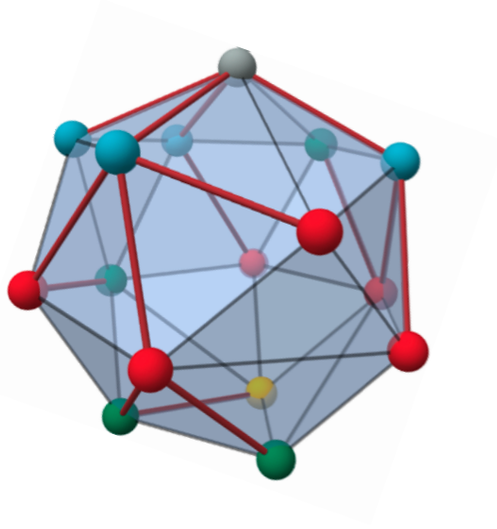
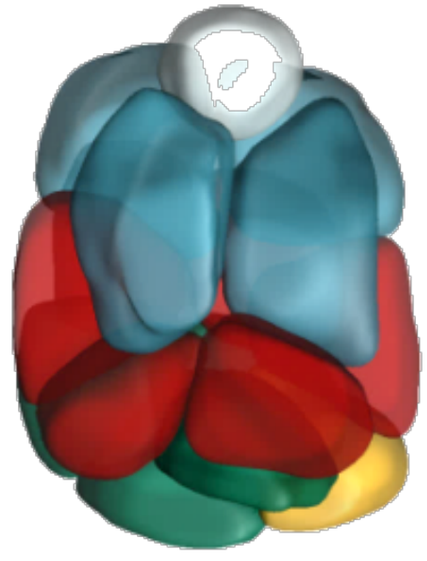




Jörn Dunkel

Mathematik komplexer Systeme

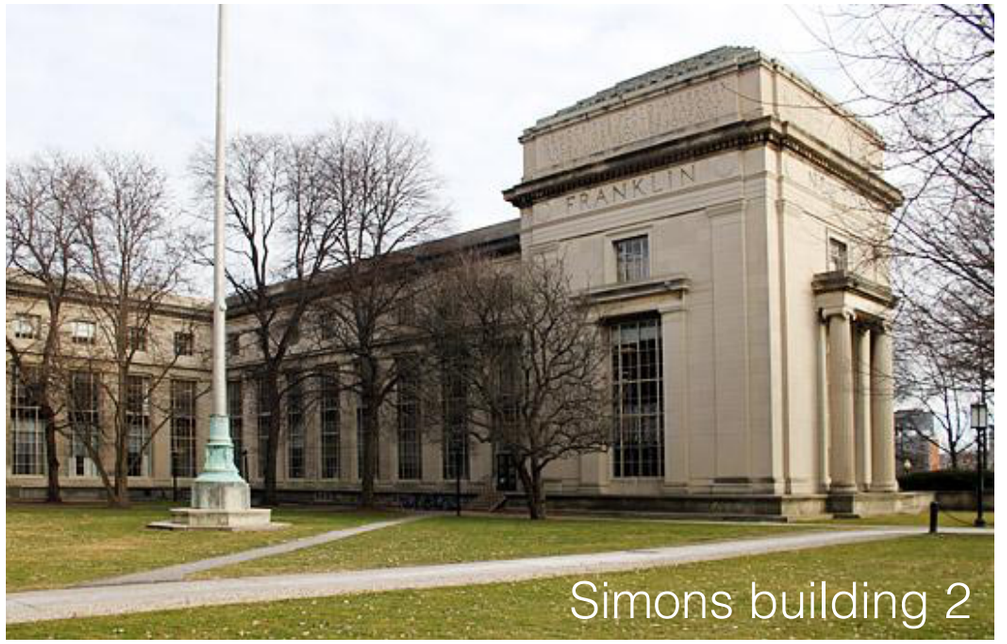
Schule-MIT-Wissenschaft
Hamburg, 27. Juni 2018




HAMBURGER
MORGEN POST
Heute 16 Uhr auf dem Stundenplan
Mathe
Fußball!
So kompliziert war eine WM für Deutschland selten: Es gibt hunderte Möglichkeiten, um ins Achtelfinale zu kommen – oder zu scheitern. Wenn Jogis Jungs den Weg durch den Rechen-Dschungel vermeiden wollen, gibt es nur eine Lösung: Spielt wie der Weltmeister!
16 Seiten WM-Beilage
adidas
!!!CASTING!!!
im AHOI Rotterdam
am 02.+03. Juli
für original St. Pauli Nachtwächter
Nebenjob: Rundgänge
Verfügbarkeit: Abends
Alter ca. 40 bis 50 Jahre
Adresse, Alter, Beruf, Telefonnr.
Anmelden: enzomail@web.de
Info auch: 0173-26 26 426
www.enzocomedy.de
HERR DER GUMMIS
Hamburgs schrägster Laden macht dicht
Aus für „Condomerie“: S. 8
KIOSK-BETREIBER
Eppendorf sammelt für toten Vater
Er ertrank in der Ostsee. Seite 17



MIT MATHEMATICS



Simons building 2





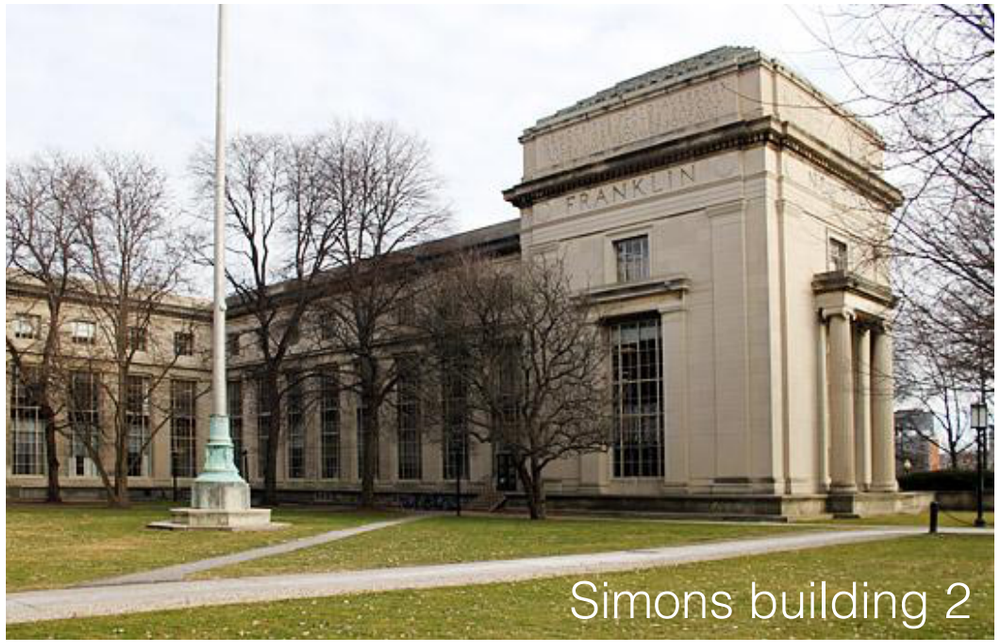
JAMES S. McDONNELL FOUNDATION

National Science Foundation

ALFRED P. SLOAN FOUNDATION



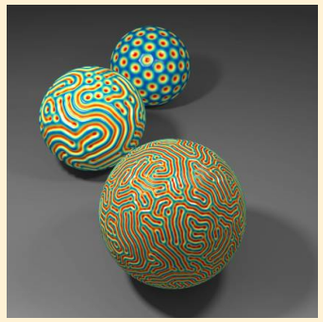
MIT MATHEMATICS

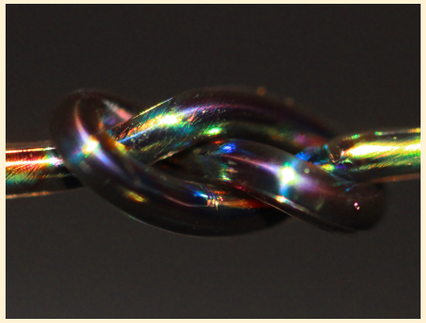


Simons building 2

Pedro Reis (Mech E)	Mathias Kolle (Mech E)	Martin Zwierlein (Physics)	Nikta Fakhri (Physics)	Adam Martin (Biology)	Alex Shalek (Chemistry)	In Song Kim (Political Sci)
						
Now @ EPFL						

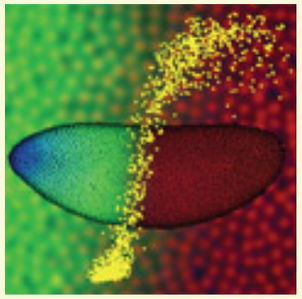
Weiche Materialien





Reis lab
Kolle lab

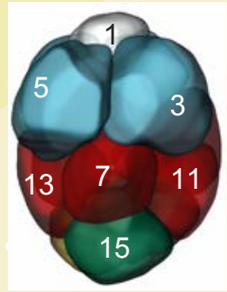
Strukturbildung in der Embryonalentwicklung

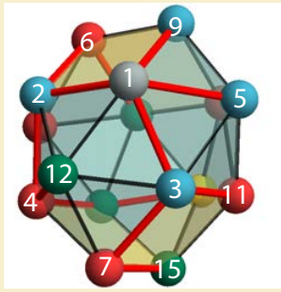




Martin lab
Fakhri lab

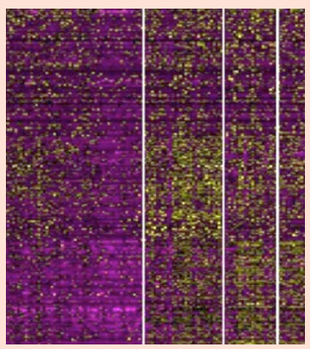
Oogenese

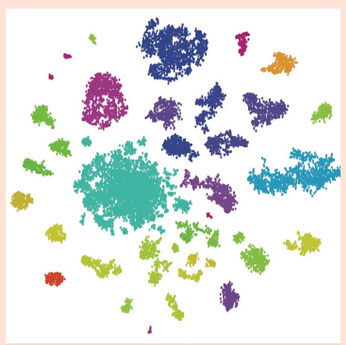




Shvartsman lab

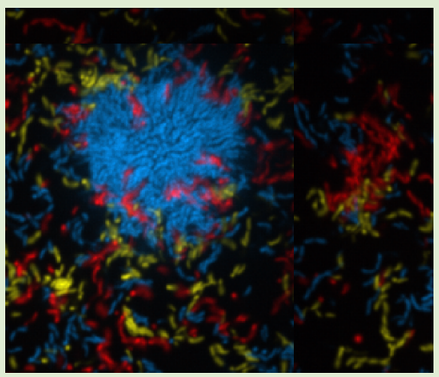
Strukturen in ‘big data’





