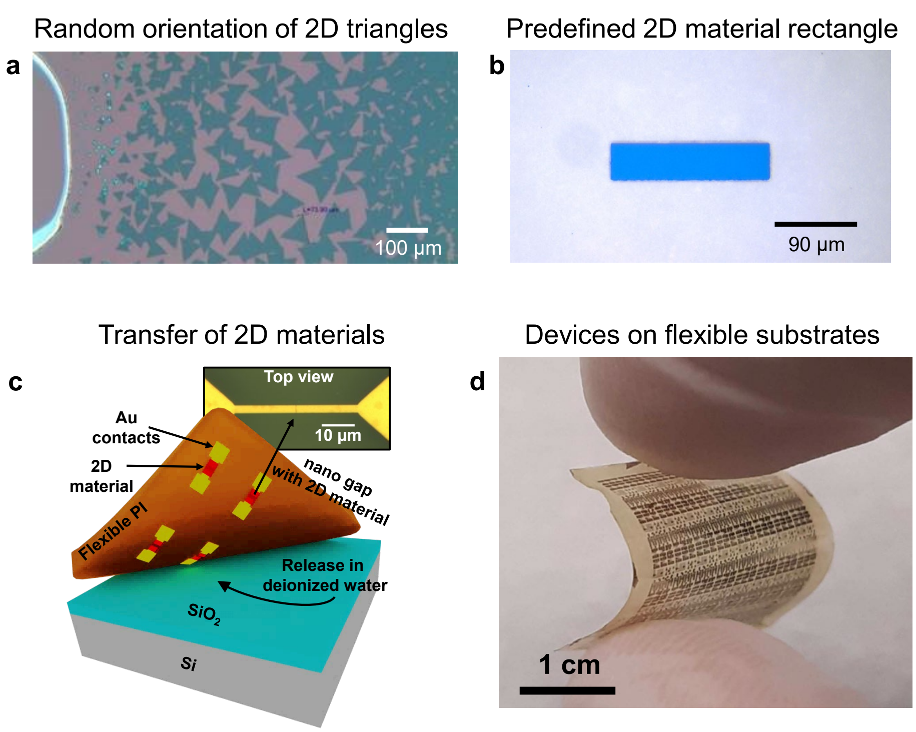

Fig. 1: (a) Example of 2D material growth on SiO_2/Si substrates showing a random orientation of monolayers of molybdenum disulfide, a 2D semiconductor. Each triangle is a single-crystal and the shiny half-ring on the left is a salt used as growth promoter [1]. (b) With a templated growth approach tungsten has been converted to tungsten disulfide, another 2D semiconductor. Here the whole rectangle of polycrystalline tungsten disulfide has been formed in a specific part of the surface. Similar work has previously been published for tungsten diselenide [2] (c) Schematic illustrating how we have transferred patterned 2D materials along with gold metal electrodes by releasing these structures with a flexible polyimide (PI) substrate from the original SiO_2/Si growth substrate. The top view image shows a structure with a nanogap for nanoscale transistor fabrication [3]. (d) Photograph of flexible 2D material transistors on an ultrathin PI plastic foil which we have recently realized [4].

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2. P.M. Campbell, A. Tarasov, C.A. Joiner, M.Y. Tsai, G. Pavlidis, S. Graham, W.J. Ready and E.M. Vogel, “Field-effect transistors based on wafer-scale, highly uniform few-layer p-type WSe_2,” *Nanoscale*, 8, 2268-2276, 2016.

3. A. Daus, S. Vaziri, V. Chen, Ç. Köroğlu, R.W. Grady, C.S. Bailey, H.R. Lee, K. Schauble, K. Brenner and E. Pop, “High-performance flexible nanoscale transistors based on transition metal dichalcogenide,” *Nature Electronics*, 4, 495-501, 2021.

4. Q.T. Phùng, L. Völkel, A. Piacentini, A. Esteki, A. Grundmann, H. Kalisch, M. Heuken, A. Vescan, D. Neumaier, M.C. Lemme and A. Daus, “Flexible p-type WSe_2 transistors with alumina top-gate dielectric,” *ACS Applied Materials & Interfaces*, 16, 60541-60547, 2024.

