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Corresponding author:
Zoë Breed; Email: z.breed@tudelft.nl

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MagnoSphere: a living computational system shaped by magnetotactic bacteria

Zoë Breed, Elvin Karana and Katherine W. Song

Industrial Design, Delft University of Technology, Delft, Netherlands

Abstract

Current bio-digital systems frequently position organisms as sensors or esthetic elements, while their inherent computational capabilities remain underutilized. At the same time, when biological processes are integrated into technical systems, they often remain hidden or abstracted away, failing to foster awareness and appreciation of the biological intelligence (Kim et al. 2023). This dual limitation prevents both technical innovation and conceptual understanding of what biological computers might become. We present MagnoSphere, a living biodesign installation that addresses both gaps by demonstrating the natural sensing and collective response capabilities of magnetotactic bacteria (MTB) as potential building blocks for bio-digital computation. The project investigates how microorganisms' intrinsic sensing and collective behavior can be made perceptible through design. Rather than implementing a complete computational system, the project investigates foundational questions: how do microorganisms respond to environmental changes in ways that could serve computational functions, and how can design make these biological dynamics perceptible and understandable? MTB biomineralize magnetic nanoparticles (magnetosomes) within their cellular structure, making them responsive to external magnetic fields (Goswami et al. 2022). MTB navigate using magnetotaxis, creating complex collective behaviors in response to magnetic stimulation. These observable responses could potentially be harnessed as forms of information processing in computational paradigms like Physical Reservoir Computing (Nakajima 2020). However, before computational implementation is possible, we must first surface, understand and characterize these responses, along with their repeatability over time. Drawing on Kim et al.'s *Surfacing Livingness* paper (Kim et al. 2023), MagnoSphere employs sensorial amplification strategies to make the bacterial responses visible and tangible for human observers. The installation emphasizes exploration: visitors manipulate the magnetic field to direct bacterial movement within the chamber, observing how populations collectively migrate, shimmer and reorganize over time. This approach enables visitors to perceive biological sensing as an observable process revealing characteristics like shimmering intensity, response speed, collective organization and temporal patterns that could serve as computational building blocks. Magnetic field manipulation serves as input, bacterial movement and lighting patterns serve as computational transformation and sensorial amplification layers make this process perceptible: real-time microscopy projections enlarge the bacterial dynamics, and data visualization tracks response characteristics over time. The system uses digital components for real-time readout of the bacterial state and amplification (supporting observation and understanding), while the biological system provides the sensing and collective response dynamics. The sensorial amplification aims at creating a communication bridge, enabling humans to witness this relationship between and explore these biological capabilities. The installation unites biodesign with computational investigation through a demonstration where living organisms' responses are made directly observable rather than abstracted away. For the biodesign community, the contribution is threefold. First, it concretizes MTB's computational potential through quantitative population-level characterization of bacterial collective behavior – thereby revealing the dynamics that underpin its computational capabilities. Secondly, it operationalizes the concept of surfacing livingness, demonstrating how sensorial amplification can reveal otherwise hidden biological intelligence. Third, it enables critical discussion about how synergistic bio-digital computational systems might be realized in practice. Conference attendees will engage with an installation where they can manipulate magnetic inputs and observe the unfolding living responses. Through this direct exploration, visitors develop intuition about bacterial dynamics, while encountering questions about how such capabilities might serve future computational functions. As an installation, MagnoSphere communicates the potential for biological intelligence and digital systems to interweave – creating dialogue about alternative computational futures.

Demo description

This demonstration builds on the findings presented in our recent work *Entangled Life and Code* (Breed et al. 2026), which examined computational relationships in microorganism-based bio-digital systems. That analysis revealed fundamental asymmetries in biological-digital

computational relationships. While organisms possess sophisticated capabilities for sensing, evaluation and adaptation, current systems constrain them to unidirectional signal transduction or input/output roles. Only a small fraction of the explored systems utilized organisms in computational roles such as evaluation or adaptation, despite these being fundamental biological processes (Breed et al. 2026). MagnoSphere addresses this gap by revealing the observable characteristics of magnetotactic bacteria (MTB) that could serve as building blocks for future bio-digital computation. The installation investigates whether and how microorganisms can actively participate in computation within a digital system. Physical Reservoir Computing (PRC) represents a long-term goal for this research. PRC requires repeatable, observable, high-dimensional responses to environmental inputs – characteristics that must first be demonstrated and characterized before computational implementation becomes feasible. This demo focuses on the foundational work: showcasing and making explorable the bacterial responses that could eventually serve as computational substrate. For MTB, navigation emerges through the coupling of magnetic alignment and directional swimming, producing continuous collective adjustment, where movement reflects ongoing environmental evaluation. This continuous reorientation appears optically as shimmering, a pattern of light-scattering fluctuations that serves as a directly observable indicator of population-level sensing dynamics. The installation surfaces these responses (and perhaps secondary, lesser-known ones), providing the foundational work needed for integrating MTB as computation in bio-digital systems.

Audience engagement

Audience engagement occurs through exploration and observation. Visitors encounter a living system where they can directly control and observe how bacterial populations sense and respond (Figure 1). Visitors can manipulate the magnetic field, experimenting with different field orientations and strengths while observing the resulting shimmering and collective reorganization. By surfacing livingness through sensorial amplification, the demo lets audiences encounter living computation, supporting understanding of alternative computational models beyond digital systems. As a proof-of-concept demonstration, the installation communicates both the technical feasibility and conceptual implications of working with living systems as computational media, inviting reflection on how biological and digital processes might coexist. To evaluate the installation's effectiveness, questions will be posed to participants after their interaction, exploring how different sensorial amplification strategies affect understanding. The goal is to assess whether the artifact helps visitors grasp the organism's computational potential and imagine its role in future bio-digital systems.