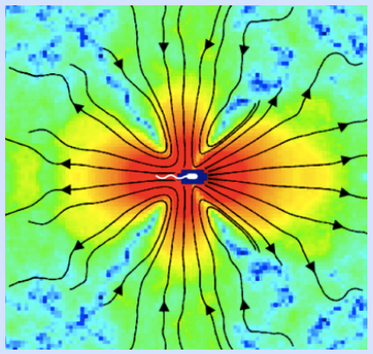
Shalek lab
In Song Kim

Entwicklung bakterieller Biofilme

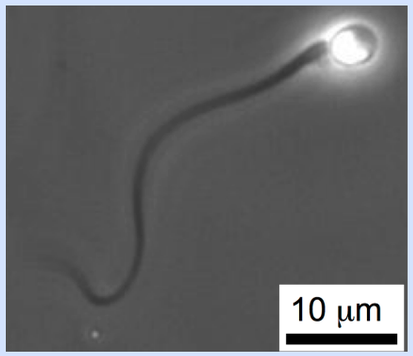


Drescher lab

Dynamik und Navigation von Mikroorganismen



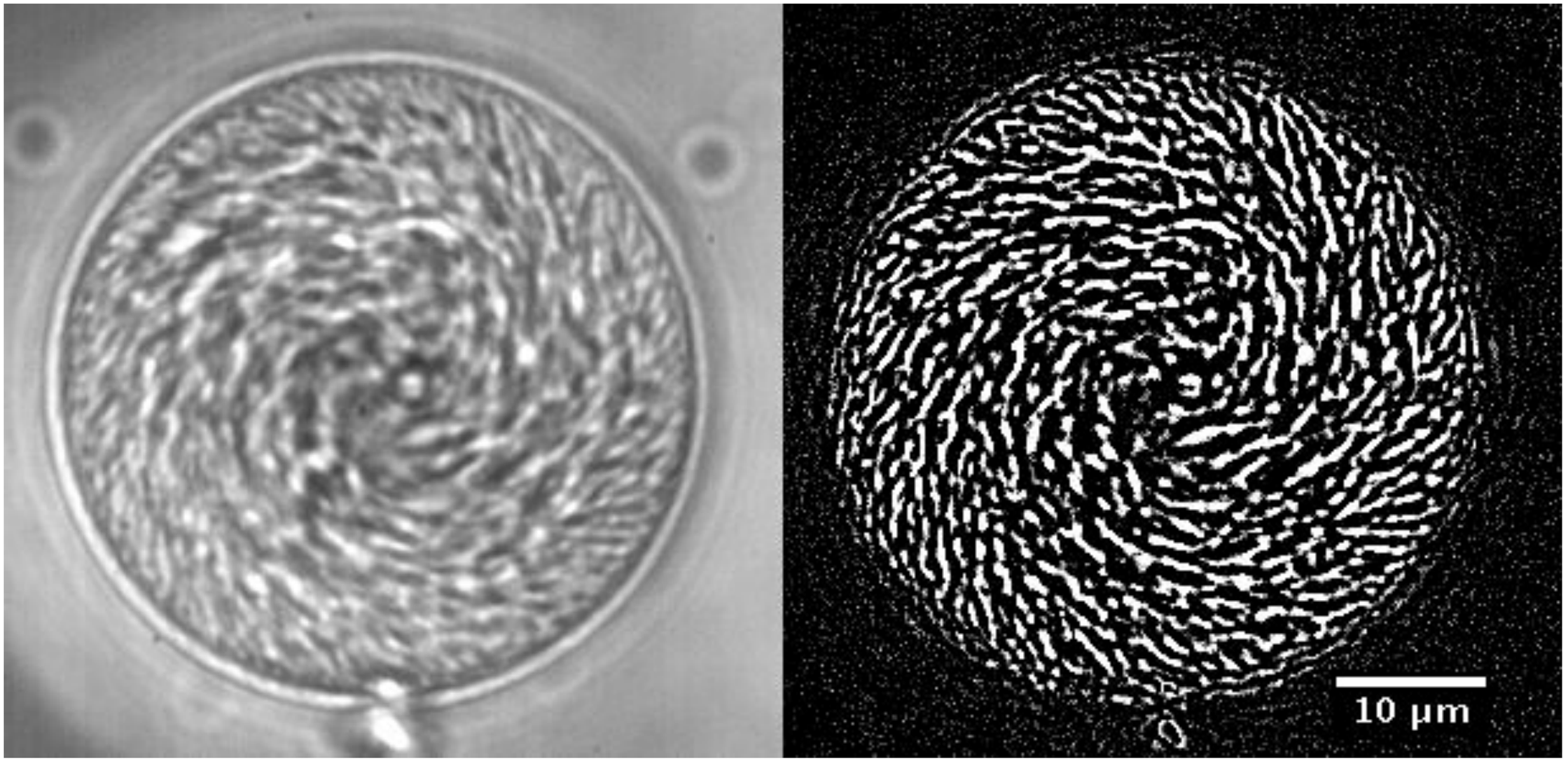
Goldstein group

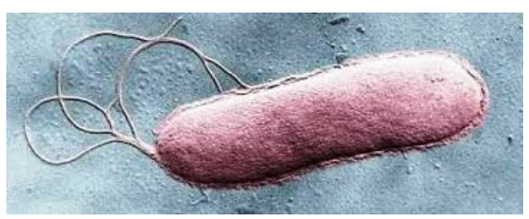


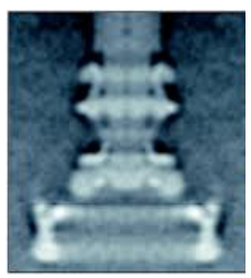
Guasto lab

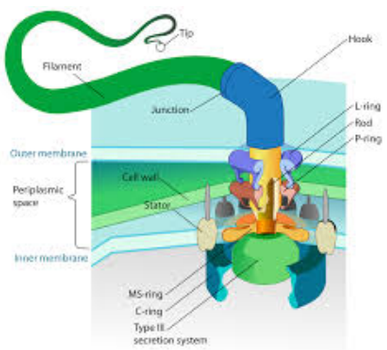
Geometrische Kontrolle

PRL 2013

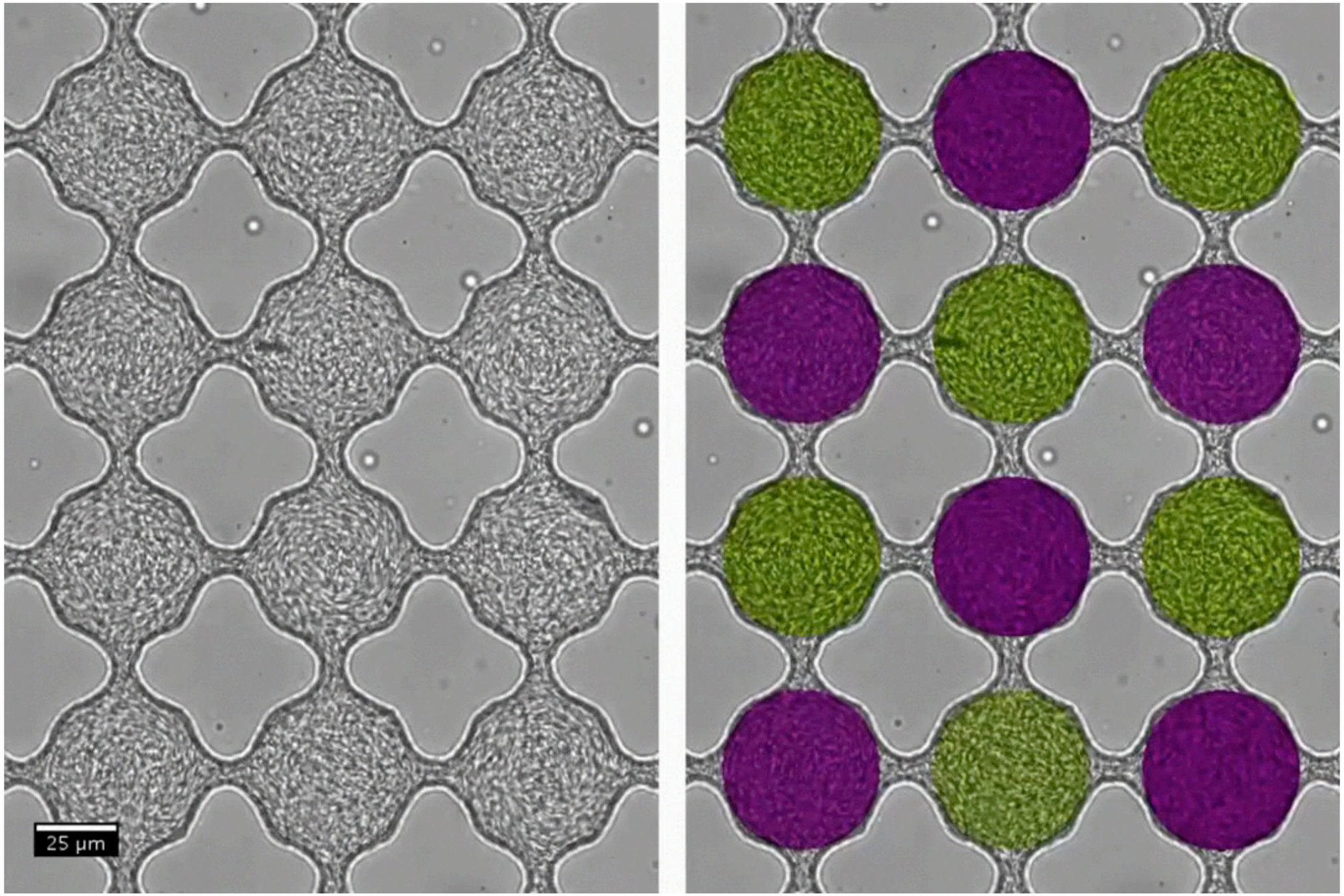






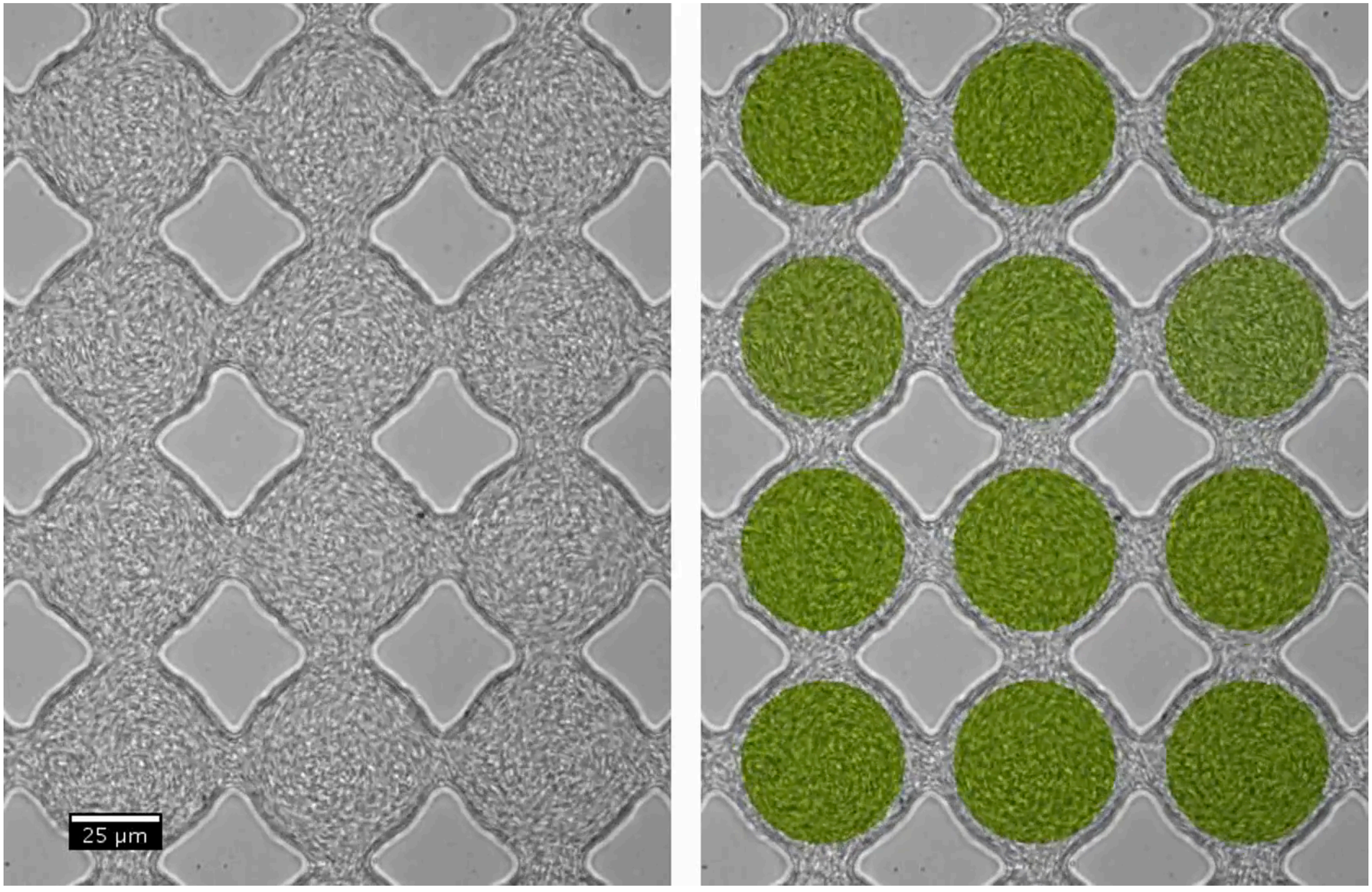


Anti-ferromagnetische Ordnung



Nature Physics 2016

Ferromagnetische Ordnung



Gleiche Mathematik wie für Aktienkurse

Nature Physics 2016

Warum Grundlagenforschung ?



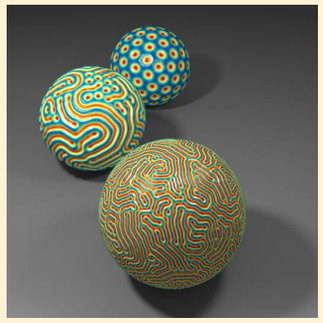
“The electric light did not come from the continuous improvement of candles” – (Oren Harari)

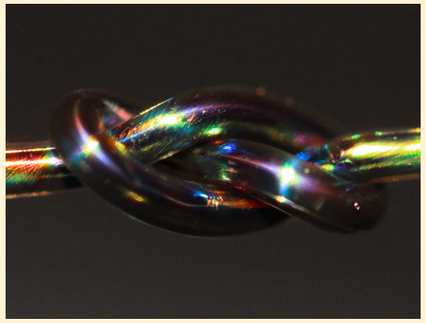


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Innovation Training & Consultancy

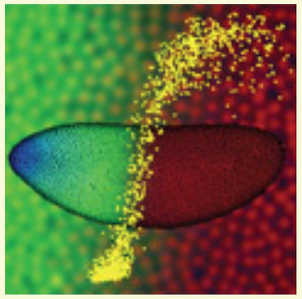
Weiche Materialien





Reis lab
Kolle lab

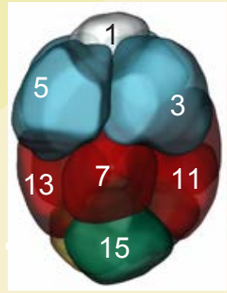
Strukturbildung in der Embryonalentwicklung

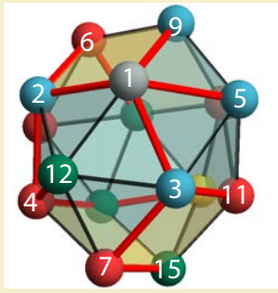




Martin lab
Fakhri lab

Oogenese

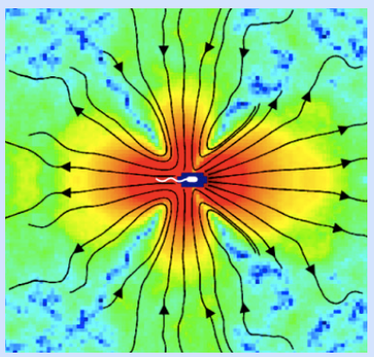


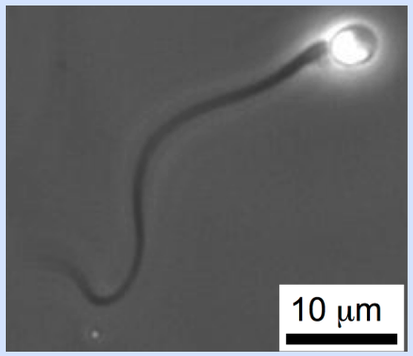


Shvartsman lab

Mathematik = gemeinsame Sprache aller quantitativen Wissenschaften

Dynamik und Navigation von Mikroorganismen

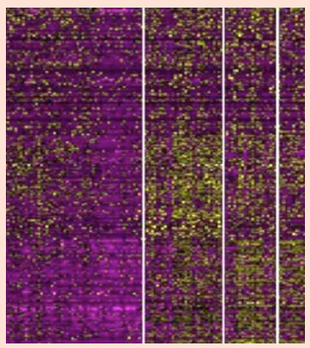


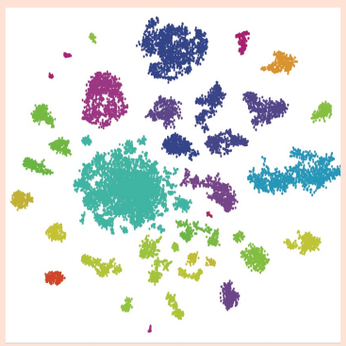


Goldstein group
UNIVERSITY OF CAMBRIDGE

Guasto lab

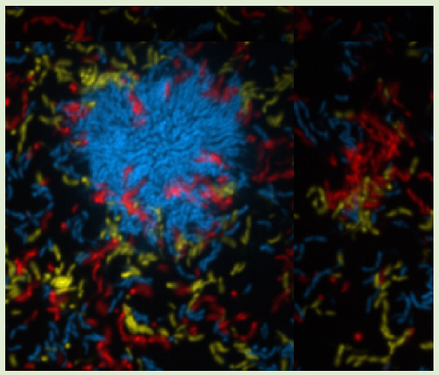
Strukturen in ‘big data’





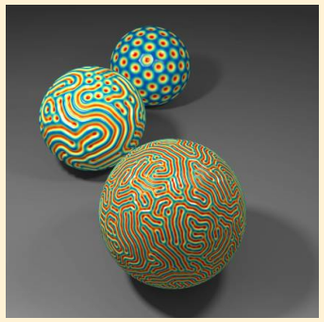
Shalek lab
In Song Kim

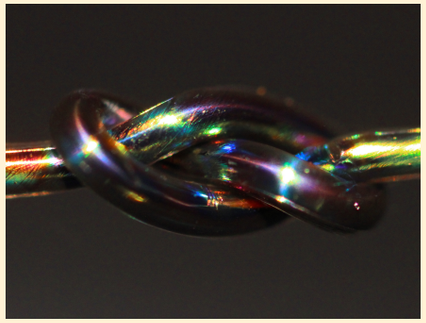
Entwicklung bakterieller Biofilme



Drescher lab
MAX-PLANCK-GESELLSCHAFT

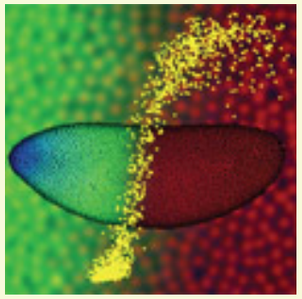
Weiche Materialien





Reis lab
Kolle lab

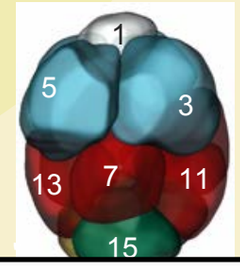
Strukturbildung in
der Embryonalentwicklung

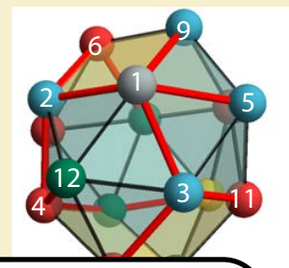




Martin lab
Fakhri lab

Oogenese



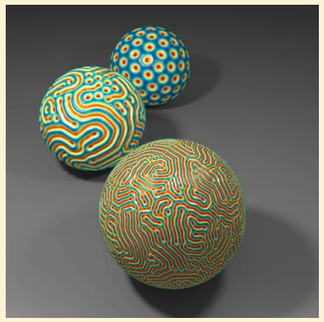


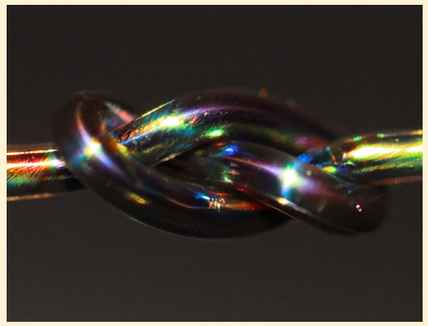
Kontinuumsmodelle
(partielle Differentialgleichungen)

$$\frac{\partial}{\partial t}c(t,x,y) = D\frac{\partial^2}{\partial x^2}c(t,x,y) + D\frac{\partial^2}{\partial y^2}c(t,x,y)$$

+ Anfangs- und Randbedingungen

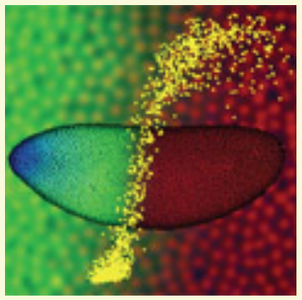
Weiche Materialien





Reis lab
Kolle lab

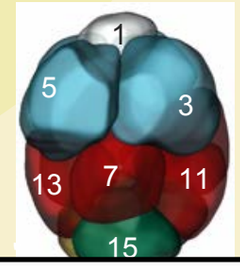
Strukturbildung in der Embryonalentwicklung