Everything Flows: Collective Dynamics Across Scales

Motoki Nakata, Komazawa University

"*Everything flows. There is nothing permanent except change. No man ever steps in the same river twice, for it is not the same river and he is not the same man.*"

These words, attributed to the ancient Greek philosopher Heraclitus, vividly capture the essence of "flow." Centuries later, Leonardo da Vinci, a leading figure of the Renaissance, was likewise deeply fascinated by flow phenomena. His meticulous drawings of fluid motion may represent one of the earliest scientific attempts to visualize Heraclitus's philosophy. Fluctuations are indeed present at every scale within flows and vortices, and the interplay between order and disorder eventually gives rise to dynamic patterns (Fig.1). Such "flows and pattern formations" have been one of the fundamental intellectual pursuits of humankind, continuing from the ancient era to the present day.

Building on the insights of Heraclitus and da Vinci, this session provides a comprehensive overview of "flows and pattern formations" as trans-scale phenomena spanning 41 orders of magnitude, e.g., from quantum vortices at the 10^{-15} meter scale to the web-like structure of galaxies across the 10^{26} meter scale. Our aim is to explore emerging research frontiers that transcend disciplinary boundaries. To this end, we welcome leading experts in aerodynamics, including wind turbine technologies, and in astro-plasma dynamics, such as supernova explosions, to present the latest advances in their fields.

Fig. 1: A drawing of flows and vortices by Leonardo da Vinci: Studies of water (RCIN912660)

While it is not feasible to comprehensively survey all flow systems within this session, the essence of "flows and pattern formations" lies in their universal physical characteristics that transcend individual systems. A key perspective in identifying such essential features across diverse flow systems is the recognition that “fluid,” as the medium for pattern formation, should not be narrowly understood as merely a continuum of a particular substance. Rather, it can be generalized as a collective phenomenon emerging from the interactions of many elements, e.g., particles, waves, fields, living organisms, or even social systems. From this perspective, fluctuations play a critical role. Under nonlinear interactions, fluctuations give rise to structures, leading to emergent order that cannot be reduced to the properties of individual elements. In contrast, in a linear system, there is no interaction between modes or elements even if individual modes grow due to instability. The presence of such nonlinear fluctuations constitutes a fundamental mechanism of pattern formation.

Furthermore, as exemplified today by deep learning and generative AI, this perspective has evolved into a scientific and technological framework that treats the flow of information and data as a collective phenomenon. This reveals new horizons where physical entities and information begin to converge.

Researchers from diverse disciplines will come together in this session to engage in in-depth discussions on universal physical principles, shared mathematical structures, and common methodologies that bridge different scientific domains. At the same time, the session aims to highlight the distinctive and intrinsic appeal of each individual research subject.

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M. C. Cross and P. C. Hoheburg, Review of Modern Physics vol. 65, 851 (1993)
DOI: https://doi.org/10.1103/RevModPhys.65.851

Z. Yoshida, “Nonlinear Science: The Challenge of Complex Systems”, Springer (2010), ISBN-13: 978-3642034053.
https://link.springer.com/book/10.1007/978-3-642-03406-0

From Stellar Death to Cosmic Rebirth: A Symphony of Structure in Supernovae

David Vartanyan, University of Idaho

The astrophysical origin of the atomic building blocks of life persists, in equal measures, as an enduring and tantalizing challenge. The explosive deaths of massive stars − stars more than ~8 times the mass of our sun − as core-collapse supernovae (CCSNe) are understood now to source directly or indirectly much of the atomic composition of life around us. These nuclear recycling plants produce and liberate the constituents of organic life, from the carbon in crucial phospholipids to the oxygen pumped in our blood cells. Yet, understanding the mechanism of how such massive stars explode has presented a more-than-half century dilemma.

Through a confluence of laboratory experiments, supercomputer simulations, theoretical developments, and decades of supernovae observations, the prevailing theory is that neutrinos − neutral, almost massless and weakly interacting particles − are responsible for powering CCSNe explosion. These particles are produced in copious abundance during the gravitational collapse of massive stars at the end of their lives and, in turn, couple to and unbind the stellar envelope in a vibrant supernovae explosion.