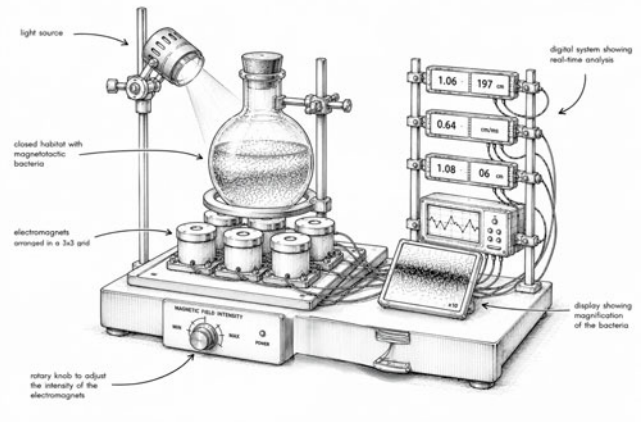


Figure 1. Technical schematic of the interactive system demonstrating magnetic control of collective optical behavior (image generated with the assistance of OpenAI and Adobe Firefly).

Technical details

The installation consists of a living culture of *Magnetospirillum gryphiswaldense* (MSR-1) cultivated in a liquid media. MSR-1 is a marine, microaerophilic bacterium that prefers low oxygen concentrations (Figure 2). The bacteria navigate using both magnetotaxis (alignment with Earth's magnetic field) and aerotaxis (movement along oxygen gradients). The culture is maintained in a custom microbial habitat developed to ensure biological safety and environmental stability during operation. Visitors interact with the system by manipulating an array of electromagnets positioned next to the chamber, inducing directed collective migration. This input influences bacterial distribution and movement, serving as inputs to the living system.

At sufficient density, collective bacterial motion can be observed directly (Figure 3); however, microscopic imaging is used to enhance perceptibility. Live microscopy footage is projected on an external monitor, allowing audiences to observe changes in collective behavior over time. A secondary visualization window presents population distribution over time. When the magnetic field is reoriented, MSR-1 populations exhibit distinct collective patterns. These include:

- **Directed migration:** Collective movement along magnetic field gradients toward the applied field.
- **Shimmering:** Visible fluctuations in light brightness caused by collective reorientation of cells.
- **Temporal adaptation:** Response patterns evolve over time as populations equilibrate to the new field orientation.



Figure 2. *Magnetospirillum gryphiswaldense* (MSR-1) with magnetosomes in orange (Evans 2015).

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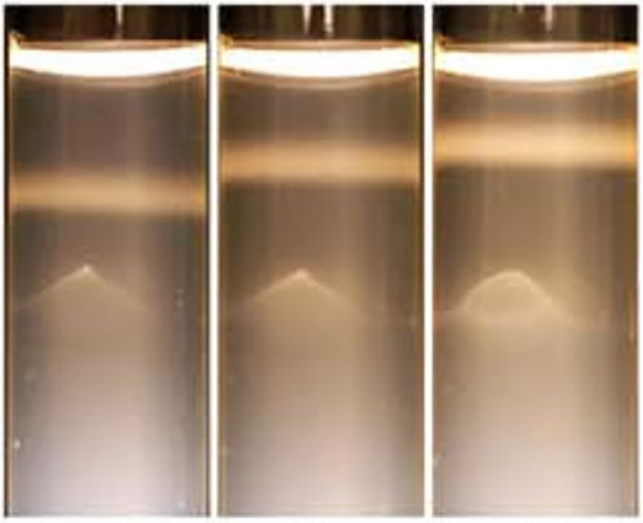


Figure 3. *Magnetococcus marinus* (MC-1) aggregated as a microaerophilic band at the oxic-anoxic interface in semi-solid medium (Lefèvre et al. 2016).

System components

The system comprises the following components to enable real-time observation:

- **Magnetic array:** Programmable array of electromagnets for visitor-controlled manipulation of bacterial movement inside the chamber.
- **Habitat:** Custom-fabricated sealed chamber, designed for biological safety and stable observation conditions.
- **Imaging system:** USB camera providing continuous real-time observation of bacterial movement.
- **Computing platform:** Laptop running analysis and visualization scripts for data processing and display, including real-time readout of bacterial state.
- **Visual display:** External monitor for audience viewing, showing live microscopy and feature extraction.

Technical requirements

- Table space for core system and display.
- Access to standard electrical outlets (230V standard EU).

Biological safety

MSR-1 is a wild-type, nonpathogenic environmental marine bacterium (Biosafety Level 1, no genetic modification). The sealed observation chamber prevents culture release. Compliance with local biosafety regulations will be confirmed with the venue prior to the conference.

Accessibility considerations

- Installation viewable from wheelchair height (displays positioned accordingly).
- Seating available for visitors who wish to observe over extended periods.
- Clear pathways for wheelchair access around installation.

Data availability statement. Data availability is not applicable to this article as no new data were created or analyzed in this study.

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Competing interests. None.

Ethical standards. This study involves human participants and is currently pending approval from the Human Research Ethics Committee. Data collection will only commence upon receiving full ethical clearance prior to the conference, and all participant responses will be fully anonymized.

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