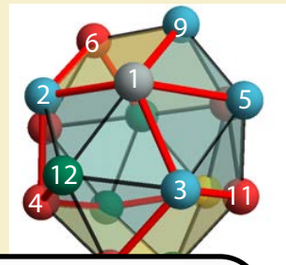




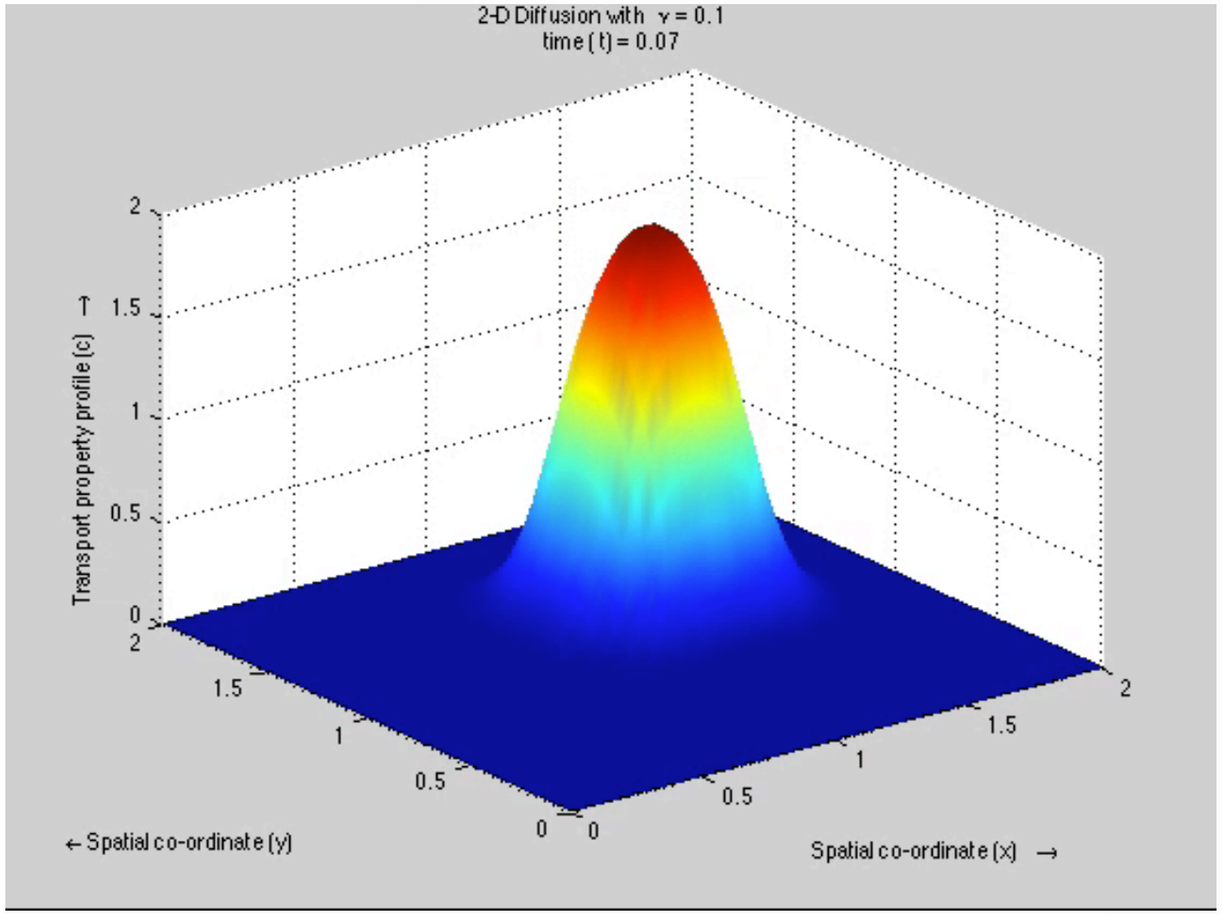
Martin lab
Fakhri lab

Oogenese





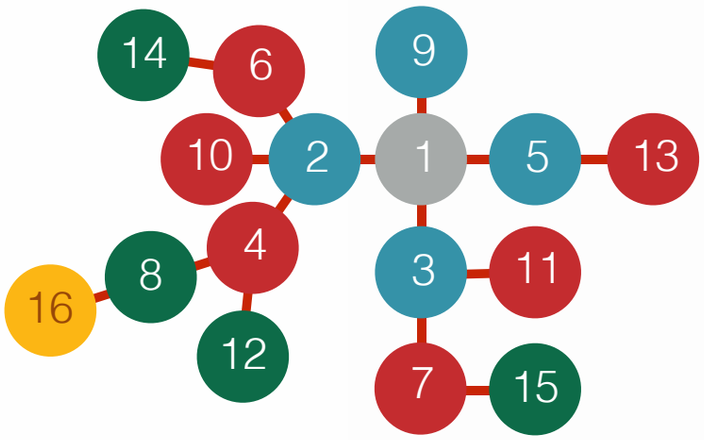
$$\frac{\partial}{\partial t}c(t,x,y) = D\frac{\partial^2}{\partial x^2}c(t,x,y) + D\frac{\partial^2}{\partial y^2}c(t,x,y)$$



Weiche Materialien

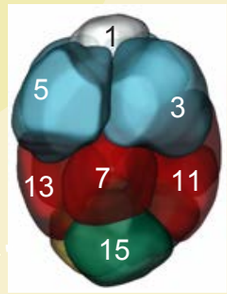
Strukturbildung in
der Embryonalentwicklung

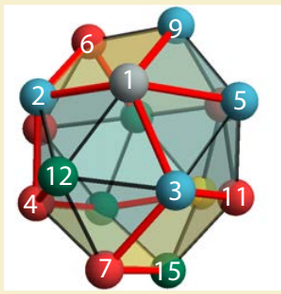
Graphentheorie
&
Kombinatorik





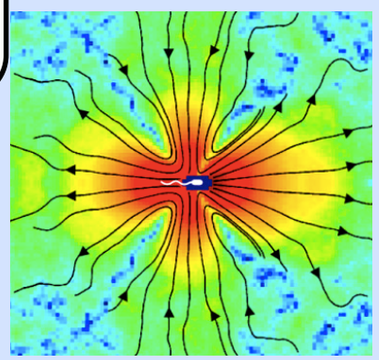
Oogenese





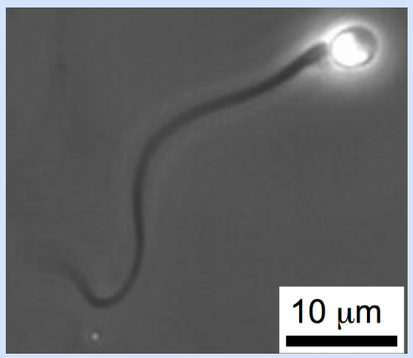
Shvartsman
lab

Dynamik und Navigation
von Mikroorganismen



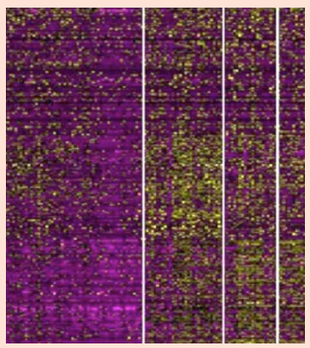
Goldstein group

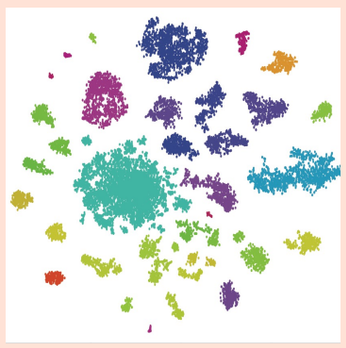
UNIVERSITY OF CAMBRIDGE



Guasto lab

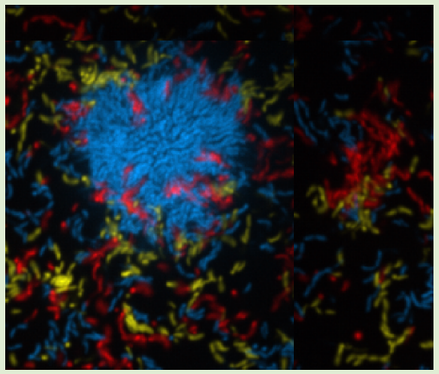
Strukturen in 'big data'





Shalek lab
In Song Kim

Wachstum
bakterieller Biofilme



MAX-PLANCK-GESELLSCHAFT

Drescher lab

Teilchenmodelle

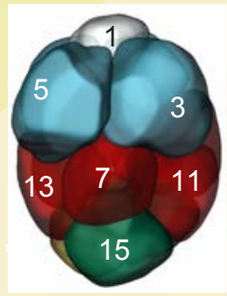
(gewöhnliche und stochastische Differentialgleichungen)

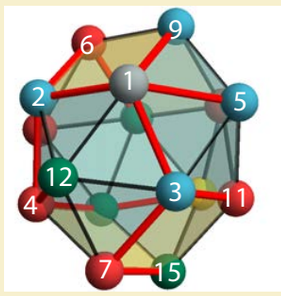
$$\frac{d}{dt}\mathbf{x}(t) = \mathbf{F}[\mathbf{x}(t)] + \xi(t)$$

icklung



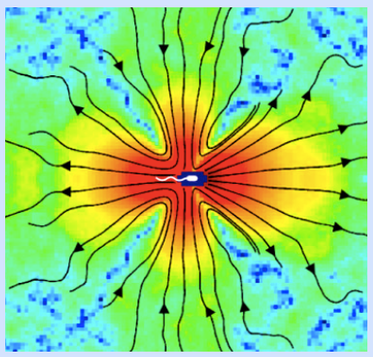
Oogenese





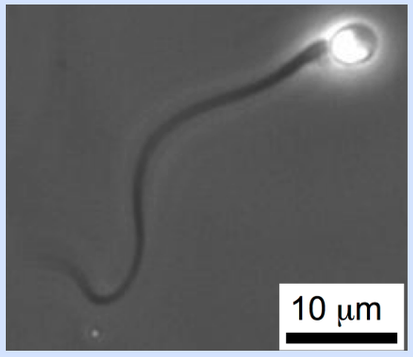
Shvartsman lab

Dynamik und Navigation von Mikroorganismen



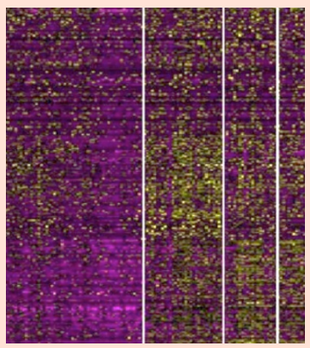
Goldstein group

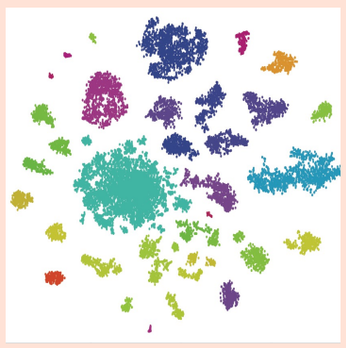
UNIVERSITY OF CAMBRIDGE



Guasto lab

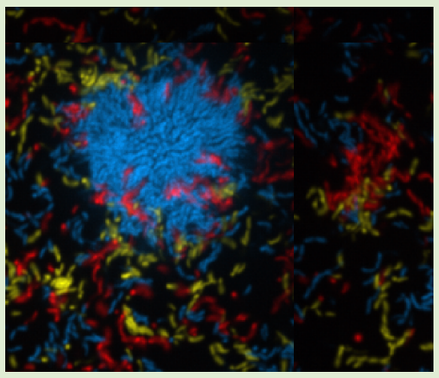
Strukturen in ‘big data’





Shalek lab
In Song Kim

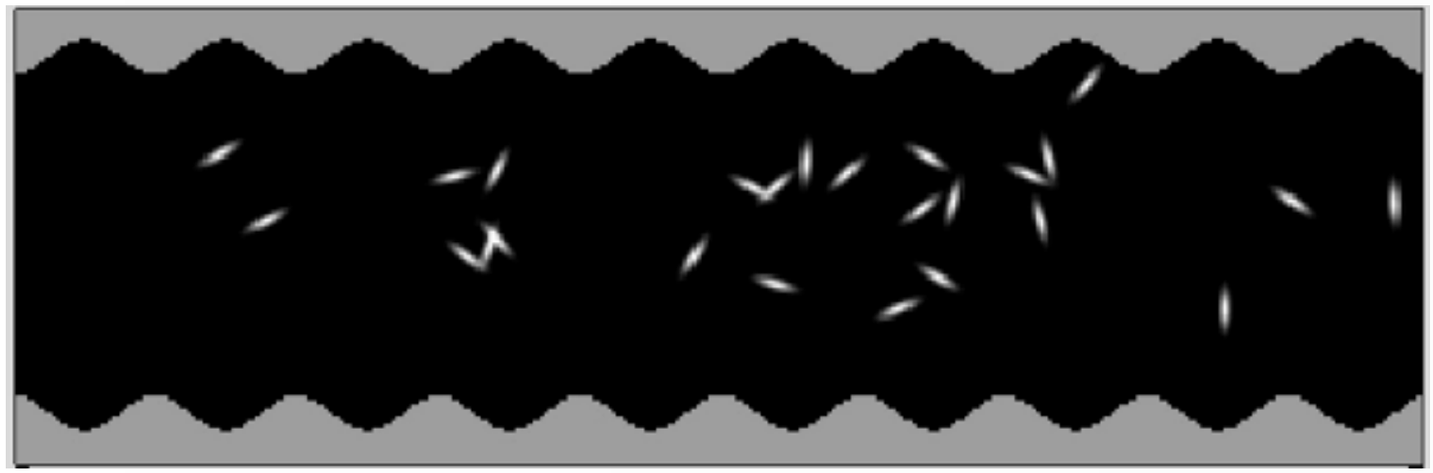
Wachstum bakterieller Biofilme



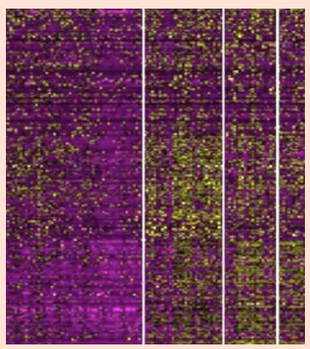
Drescher lab

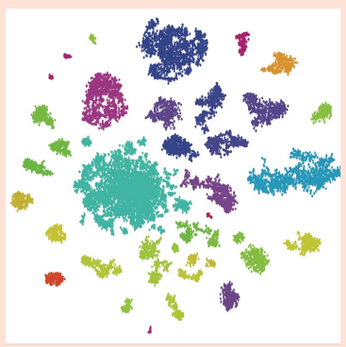
Teilchenmodelle

(gewöhnliche und stochastische Differentialgleichungen)



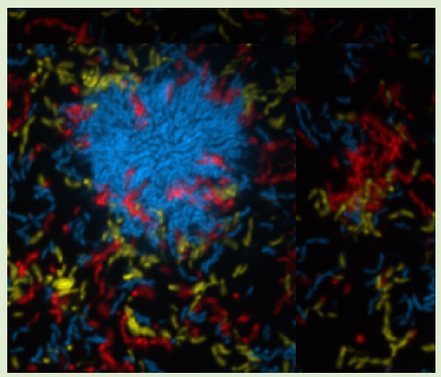
Strukturen in ‘big data’





Shalek lab
In Song Kim

Wachstum bakterieller Biofilme



Drescher lab

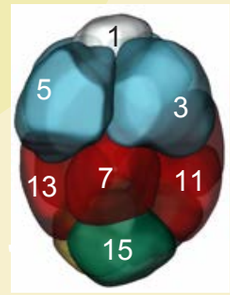
MAX-PLANCK-GESELLSCHAFT

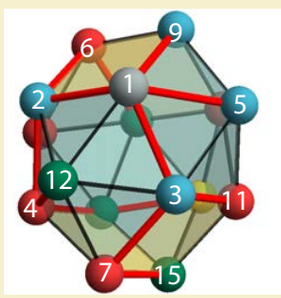
Entwicklung in

icklung



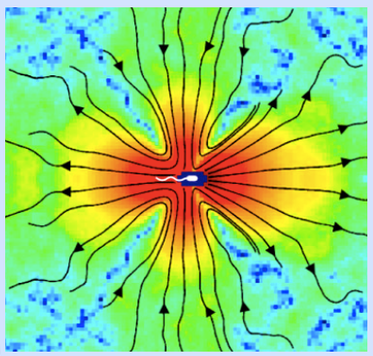
Oogenese





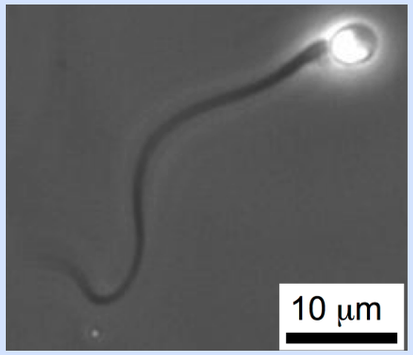
Shvartsman lab

Dynamik und Navigation von Mikroorganismen



Goldstein group

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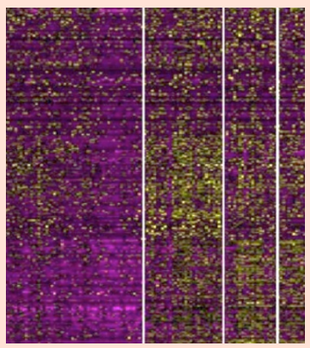


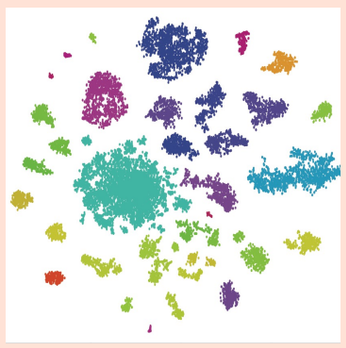
Guasto lab

Effektive Teilchenmodelle & **Lineare Algebra**

$$D = T \times W$$

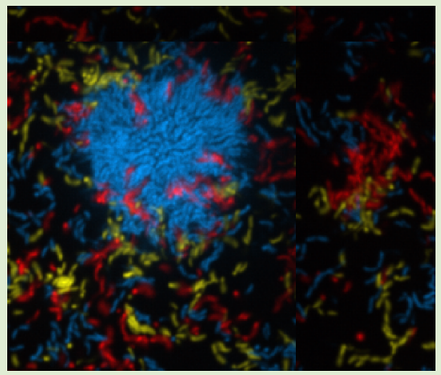
Strukturen in ‘big data’