Recent success, motivated by global collaborations, in modeling explosions in the face of six decades of failure reveals the next frontier. Do our CCSNe models agree with observations? Early work suggests yes. We can reproduce explosions with reasonable energies, correct elemental yields (including, e.g., nickel and titanium), and remnant properties (black holes, neutron stars, with ensuing kinematics). However, reproducing the correct diagnostics yields is insufficient − we must also reproduce the correct geometries.

CCSNe have long been known to be inherently asymmetric at all scales, from the innermost core to the stellar mantle, its envelope, and its host environments. Observations of supernovae like the Crab Nebula (first seen roughly a millenium ago), Cassiopeia A (~ 400 years ago), and SN1987A (~40 years ago) with instruments like the Hubble Space Telescope, the Chandra X-Ray Observatory, and the newly minted James Webb Space Telescope unveil in unprecedented detail the litany of structures, morphologies, and asymmetries in supernovae.

What are the origins of such multi-scale structure? I will present a unified effort to model CCSNe from seconds to centuries to explore the origin, preservation, and evolution of geometry, from turbulent neutrino-driven convective flows in the first moments to radiation-hydrodynamic mushroom patterns long after explosion. Such instabilities heavily mix chemical composition in CCSNe, affecting both how we observe these elements and the relative distributions recycled into the universe to seed formation of new stars, new systems, and new planets.

Background Review Article:

Nature, Volume 589, Issue 7840, p.29-39, “Core-Collapse Supernovae Explosion Theory”, A. Borrows & D. Vartanyan.10.1038/s41586-020-03059-w, https://arxiv.org/pdf/2009.14157

How do wind turbines interact with the atmosphere?

