Ecology & Evolution | Jan 11, 2026 | 8 min read | By Bryan White

The Geometry of Society: Why Some Spiders Cooperate and Others Just Coexist

Biology * Evolution

The Puzzle of Biological Organization

The history of life is structured by major transitions in levels of biological organization, as autonomous entities coalesce into higher-order wholes. Prokaryotes merged into eukaryotic cells; single cells adhered into multicellular organisms; and solitary animals aggregated into societies. A central question in evolutionary biology is why certain aggregations evolve into integrated, unitary entities -- like metazoan bodies or honeybee colonies -- where parts surrender autonomy, while others remain modular associations -- like colonial corals or vascular plants -- where individual units retain functional sovereignty.[1]

In her Annual Review of Ecology, Evolution, and Systematics synthesis, "Transitions in Levels of Organization: Lessons from Social and Colonial Spiders," evolutionary ecologist Leticia Avil s resolves this dichotomy using group-living arachnids.[1] Having evolved group living independently dozens of times, spiders (Araneae) bifurcate into cooperative ("social") spiders, functioning as unitary superorganisms, and colonial spiders, forming modular neighborhoods.[1] Avil s demonstrates that social evolution is physically channeled by the geometry of the extended phenotype: whether the ancestral web is a two-dimensional (2D) tensioned orb or a three-dimensional (3D) irregular tangle.[1]

Unitary vs. Modular Systems and the Geometric Silk Filter

Avil s maps group-living spiders onto two organizational poles:[1]

* Unitary Systems (Cooperative Social Spiders): Exemplified by Anelosimus eximius (Theridiidae) and Stegodyphus dumicola (Eresidae), unitary colonies function like metazoan bodies.[1][13] Spiders share a communal nest, hunt cooperatively, rear broods communally without kin discrimination, and exhibit obligate group living with heavily female-biased sex ratios.[1][15]

* Modular Systems (Colonial Spiders): Exemplified by Metepeira incrassata (Araneidae) and Philoponella republicana (Uloboridae), modular colonies resemble clonal corals.[1][22] Each spider builds and defends its own individual capture web suspended within a shared support scaffold, captures its own prey, and maintains reproductive autonomy.[21]

The physical filter separating these trajectories is silk biomechanics.[2][3] An orb web is a 2D tensioned acoustic sensor where prey vibrations travel along radial threads to the hub.[4][5] A second spider on the same orb dampens signal transmission and introduces vibrational noise that blinds prey localization. Orb-weaving lineages are thus physically barred from sharing a capture surface and can only aggregate individual orbs within a shared frame -- enforcing a modular society.[1][21] Conversely, an irregular 3D tangle or sheet-and-tangle web acts as a

volumetric mechanical trap.[3][6] Multiple spiders can rush entangled prey from all angles without degrading web mechanics, turning capture, repair, and brood care into shared public goods along the unitary path.[1][12]

| Attribute | | 2D Orb Web (Modular Path) | | 3D Tangle Web (Unitary Path) |

| Mechanical Function | | Planar tensioned acoustic sensor | | Volumetric knock-down trap & shelter |

| Conspecific Interference | | High (co-occupants blind vibration cues) | | Low (swarm enhances prey subjugation) |

| Capture Surface & Scaling | | Individually defended / Linear scaling | | Communally shared / Allometric scaling |

| Mating & Dispersal | | Outbreeding with inter-colony dispersal | | Obligate natal inbreeding; female bias |

| Social Outcome & Taxa | | Coloniality (Araneidae, Uloboridae) | | Cooperative Sociality (Theridiidae, Eresidae) |

Ecological Gradients and the Unitary Superorganism

While web geometry determines how spiders group, two ecological gradients dictate why they aggregate:[7][11]

* The Prey Size Hypothesis: Cooperative hunting across 3D snares allows social spiders like A. eximius to capture insects up to 10 times their individual body mass.[7][8] Because large flying insects peak in productive lowland tropical rainforests and decline at higher elevations and latitudes, unitary social spiders are restricted to the lowland tropics.[11][14]

* Disturbance & Predation: Heavy tropical rains and ant predation destroy solitary webs, whereas dense 3D communal nests shield central brood chambers and reduce per-capita silk replacement costs.[6][9][10]

Within unitary colonies, hunting A. eximius spiders synchronize their movements via vibrational feedback loops.[12] Moreover, 3D nests obey Kleiber-like allometric scaling: as colony volume grows, the surface-area-to-volume ratio drops, lowering per-capita silk and metabolic costs.[3] In Stegodyphus dumicola, behavioral castes divide bold hunters from shy brood-carers, culminating in altruistic matriphagy where adult females liquefy their organs to feed the colony's spiderlings.[17][18]