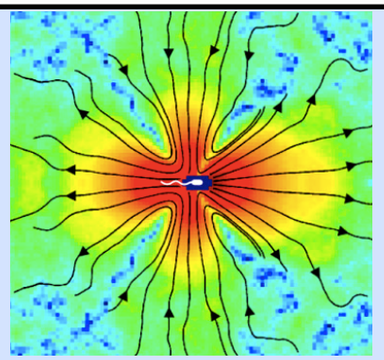


Shalek lab
In Song Kim

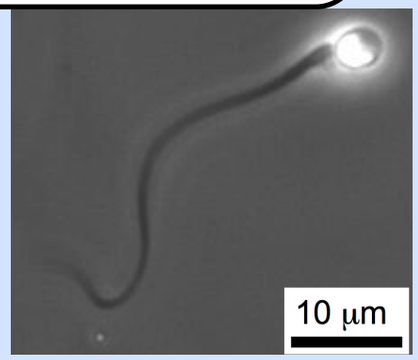
Wachstum bakterieller Biofilme



Drescher lab

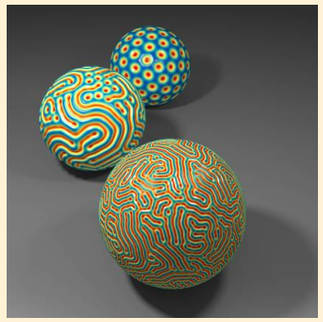


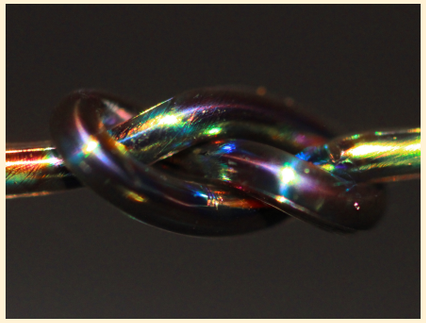
Goldstein group
UNIVERSITY OF CAMBRIDGE



Guasto lab

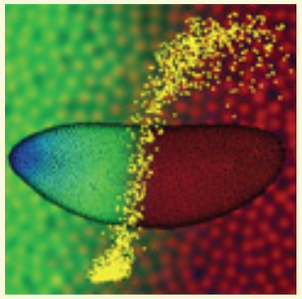
Weiche Materialien





Reis lab
Kolle lab

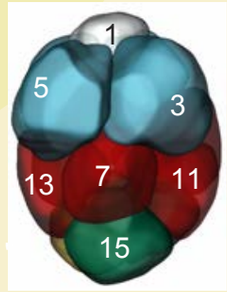
Strukturbildung in der Embryonalentwicklung

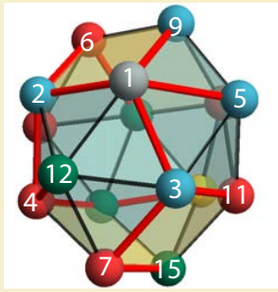




Martin lab
Fakhri lab

Oogenese

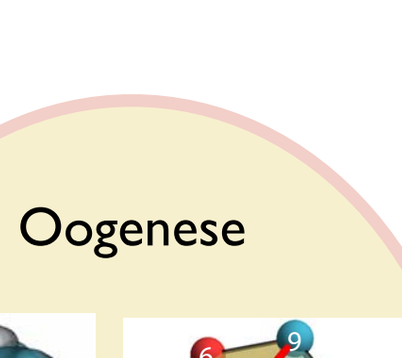




Shvartsman lab

Dynamik und Navigation von Mikroorganismen



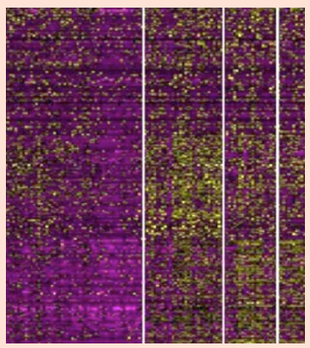


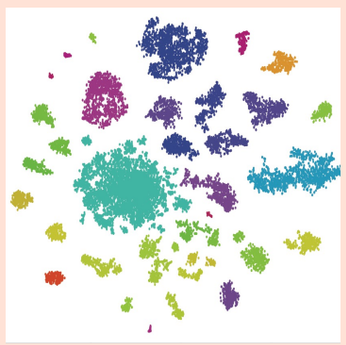
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Guasto lab

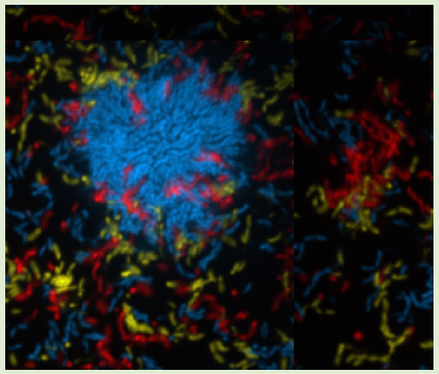
Strukturen in ‘big data’





Shalek lab
In Song Kim

Wachstum bakterieller Biofilme



MAX-PLANCK-GESELLSCHAFT

Drescher lab

Packen von Zell-stamm-bäumen

Stas Shvartsman's lab



Packen von Zell-stamm-bäumen



Jasmin Imran Alsous
Princeton



Norbert Stoop
MIT



Paul Villoutreix
Weizmann

Praktische und mathematische Packungsprobleme

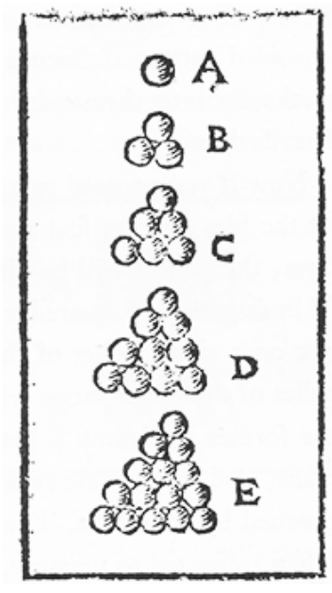
Johannes Kepler
(1571-1630)



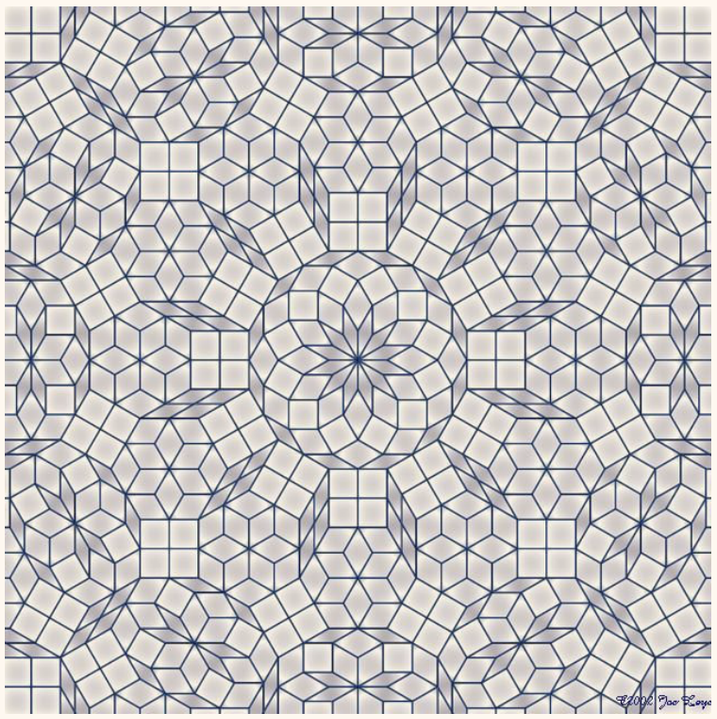
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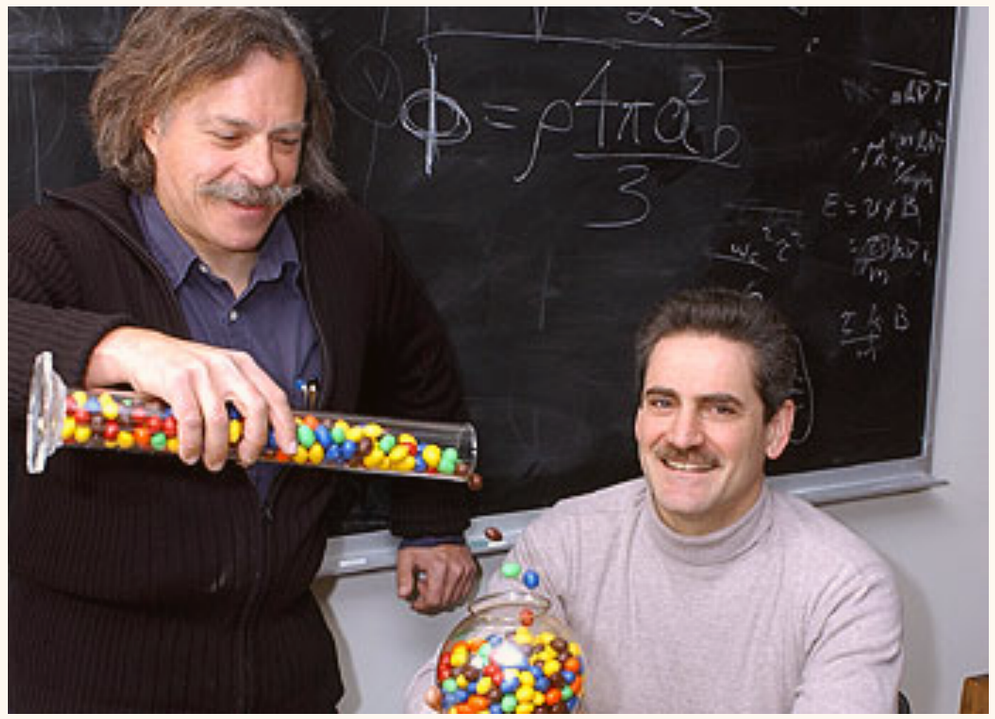


Cum Priuilegio S. Cæs. Maiest. ad annos XV.
FRANCOFVRTI AD MOENVM,
apud Godefridum Tampach.
Anno M. DC. XI.