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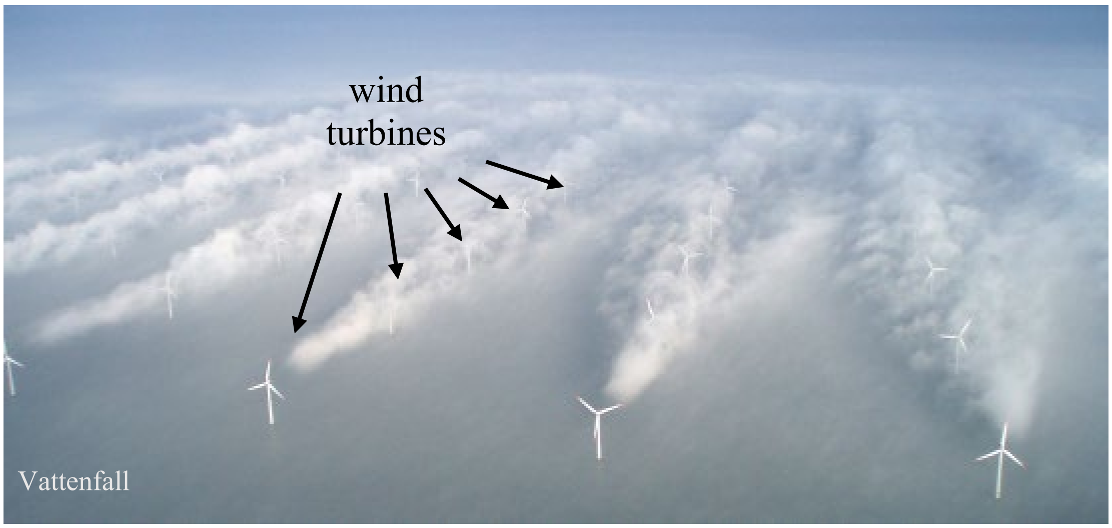
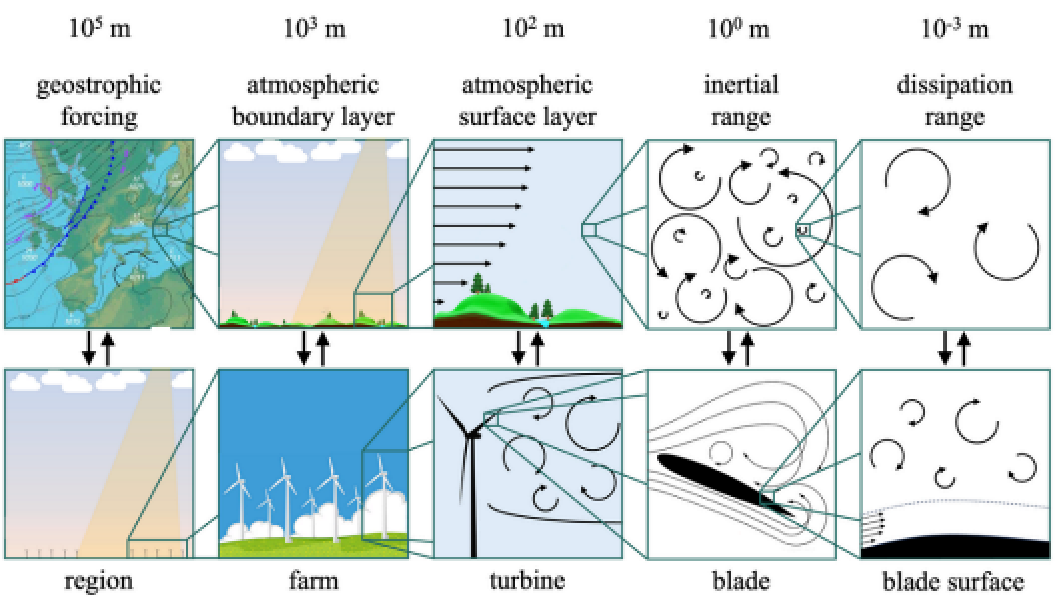
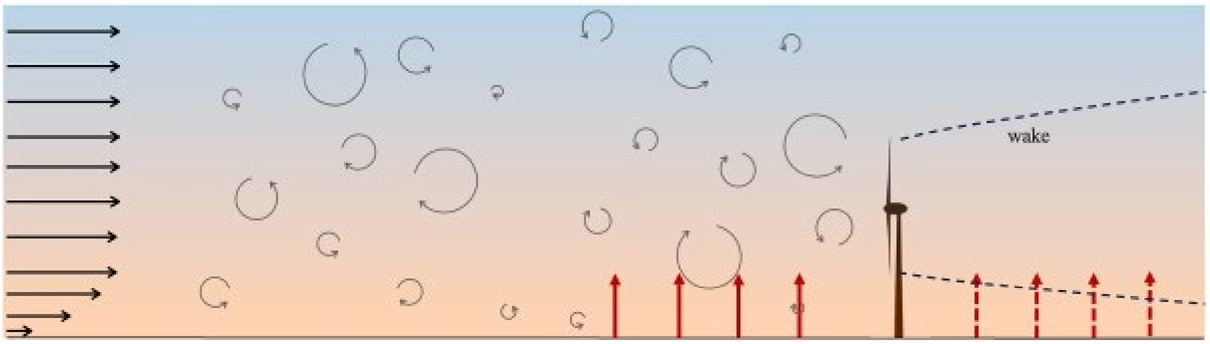
Over the last three decades, wind energy has transitioned from an esoteric niche technology to one of the world's main sources of renewable energy, using some of the largest machines ever built. When multiple wind turbines are arranged in a farm, the wakes of upstream turbines interfere with downstream turbines, reducing their performance.



How the wake of a wind turbine develops depends in large part on the local atmospheric conditions. In order to optimize the layout and accurately predict the performance of wind farms, we therefore need to understand how wind turbines interact with each other as well as with the surrounding atmosphere. Due to the complexity of atmospheric flows, this is extremely challenging. They are highly turbulent over a wide range of scales, the smallest being on the order of millimeters and the largest on the order of kilometers.



Flows are highly non-linear and although we know the mathematical equations to describe them, the chaotic nature of turbulence makes these equations impossible to solve for large atmospheric flows. Furthermore, they are changing in space (e.g. due to the local topography) and in time (e.g. due to the diurnal cycle). This means that many of the physical models we have developed to describe canonical turbulence do not apply to atmospheric flows.



A wind turbine acts as a perturbation to the atmospheric flow. The flow then gradually responds to the presence of the turbine and eventually reaches a new equilibrium. A better understanding of these interactions between wind turbines and the surrounding atmosphere will allow us to further optimize wind farms, as well as to better represent them in weather models.