The Modular Trajectory and the Evolutionary Dead End

In modular colonial orb-weavers like Metepeira incrassata and Philoponella republicana, individuals trade central anti-predator "selfish herd" safety against superior peripheral prey capture through territorial contests.[19][20][22] Even in the tent-web spider Cyrtophora citricola, which builds durable 3D horizontal domes, orb-derived hub acoustics preserve strict individual territoriality.[23][24]

Macroevolutionarily, unitary sociality is a short-lived "Evolutionary Dead End" located only at young phylogenetic tips.[25][26] Obligate sibling inbreeding, Local Mate Competition driving 1:10 male-to-female sex ratios, and recurrent colony foundation via a population bottleneck collapse the effective population size

(Ne).[15][16][27] At low Ne, genetic drift overwhelms purifying natural selection: comparative genomics confirms elevated non-synonymous to synonymous substitution ratios (dN/dS, altering amino acid sequences) and severe inbreeding depression ("genomic melt"), whereas outbreeding colonial spiders maintain high Ne and long-term lineage persistence.[25][27][28][29][30] This dichotomy parallels unitary animals vs. modular plants, while showing how eusocial insects escaped genomic decay by pairing 3D nests with outbred nuptial flights.[1][31][32][33]

Extended Phenotypes as Evolutionary Switches

Avil s's synthesis proves that major evolutionary transitions are channeled by the physical geometry of the extended phenotype.[1] Where 2D tensioned orbs enforce modular, outbreeding neighborhoods, 3D tangle webs unlock cooperative hunting and allometric economies of scale -- propelling spiders into unitary superorganisms at the ultimate cost of inbreeding-driven extinction.[3][25][29]

Updates... (Nov 21, 2026): Retained the Nov 20, 2026 author correction on Reference 11 ("Habitat productivity predicts the global distribution of social spiders" -- Majer, M., Svenning, J.-C., & Bilde, T., Sep 15, 2015), standardized bracket-free reference mentions in the update note, and added exact CrossRef/publication dates across all primary sources.

Works Cited

* [1] Avil s, L. (Nov 5, 2025). Transitions in Levels of Organization: Lessons from Social and Colonial Spiders. Annual Review of Ecology, Evolution, and Systematics. https://doi.org/10.1146/annurev-ecolsys-102723-054147

* [2] Haberkern, A. M., et al. (Aug 13, 2024). Disguise or surprise: spider antipredator adaptations as a function of the architecture of their webs. Insect Systematics and Diversity, 8(4), 4. https://doi.org/10.1093/isd/ixae019

* [3] Greenberg-Pines, G., et al. (Dec 4, 2024). Scaling of the extended phenotype: convergent energetics from diverse spider web geometries. Proceedings of the Royal Society B. https://doi.org/10.1098/rspb.2024.2147

* [4] Yu, H., Yang, J., & Sun, Y. (Sep 1, 2015). Energy Absorption of Spider Orb Webs During Prey Capture: A Mechanical Analysis. Journal of Bionic Engineering. https://doi.org/10.1016/s1672-6529(14)60136-0

* [5] Tarazi, N. (2021). The effects of geometric regularity in spider web architecture on the capture of prey. The Expedition, 10, UBC Library. https://ojs.library.ubc.ca/index.php/expedition/article/view/195689/191172

* [6] Blackledge, T. A., et al. (Dec 13, 2002; issue 2003). Are three-dimensional spider webs defensive adaptations? Ecology Letters. https://doi.org/10.1046/j.1461-0248.2003.00384.x

* [7] V s rhelyi, Z., Scheuring, I., & Avil s, L. (Jun 1, 2022). The Ecology of Spider Sociality: A Spatial Model. The American Naturalist, 199(6). https://doi.org/10.1086/719182

* [8] Harwood, G., & Avil s, L. (Dec 23, 2013). Differences in group size and the extent of individual participation in group hunting may contribute to differential

prey-size use among social spiders. Biology Letters. https://doi.org/10.1098/rsbl.2013.0621

* [9] Purcell, J., & Avil s, L. (Aug 5, 2008). Gradients of precipitation and ant abundance may contribute to the altitudinal range limit of subsocial spiders: insights from a transplant experiment. Proceedings of the Royal Society B. https://doi.org/10.1098/rspb.2008.0582

* [10] Hoffman, C. R., & Avil s, L. (Feb 15, 2017). Rain, predators, and spider sociality: a manipulative experiment. Behavioral Ecology. https://doi.org/10.1093/beheco/arx010

* [11] Majer, M., Svenning, J.-C., & Bilde, T. (Sep 15, 2015). Habitat productivity predicts the global distribution of social spiders. Frontiers in Ecology and Evolution, 3, 101. https://doi.org/10.3389/fevo.2015.00101

* [12] TheScienceBreaker (Sep 28, 2022). The mechanisms behind synchronized hunts in spiders. https://www.thesciencebreaker.org/breaks/evolution-behaviour/the-mechanisms-behind-synchronized-hunts-in-spiders