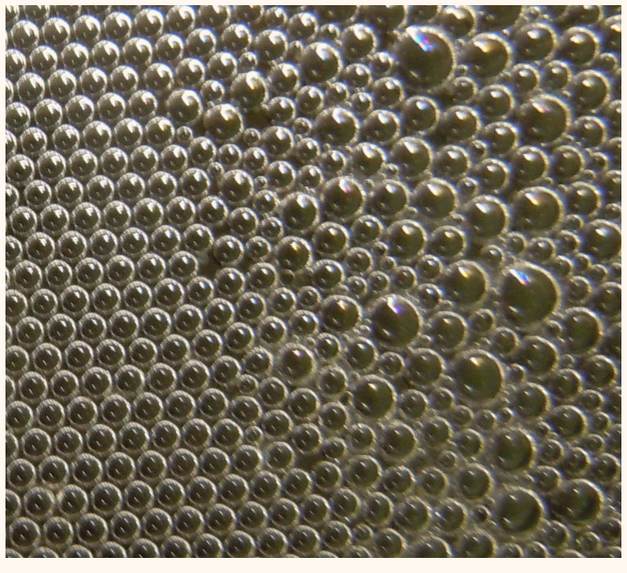


bit-player.org/2012/keplers-snowflake

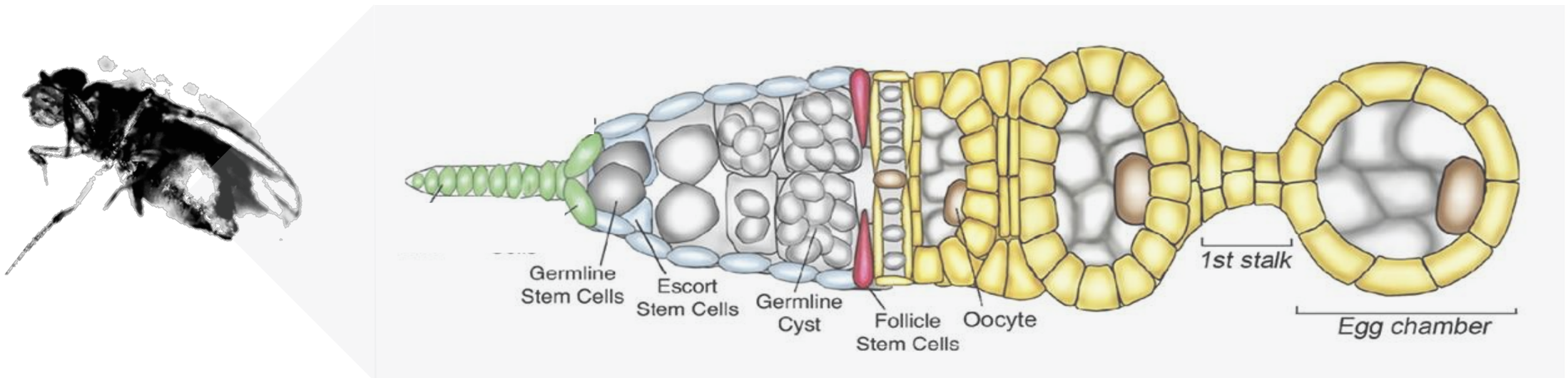




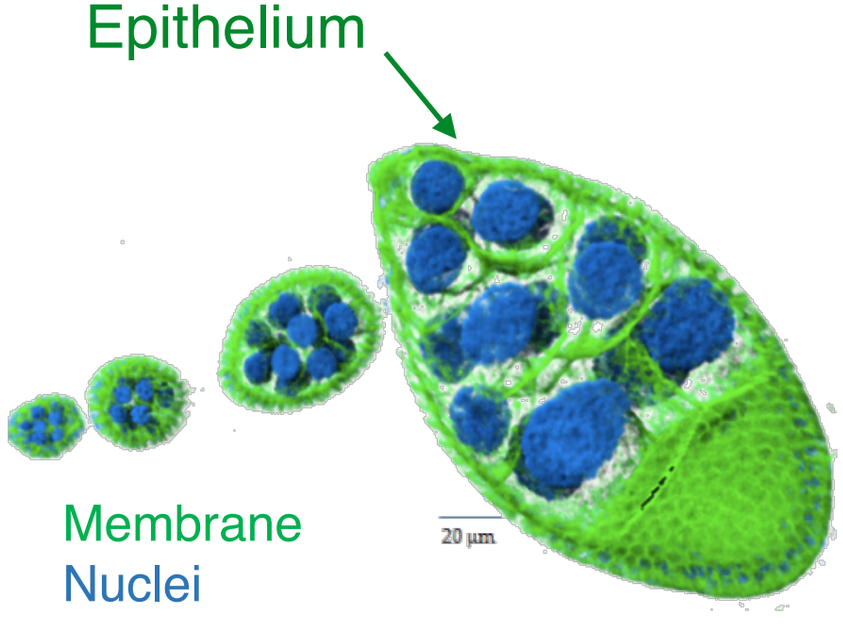


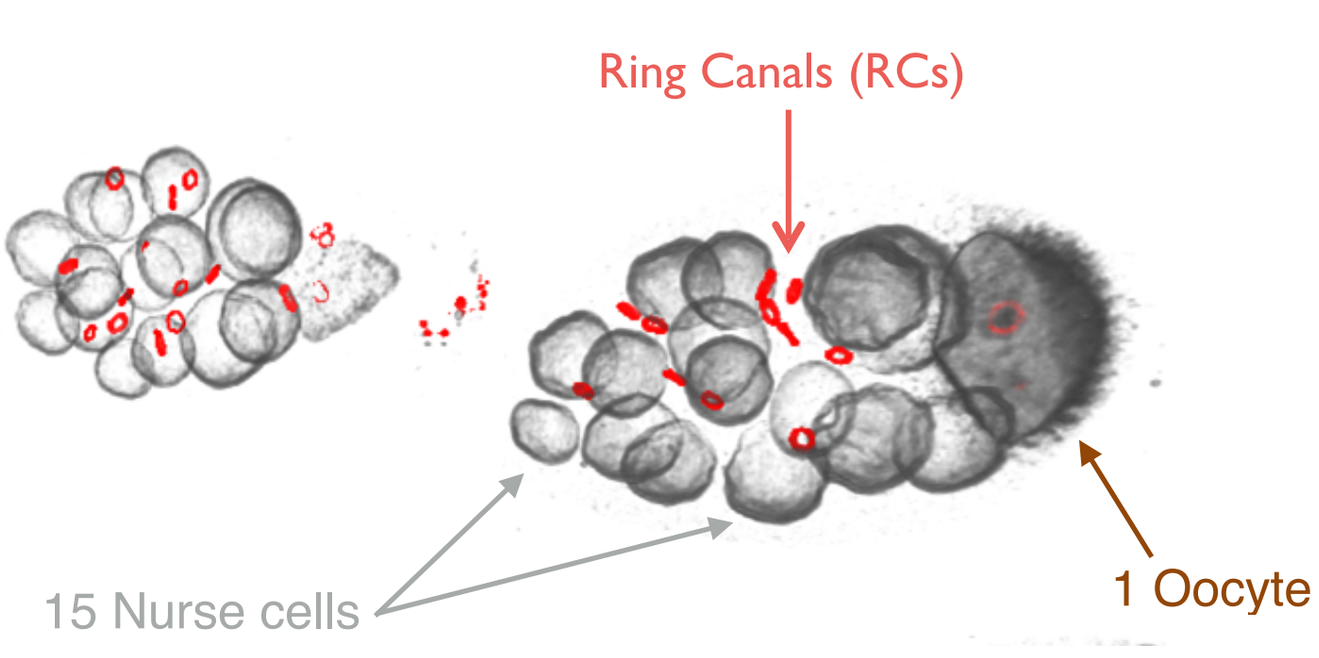


Biologisches Packungsproblem



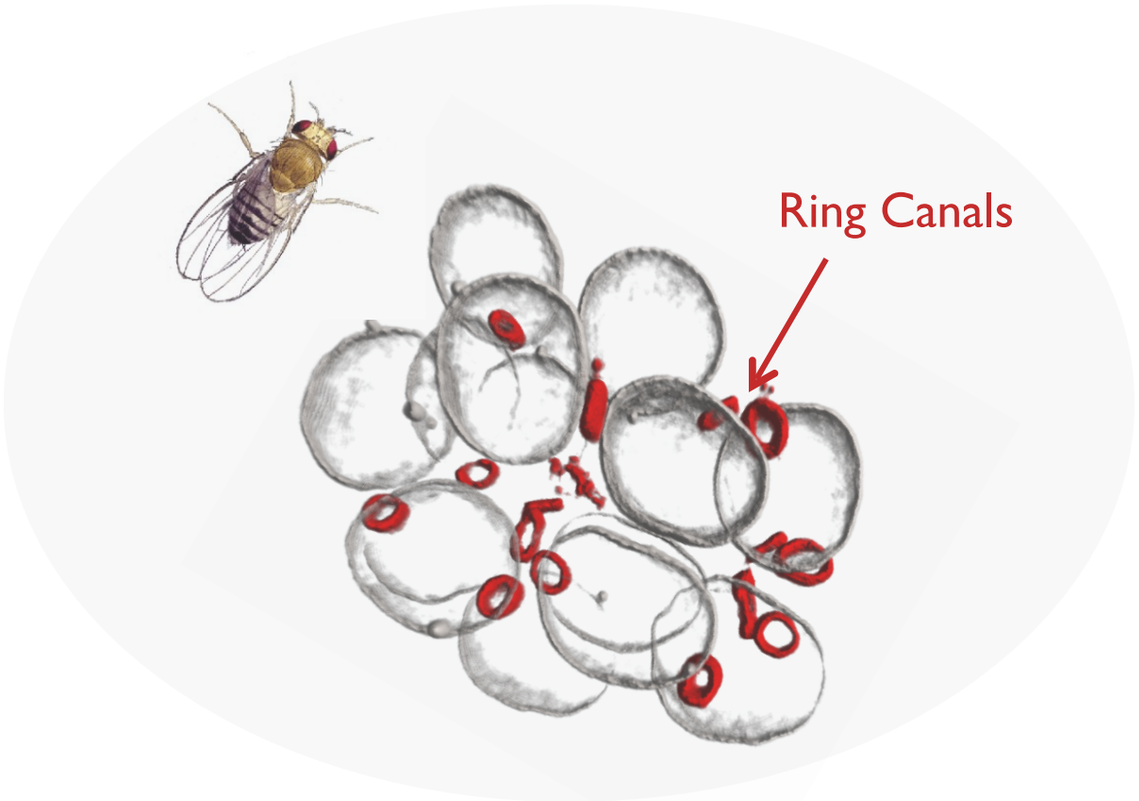
Hartmann et al, J Cell Biol (2010)



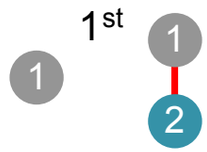


Unvollkommene Zellteilung in der frühen Eizellenentwicklung führt auf constrained tree-packing problems

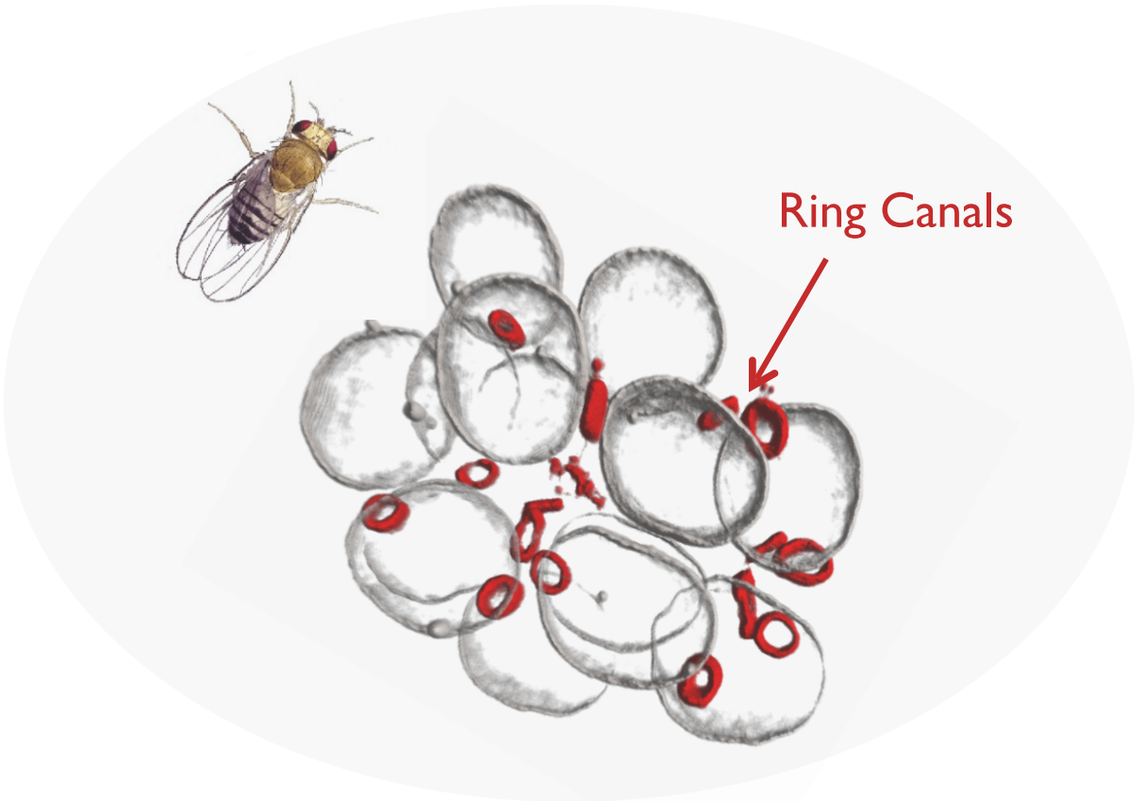
Zell-stamm-baum



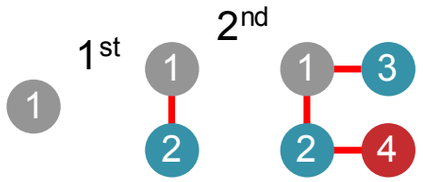
15 Nurse cells + 1 Oocyte



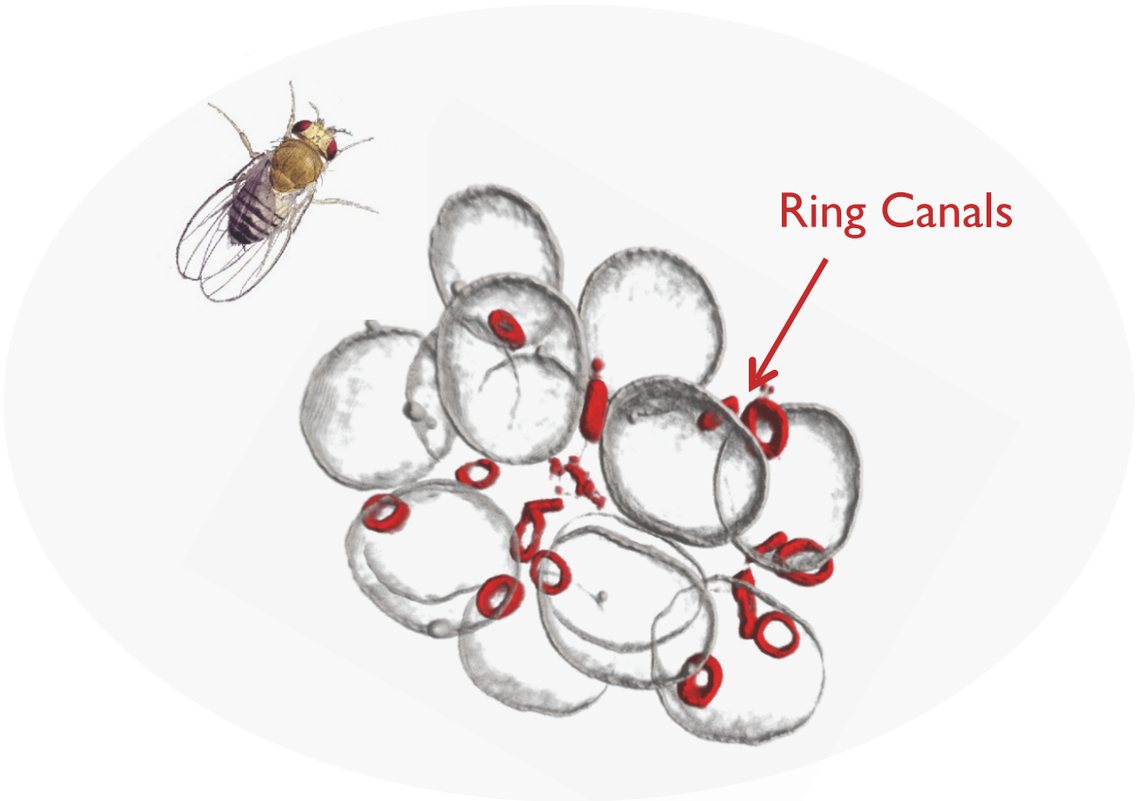
Zell-stamm-baum



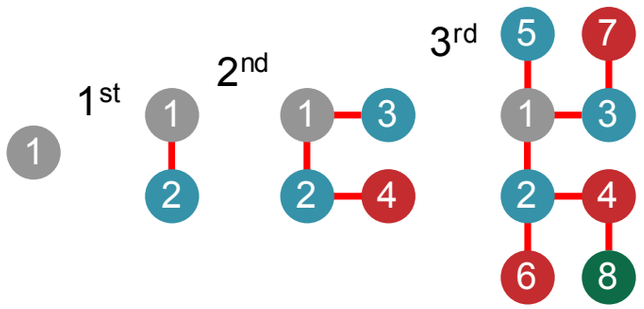
15 Nurse cells + 1 Oocyte



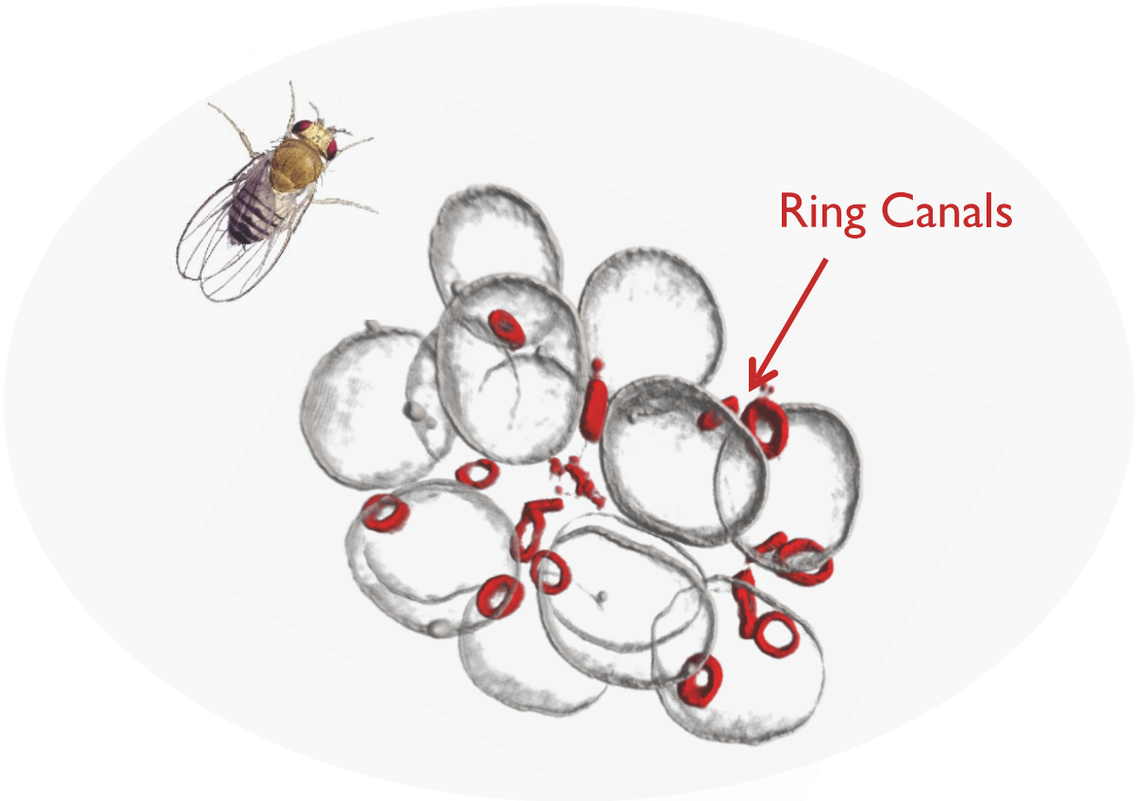
Zell-stamm-baum



15 Nurse cells + 1 Oocyte

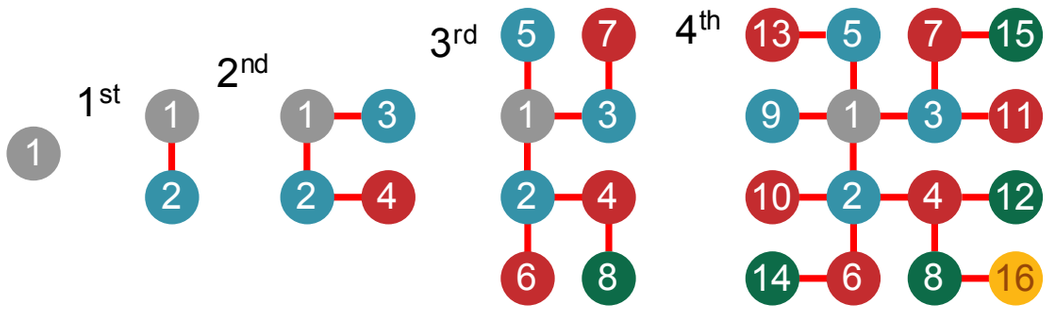


Zell-stamm-baum



15 Nurse cells + 1 Oocyte

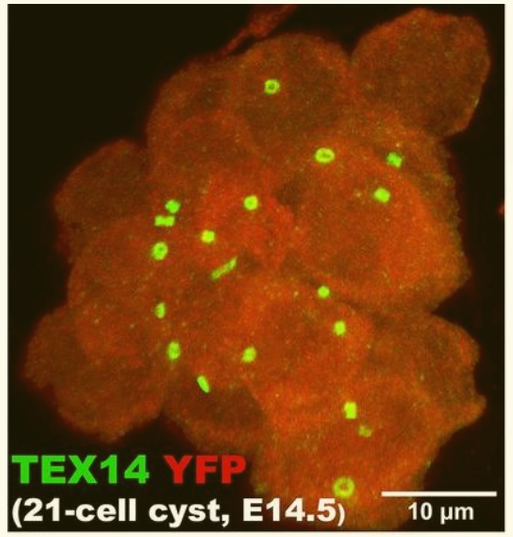
CLT uniquely labeled
by leave sequence



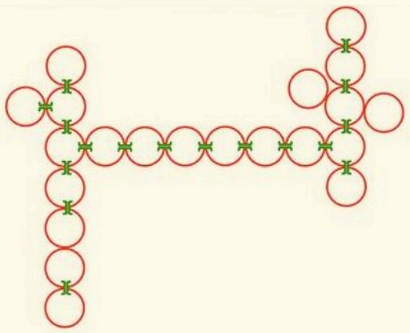
[16, 12, 11, 15, 13, 9, 10, 14]