<u>Glossary:</u>

Wake: the region downstream of a wind turbine (or farm) where the flow is affected by the wind turbine(s). Its extent depends on the atmospheric conditions, but can easily reach ten rotor diameters downstream.

Scales: in turbulence research, length and time scales are closely linked and sometimes used interchangeably. The range of scales in a turbulent flow can loosely be interpreted as the range of sizes of the eddies in the turbulence.

Non-linearity: Atmospheric flows can be described using the Navier-Stokes equations. These equations are nonlinear, for example the acceleration of the flow depends on its velocity. This can lead to pattern formation (e.g. waves), or chaotic behavior (e.g. turbulence).

<u>Further reading:</u>

Veers, P. et al.: Grand challenges in the science of wind energy. *Science* **366**, eaau2027 (2019). DOI: 10.1126/science.aau2027

Kosović, B., Basu, S., Berg, J., Berg, L. K., Haupt, S. E., Larsén, X. G., Peinke, J., Stevens, R. J. A. M., Veers, P., and Watson, S.: Impact of atmospheric turbulence on performance and loads of wind turbines: Knowledge gaps and research challenges. *Wind Energ. Sci. Discuss.* [preprint], DOI: 10.5194/wes-2025-42, in review, 2025.

Re-Defining the Suburbs for adapting Conurbation to its Shrinkage

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Over the last decades of the 20th century, modern developed countries tended to have conurbations that rapidly spread into suburbia, which have experienced dramatic demographic changes and an aging society today[1]. Therefore, redesigning expanded housing areas in such conurbations is essential in most developed countries. Since suburbs have developed during periods of economic and demographic growth, planners must consider the current conditions of demographic stagnation or decline, as well as the financial constraints of costly spatial, physical, and infrastructural settings[2]. To adapt the conurbation structure to shrinkage, we need to update our understanding of social change among suburbanites. Thus, my researches challenge the redefinition of suburbs from the perspective of the social transition of suburbanites' lifestyles, using a macro-micro scale analysis.

In Japan, suburban areas have been regarded as ideal residential areas. As a result of people's desire for homeownership and rapid residential development, these areas have become places where people of similar generations live similar lifestyles. However, as conurbations shrink, it is unlikely that suburban areas will undergo uniform change, and differentiation between areas is occurring. Surveys on household attributes, economic characteristics, daily activities, and work styles of suburbanites have revealed a shift from homogeneity to diversity. These changes are related to the spatial characteristics. It indicates the need to reestablish suburban living areas where people can choose places to live that suit their lifestyle preferences, as well as livelihood functional cores in suburbia that are independent of central urban areas. In conclusion, I positioned it as one of the ideal forms of post-shrinking conurbations, with the name "Tolerant Conurbation Structures."