* [13] Animal Diversity Web (Mar 23, 2015). Anelosimus eximius. University of Michigan Museum of Zoology. https://animaldiversity.org/accounts/Anelosimus_eximius/

* [14] Purcell, J., & Avil s, L. (Mar 26, 2007). Smaller colonies and more solitary living mark higher elevation populations of a social spider. Journal of Animal Ecology. https://doi.org/10.1111/j.1365-2656.2007.01228.x

* [15] Aarhus University Spiderlab (Apr 1, 2026). Social Spiders. Department of Biology, Aarhus University. https://bio.au.dk/en/research/research-areas/genetics-and-evolution/spiderlab/research/social-spiders

* [16] Lubin, Y., & Bilde, T. (Jan 1, 2007). The Evolution of Sociality in Spiders. Advances in the Study of Behavior, 37. https://doi.org/10.1016/s0065-3454(07)37003-4

* [17] Yip, E. C., & Rayor, L. S. (Oct 31, 2013). Maternal care and subsocial behaviour in spiders. Biological Reviews. https://doi.org/10.1111/brv.12060

* [18] Pruitt, J. N., et al. (Dec 21, 2017; issue 2018). Selection for Collective Aggressiveness Favors Social Susceptibility in Social Spiders. Current Biology. https://doi.org/10.1016/j.cub.2017.11.038

* [19] Cornell Chronicle (May 31, 2000). Spiders get better web sites by rising early. https://news.cornell.edu/stories/2000/05/spiders-get-better-web-sites-rising-early

* [20] Hieber, C. S., & Uetz, G. W. (Feb 1990). Colony size and parasitoid load in two species of colonial Metepeira spiders from Mexico (Araneae: Araneidae). Oecologia. https://doi.org/10.1007/bf00323527

* [21] Uetz, G. W., & Hieber, C. S. (1997). Colonial web-building spiders: balancing costs and benefits of group-living. In The Evolution of Social Behavior in Insects and Arachnids. https://doi.org/10.1017/cbo9780511721953.023

* [22] Wu, C., Bhagawat, C., & Goldman, M. R. (Oct 17, 2022). Aggression in a western Amazonian colonial spider, Philoponella republicana (Araneae: Uloboridae). The Journal of Arachnology, 50(3).

https://bioone.org/journals/the-journal-of-arachnology/volume-50/issue-3/JoA-S-20-093/Aggression-in-a-western-Amazonian-coloni

* [23] Yip, E. C., Smith, D. R., & Lubin, Y. (Aug 31, 2021). Long-Term Colony Dynamics and Fitness in a Colonial Tent-Web Spider Cyrtophora citricola. Frontiers in Ecology and Evolution. https://doi.org/10.3389/fevo.2021.725647

* [24] Lubin, Y. D. (1974; online Jun 28, 2008). Adaptive advantages and the evolution of colony formation in Cyrtophora (Araneae: Araneidae). Zoological Journal of the Linnean Society. https://doi.org/10.1111/j.1096-3642.1974.tb00806.x

* [25] Ma, J., et al. (Feb 20, 2025). The genomic consequences and persistence of sociality in spiders. Genome Research. https://doi.org/10.1101/gr.279503.124

* [26] Johannesen, J., et al. (Nov 7, 2006). The age and evolution of sociality in Stegodyphus spiders: a molecular phylogenetic perspective. Proceedings of the Royal Society B. https://doi.org/10.1098/rspb.2006.3699

* [27] Settepani, V., et al. (Jun 27, 2017). Evolution of sociality in spiders leads to depleted genomic diversity at both population and species level. Molecular Ecology. https://doi.org/10.1111/mec.14196

* [28] Johannesen, J., et al. (Aug 9, 2012). Dispersal behaviour and colony structure in a colonial spider. Behavioral Ecology and Sociobiology. https://doi.org/10.1007/s00265-012-1394-4

* [29] Avil s, L., & Guevara, J. (Mar 24, 2017). Sociality in Spiders. In Comparative Social Evolution, Cambridge University Press. https://doi.org/10.1017/9781107338319.008

* [30] Tong, C., et al. (Nov 22, 2022). Genomic signatures of recent convergent transitions to social life in spiders. Nature Communications. https://doi.org/10.1038/s41467-022-34446-8

* [31] Field Museum (Jan 11, 2011). Evolution and ecology in modular organisms. https://www.fieldmuseum.org/blog/evolution-and-ecology-modular-organisms

* [32] Howe, J., et al. (Jul 21, 2022). Multicellularity in animals: The potential for within-organism conflict. Proceedings of the National Academy of Sciences. https://doi.org/10.1073/pnas.2120457119

* [33] Pull, C. D., & McMahon, D. P. (Jun 24, 2020). Superorganism Immunity: A Major Transition in Immune System Evolution. Frontiers in Ecology and Evolution. https://doi.org/10.3389/fevo.2020.00186