Weitverbreiteter Prozess





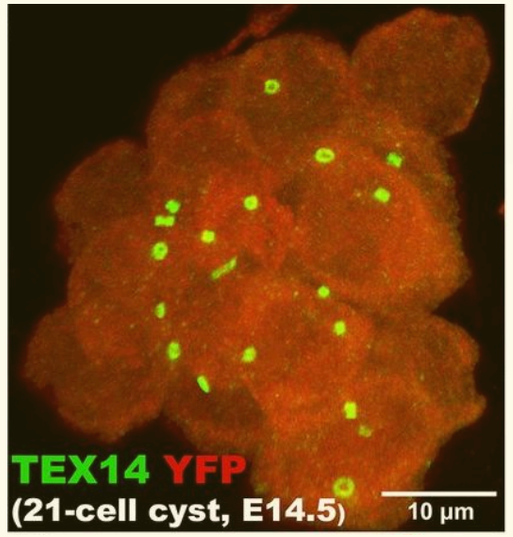




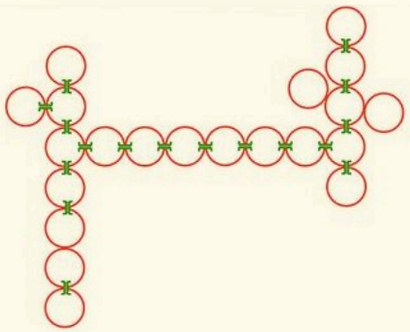
Lei & Spradling, Science (2016)

Weitverbreiteter Prozess



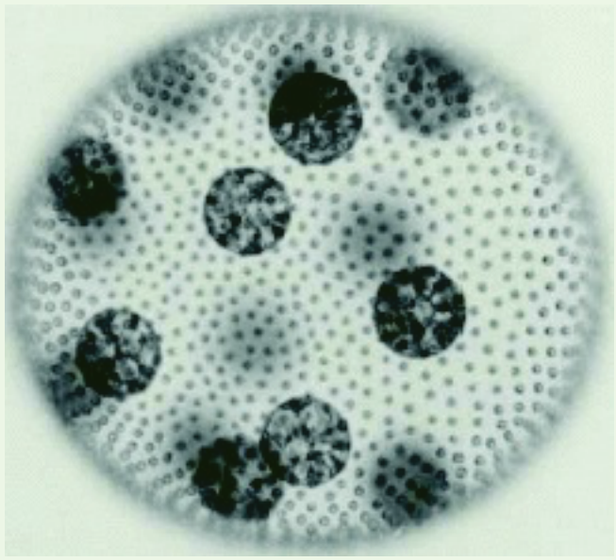


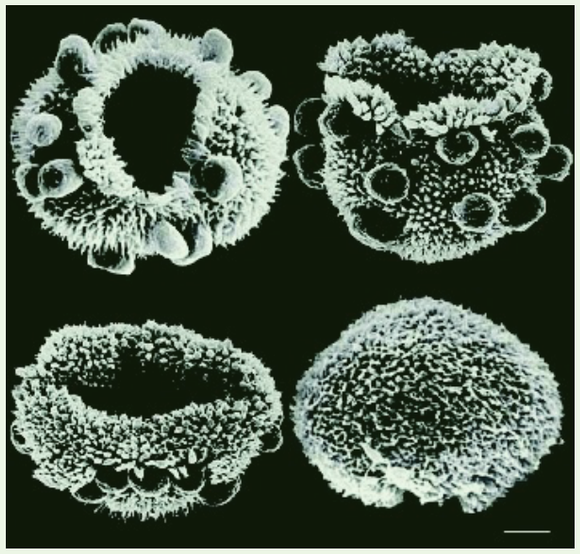




Lei & Spradling, Science (2016)

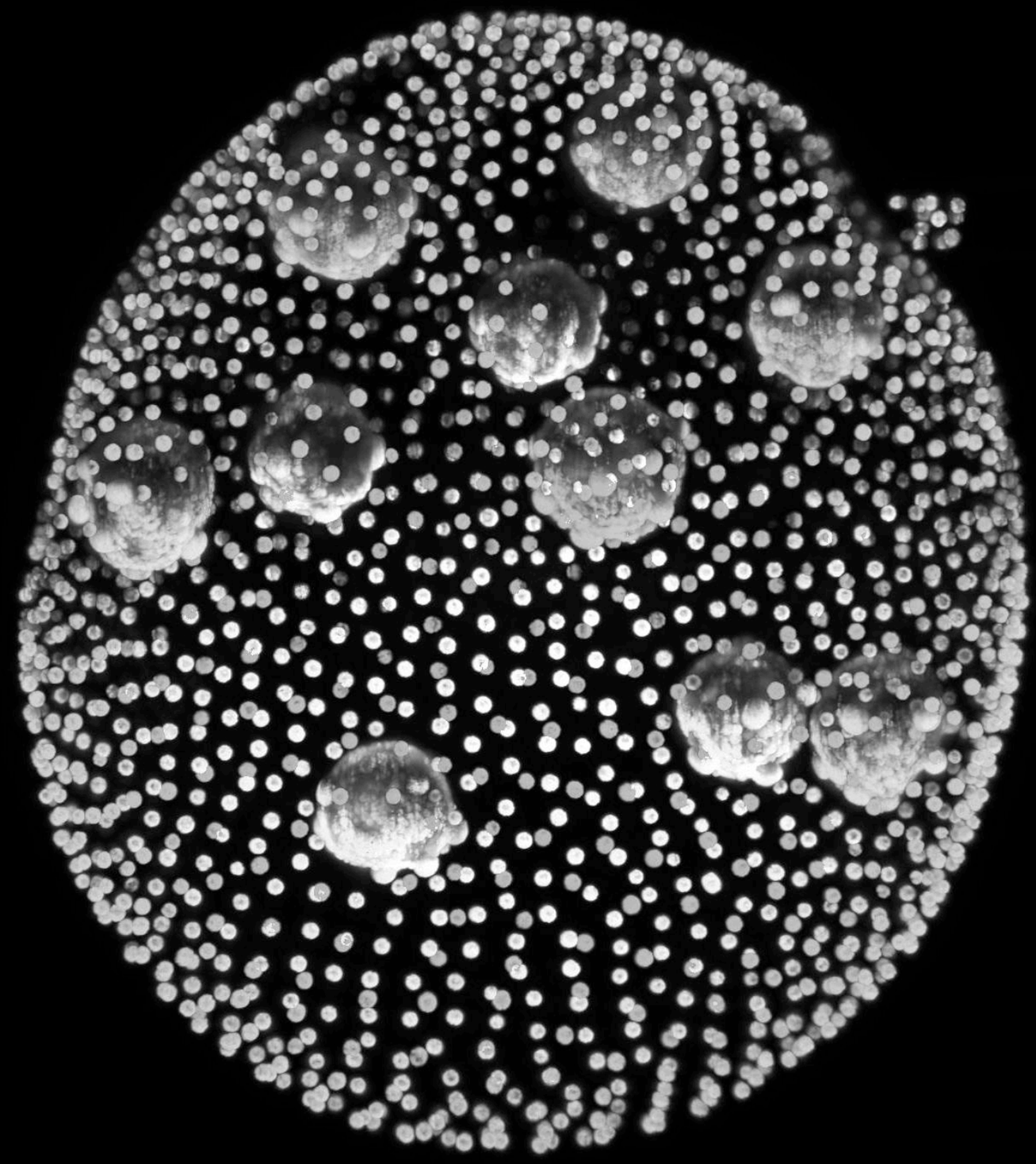
Volvox







Hoops et al (2006)
In *Cell-Cell Channels*



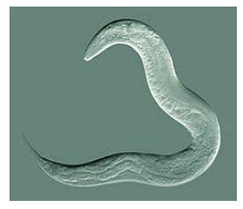
Ray Goldstein’s lab, Cambridge

Constrained cell-tree packings are common

Haglund et al, Commun Integr Biol (2011)

Table 1. Stable intercellular bridges in the germline and in somatic tissues in diverse metazoans

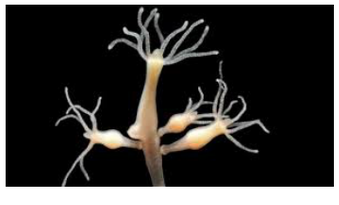
Organism	Bridge type and tissue	Known intercellular bridge components	Diameter and morphology	Proposed intercellular bridge functions
Female germline				
Mammals (Human, rat, hamster, rabbit, see mouse below)	Ring canals interconnecting germ cells in cysts	N.D.	0.5–1 μm, one electron dense rim	Synchronization of mitotic germ cell divisions and entry into meiosis, germ cell degeneration and intercellular transport of organelles
Mouse (*Mus musculus*)	Ring canals interconnecting germ cells in cysts	TEX14, MKLP1	0.5–1 μm, one electron dense rim	Synchronization of mitotic germ cell divisions and entry into meiosis, germ cell degeneration and intercellular transport of organelles, not required for fertility
Chicken	Ring canals interconnecting germ cells in cysts	N.D.	0.5–1 μm, one electron dense rim	Synchronization of cell cycles and intercellular communication
Froglet (*Xenopus laevis*)	Ring canals interconnecting germ cells in cysts	Actin, Ov-htsRC, Kelch	0.5–1 μm, one electron dense rim	Likely directional transport of nutrients to the developing oocyte
Fruit fly (*Drosophila melanogaster*)	Ring canals interconnecting germ cells in cysts	Mature RC: Actin, Ovhts-RC, Kelch, Cheerio, Pav-Klp, Tec29, mucin-D. Transient: Cindr, Anillin.	0.5–10 μm, two rims, an outer electron dense and an inner less electron dense	Directional transport of cytoplasm, nutrients, organelles, proteins and mRNA from the nurse cells to the developing oocyte through the ring canals, required for fertility
Other insects (Honey bee, mosquito, aphid)	Ring canals interconnecting germ cells in cysts	Probably actin	~2–4 μm, one electron dense rim	Directional transport of nutrients to the developing oocyte, oocyte determination
Male germline				
Mammals (Human, goat, cat, rabbit, rat, hamster, squirrel, see mouse below)	Ring canals interconnecting germ cells in cysts	Actin (shown in rat and squirrel)	1–1.5 μm, one electron dense rim	Synchronization of development and entry into meiosis, sharing of haploid gene products
Mouse (*Mus musculus*)	Ring canals interconnecting germ cells in cysts	Actin, TEX14, MKLP1, CEP55, Pericentrin, plectin, δ-tubulin	1–1.5 μm, one electron dense rim	Synchronization of development and entry into meiosis, sharing of haploid gene products, required for fertility
Fruit fly (*Drosophila melanogaster*)	Ring canals interconnecting germ cells in cysts	Anillin, septins, Pav-Klp, pTyr, mucin-D	1–1.5 μm, one electron dense rim	Synchronization of development and entry into meiosis, required for fertility
Somatic intercellular bridges				
Nematode (*Caenorhabditis elegans*)	Bridges called cell division remnants	Actin	~1 μm, N.D.	Regulation of embryonic cell divisions
Fresh water polyp (*Hydra oligactis*)	Bridges between clusters of cnidioblasts	N.D.	~0.5 μm, one electron dense rim	Synchronization of cnidoblast differentiation into nematocysts
Fruit fly (*Drosophila melanogaster*)	Bridges between epithelial follicle cells	Anillin, Pav-Klp, Cindr, mucin-D, Actin	0.2–0.5 μm, two rims, an outer electron dense and an inner less electron dense	Intercellular communication to coordinate cell behavior
Fruit fly (*Drosophila melanogaster*)	Bridges between cells in larval imaginal disc epithelia	Anillin, Pav-Klp, Cindr, mucin-D	0.2–0.5 μm, two rims, an outer electron dense and an inner less electron dense	Intercellular communication to coordinate cell behavior
Fruit fly (*Drosophila melanogaster*)	Bridges between cells in the larval brain	Anillin, Pav-Klp, Cindr, mucin-D	0.2–0.5 μm, two rims, an outer electron dense and an inner less electron dense	None
Other insects (Honey bee, mosquito, stable fly)	Bridges between epithelial follicle cells	N.D.	0.2–0.5 μm, two rims, an outer electron dense and an inner less electron dense	Intercellular communication to coordinate cell behavior



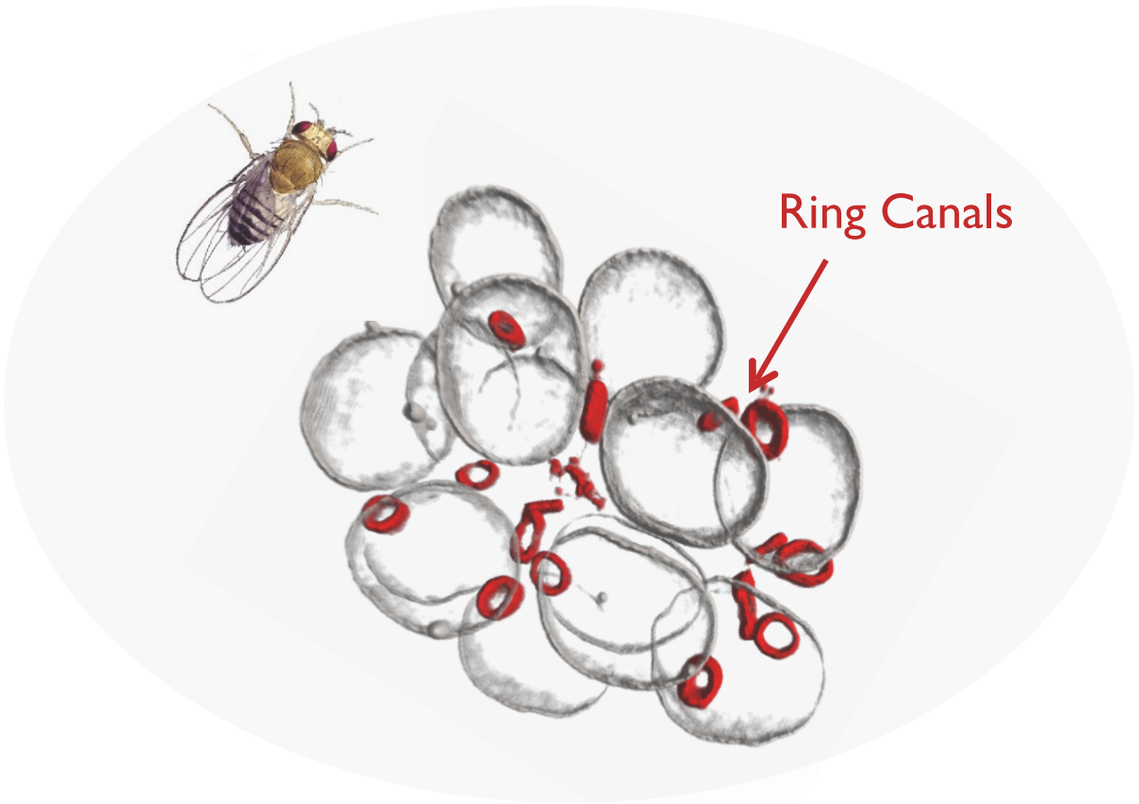






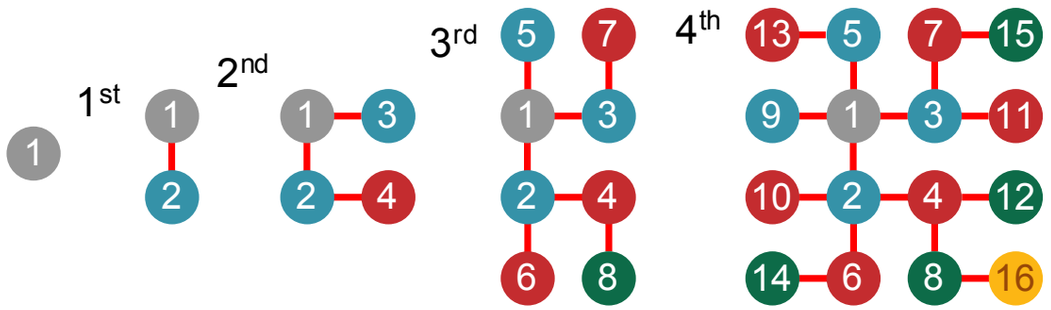



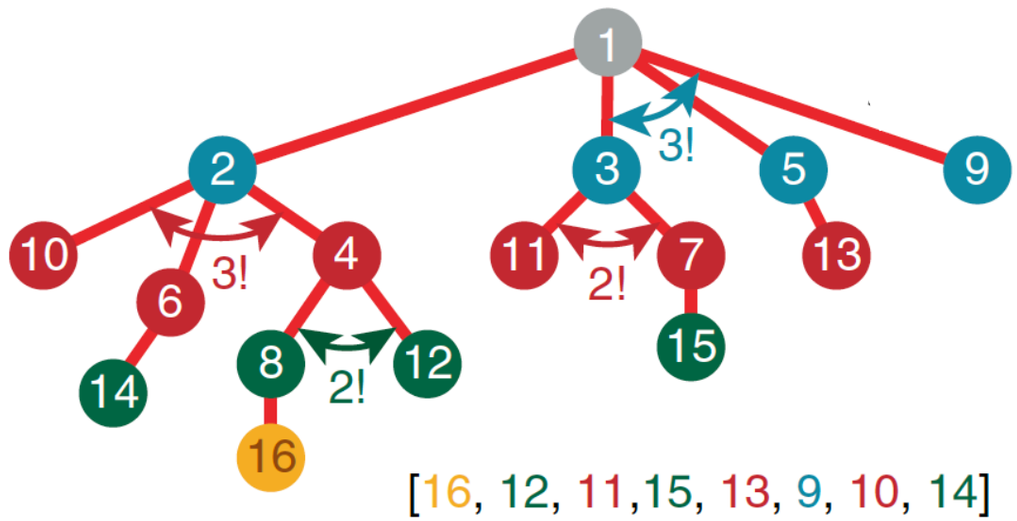

Wieviele Varianten?