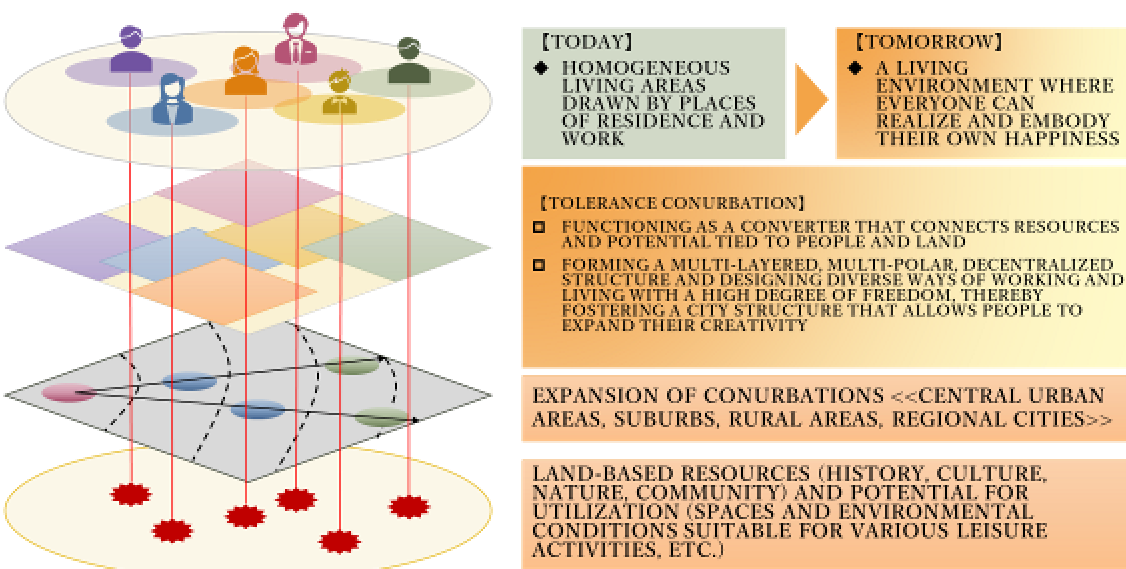

Figure: Conceptual Diagram for the Tolerant Combination Structure

References:

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[2] K. Mouratidis (2019) Compact city, urban sprawl, and subjective well-being, Cities, 92, pp. 261-272, 10.1016/j.cities.2019.04.013

Background Review Article:

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2) Aoki, T. (2022) Confronting future urban perforation: Spatial analysis of districts in Japan with potential for being sparsely inhabited, Cities, 122, 103515, https://doi.org/10.1016/j.cities.2021.103515

3) Aoki, T. (2022) Formation and Typology of Workplace Agglomerations in the Suburbs During Population Decline, Urban Regional Planning Review, 9, pp. 1-24, https://doi.org/10.14398/urpr.9.1

4) Aoki, T. (2023) Activity space compactness index from the viewpoint of trip arrival point by lifestyle activity purpose in a mature conurbation, Sustainable Cities and Society, 88, 104302, https://doi.org/10.1016/j.scs.2022.104302

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Active and Healthy Ageing, Shrinking Cities and the Role of Age-friendly Communities in Germany

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Germany's population is ageing and projected to decline significantly due to a combination of increased life expectancy and low fertility rates. As a result, retirees constitute a growing share of the population and are generally healthier than previous generations. Retirement is increasingly viewed as a distinct life stage that individuals must actively navigate. In this context, the World Health Organization promotes active ageing—the goal of enabling people to live healthy, autonomous lives for as long as possible.

Figure 3: Age-friendly city domains of action

Source: World Health Organization. (2023); adapted from WHO (7)

The socio-ecological environment, particularly one's immediate living surroundings, plays a crucial role in supporting healthy and active ageing. The Age-friendly Cities and Communities framework identifies key dimensions, such as transportation, social participation, and access to community support and healthcare services, that contribute to age-friendliness (see Figure 1). This raises the question of how urban shrinkage, often accompanying demographic ageing, impacts a city's age-friendliness. In Germany, population decline affects cities and communities in markedly different ways. In eastern Germany, many areas have lost residents due to declining birth rates, deindustrialization, and internal migration following reunification in 1990. Similar patterns have emerged in parts of western Germany, while some urban centers, such as Cologne and Berlin, have grown—partly due to immigration in recent decades. These demographic shifts are highly uneven, resulting in diverse challenges for shrinking cities.

For older residents, the key concern is how urban shrinkage affects their daily lives. For urban planners and municipal authorities, the challenge lies in designing effective policies and interventions that promote active and healthy ageing. This presents a range of research questions, such as how individuals can sustain healthy lifestyles in urban settings marked by both ageing and shrinkage. Understanding the causal relationships between city shrinkage and the lived experiences of older adults is especially complex but critical. Additionally, we must better understand the mechanisms through which age-friendliness mediates these experiences. Addressing these questions will require improved data sources that integrate individual-level information with data on local environments. Only with such linked datasets can we gain convincing insights into how to support ageing populations in the context of urban decline.

Definitions (World Health Organization, 2015):

- *Active ageing*: the process of optimizing opportunities for health, participation and security in order to enhance quality of life as people age.
- *Healthy ageing*: developing and maintaining the functional ability that enables well-being in older age.
- *Age-friendly cities and communities*: cities or communities that foster healthy and active ageing

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Interactive Dashboard on shrinking and growing cities and communities (provided by the Federal Office for Building and Regional Planning, in German): https://experience.arcgis.com/experience/624ae39956c54dda883379d87325691c/