15 Nurse cells + 1 Oocyte

CLT uniquely labeled
by leaf sequence





2 x 72 tree configurations

Minimales kombinatorisches Modell ?



George Box
1919-2013

“ All models are wrong ”
but some are useful

Minimales kombinatorisches Modell ?

Platonische Körper
(Platonic solids)



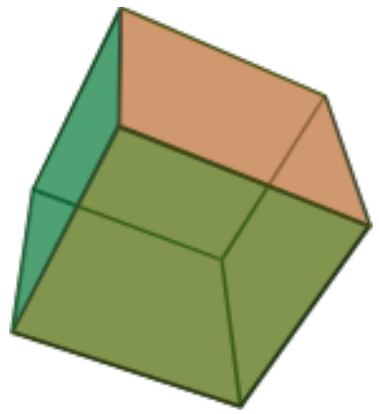
Tetrahedron

4 vertices



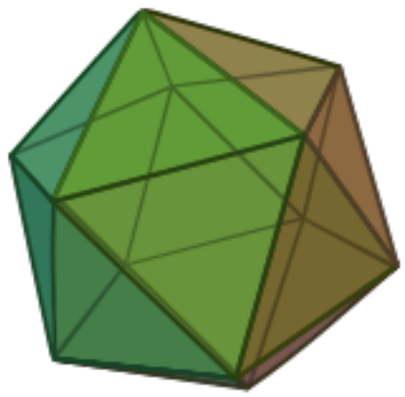
Octahedron

6 vertices



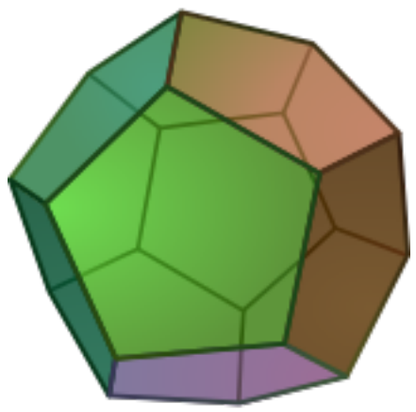
Cube

8 vertices



Isocahedron

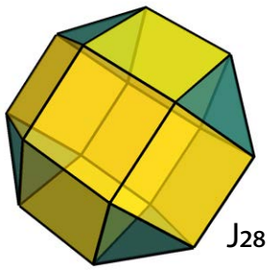
12 vertices



Dodecahedron

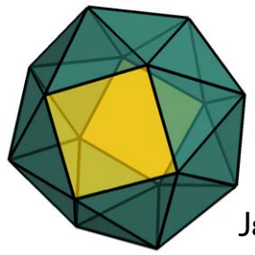
20 vertices

4 Johnson solids with 16 vertices



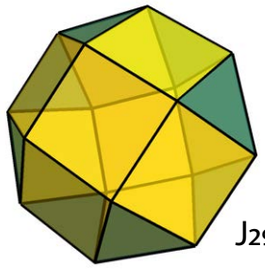
J28

Square Orthobicupola



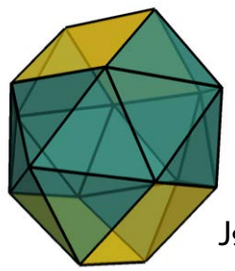
J85

Snub Square Antiprism



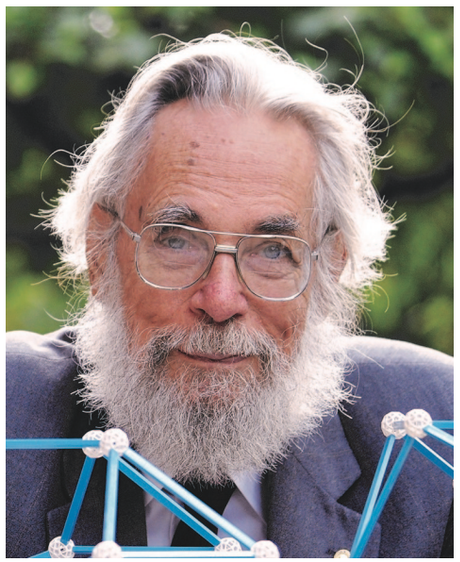
J29

Square Gyrobicupola



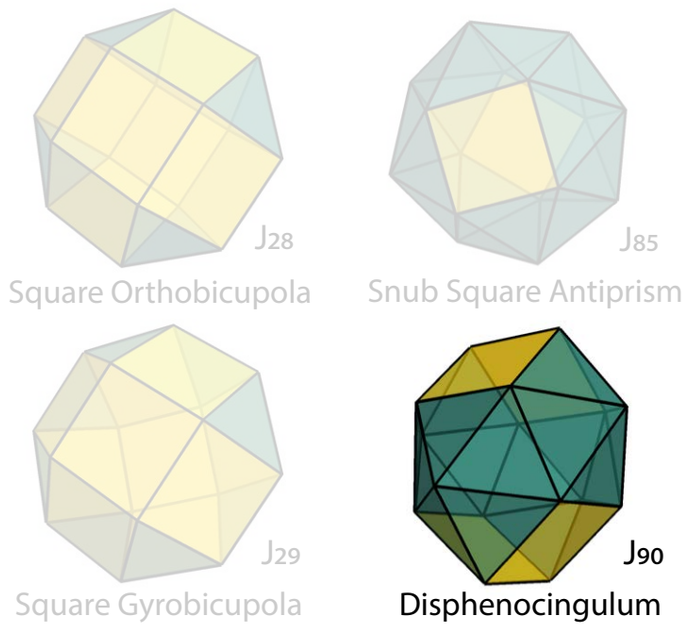
J90

Disphenocingulum

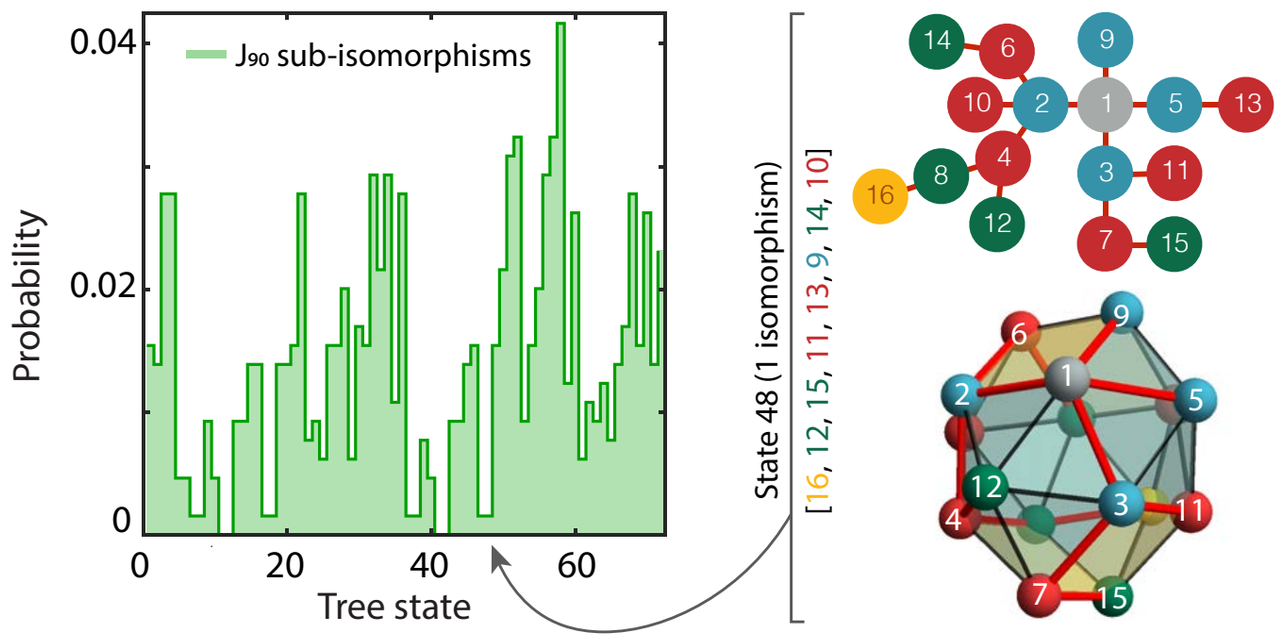


Norman Johnson
1913-2017

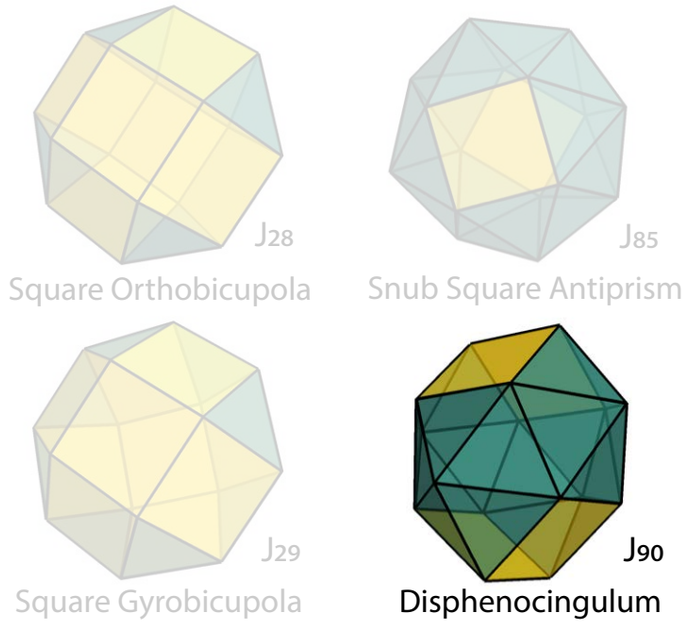
4 Johnson solids
with 16 vertices



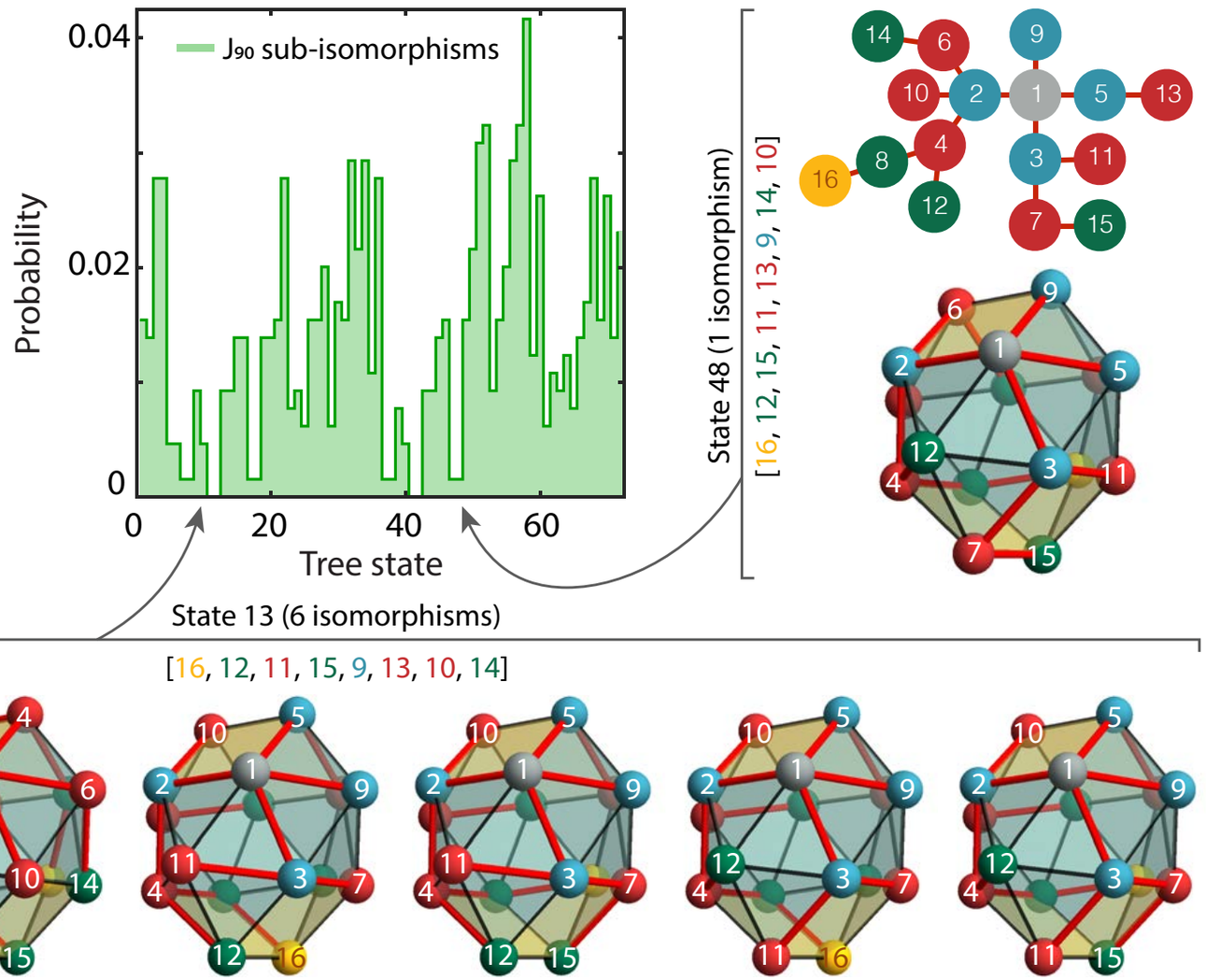
5,184 possible embeddings
of 72 trees with 16 cells on J90



4 Johnson solids
with 16 vertices



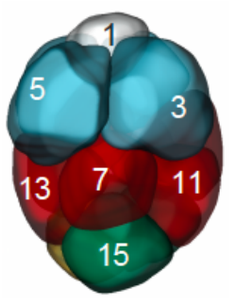
5,184 possible embeddings
of 72 trees with 16 cells on J90



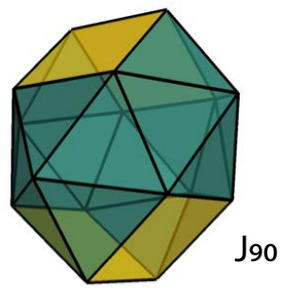
Modellvorhersage: nicht alle Zellpackungen gleich wahrscheinlich

Modellvergleiche

Experiment

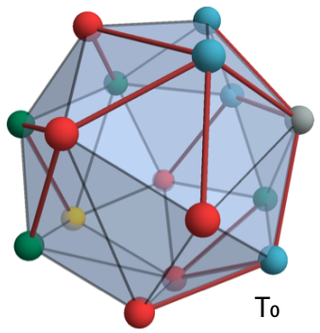


Graph-based

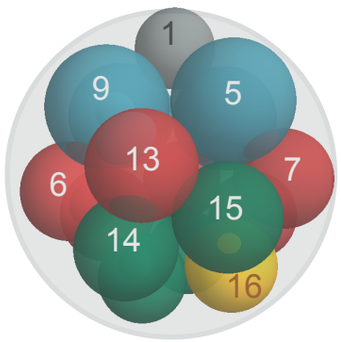


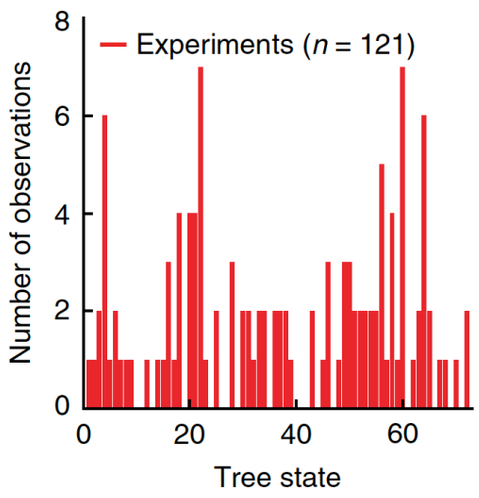
Energy-based

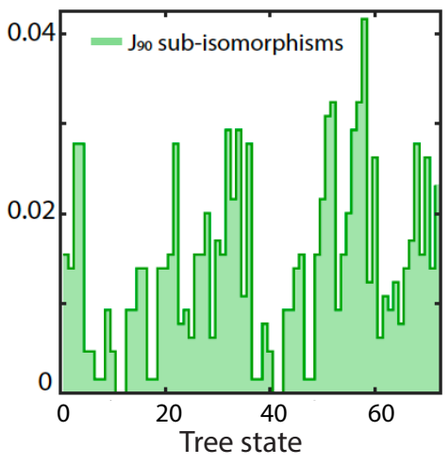
equal radii

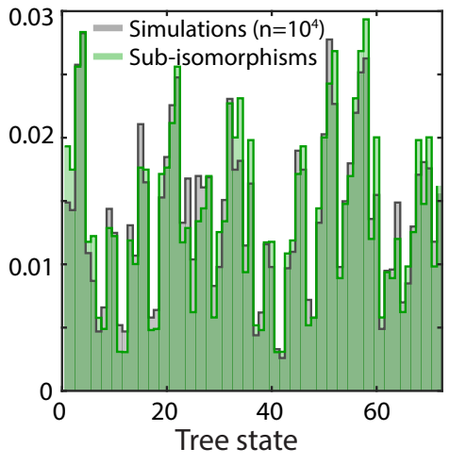


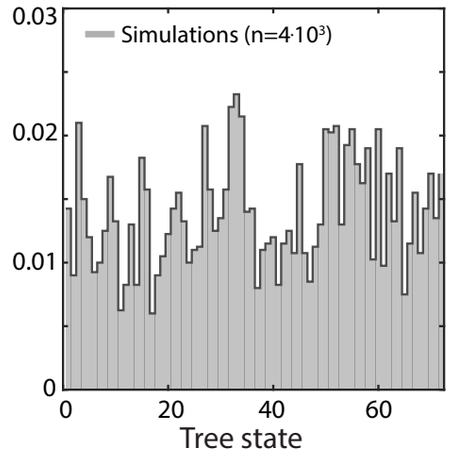
unequal radii





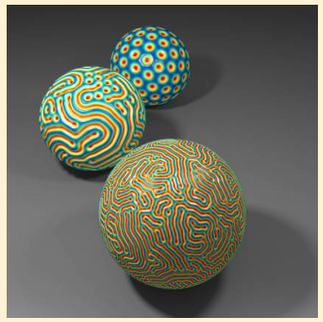


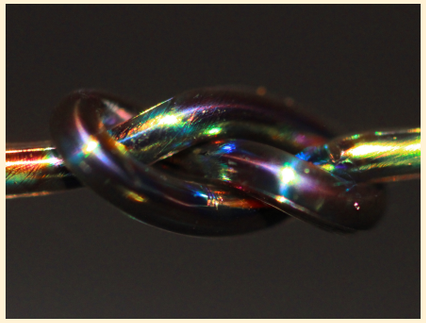




Beobachtung: nicht alle Zellpackungen gleich wahrscheinlich

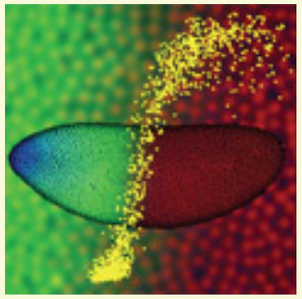
Weiche Materialien





Reis lab
Kolle lab

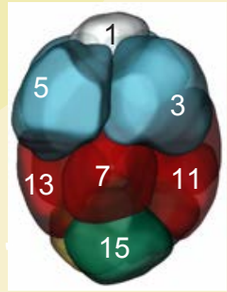
Strukturbildung in der Embryonalentwicklung

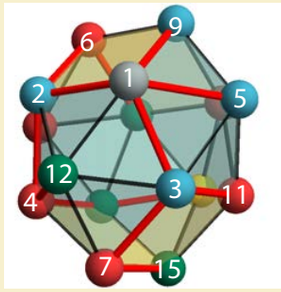




Martin lab
Fakhri lab

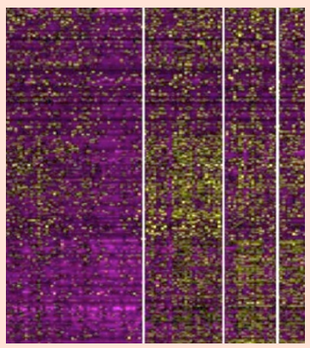
Oogenese

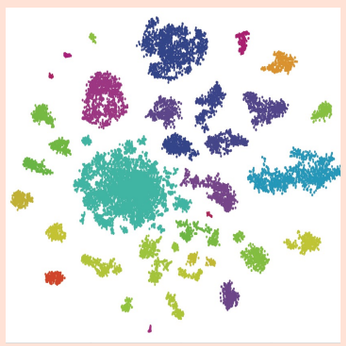




Shvartsman lab

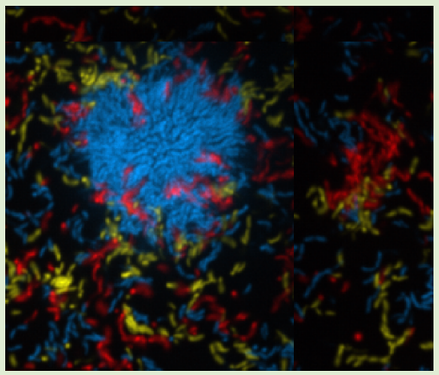
Strukturen in ‘big data’





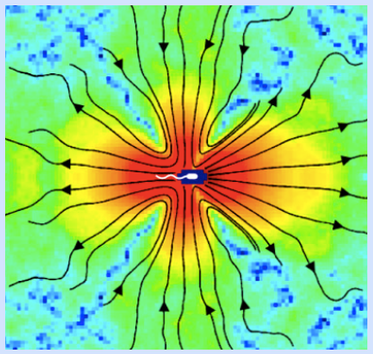
Shalek lab
In Song Kim

Entwicklung bakterieller Biofilme

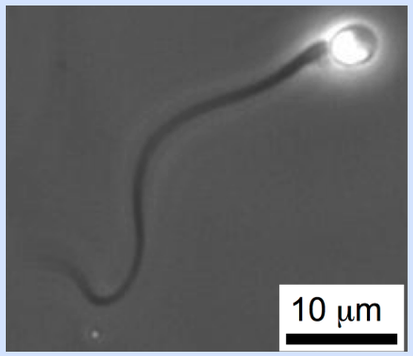


Drescher lab

Dynamik und Navigation von Mikroorganismen



Goldstein group

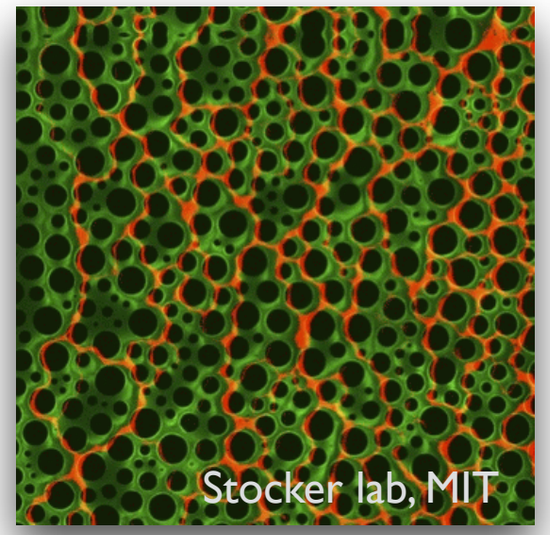


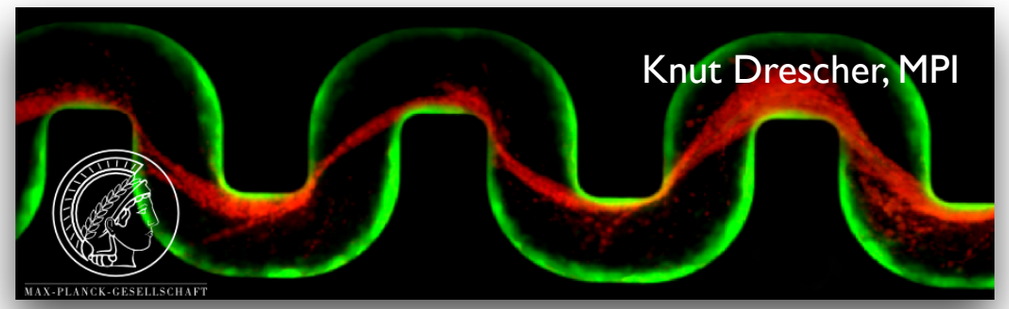
Guasto lab

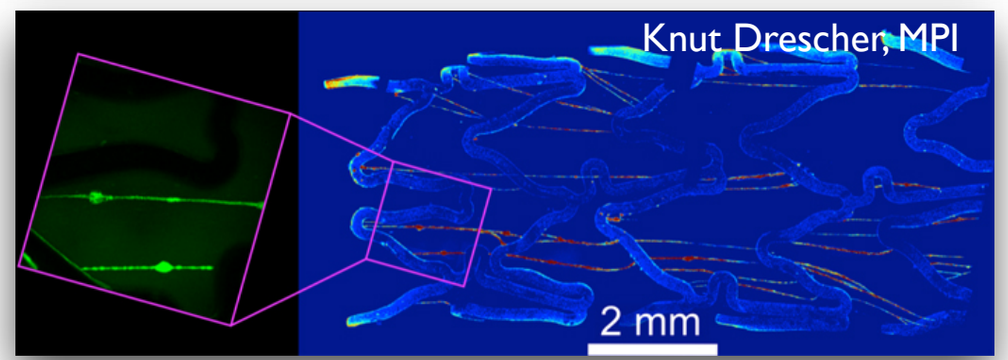
Bakterielle Biofilme



- Häufigste Lebensform ausserhalb der Ozeane
- 10 x mehr bakterielle als menschliche Zellen in unseren Körpern
- Infektionen: ~100,000 Amputationen / Jahr; > 90,000 Todesfälle / Jahr in den USA
- Antibiotischer Widerstand
- Wasserverschmutzung & Verstopfung











Bakterielle Biofilme



Biofilm formation of WT* at low shear rate

Top view

Side view

Flow

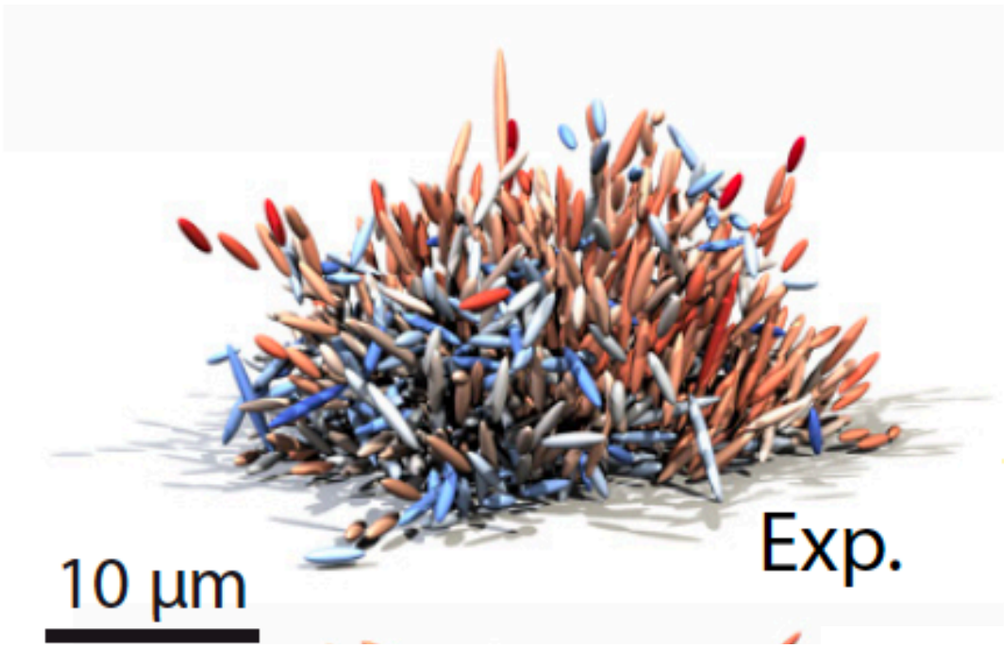
10 µm

Shear rate: 2 s^{-1}
Flow rate: 0.1 µL/min
Average flow velocity: 0.03 mm/s

N = 7 cells
t = 0.0 h

Bakterielle Biofilme



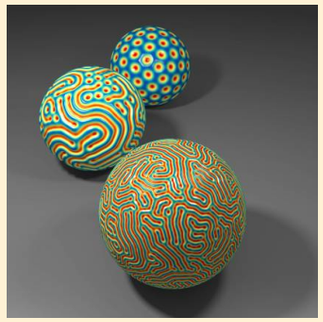


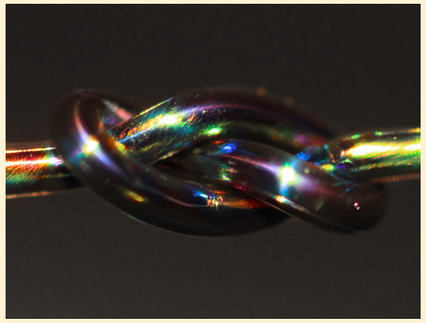


$$\frac{d}{dt}\mathbf{x}(t) = \mathbf{F}[\mathbf{x}(t)] + \xi(t)$$

Gleiche Mathematik für Bakterien, Aktienkurse, ...

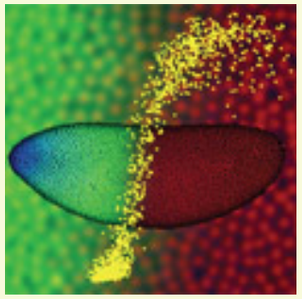
Weiche Materialien





Reis lab
Kolle lab

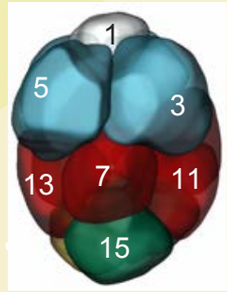
Strukturbildung in der Embryonalentwicklung

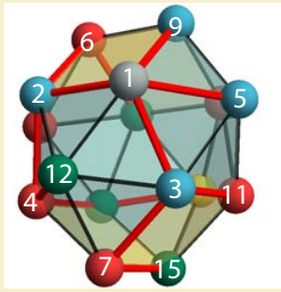




Martin lab
Fakhri lab

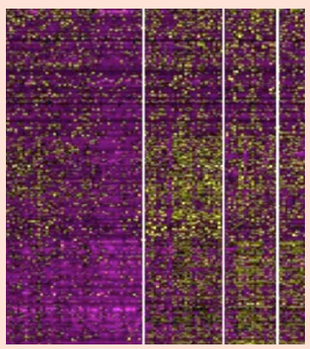
Oogenese

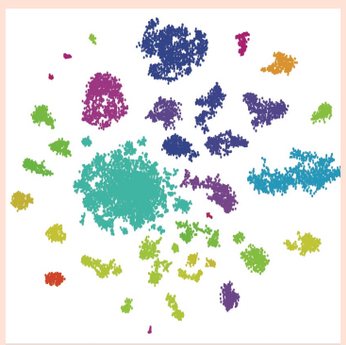




Shvartsman lab

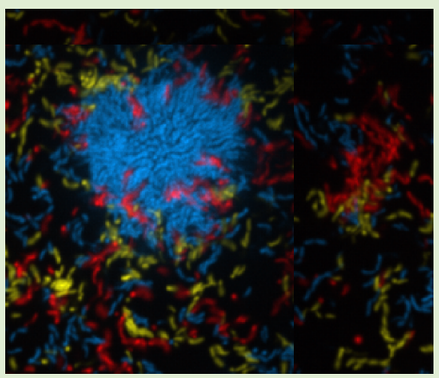
Strukturen in ‘big data’





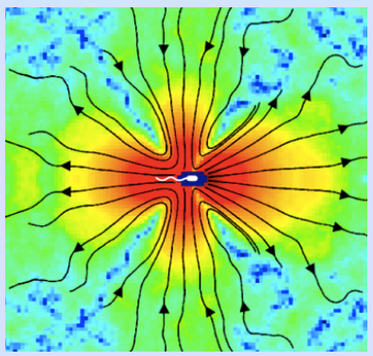
Shalek lab
In Song Kim

Entwicklung bakterieller Biofilme

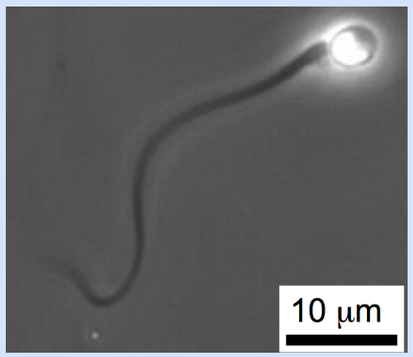


Drescher lab

Dynamik und Navigation von Mikroorganismen



Goldstein group



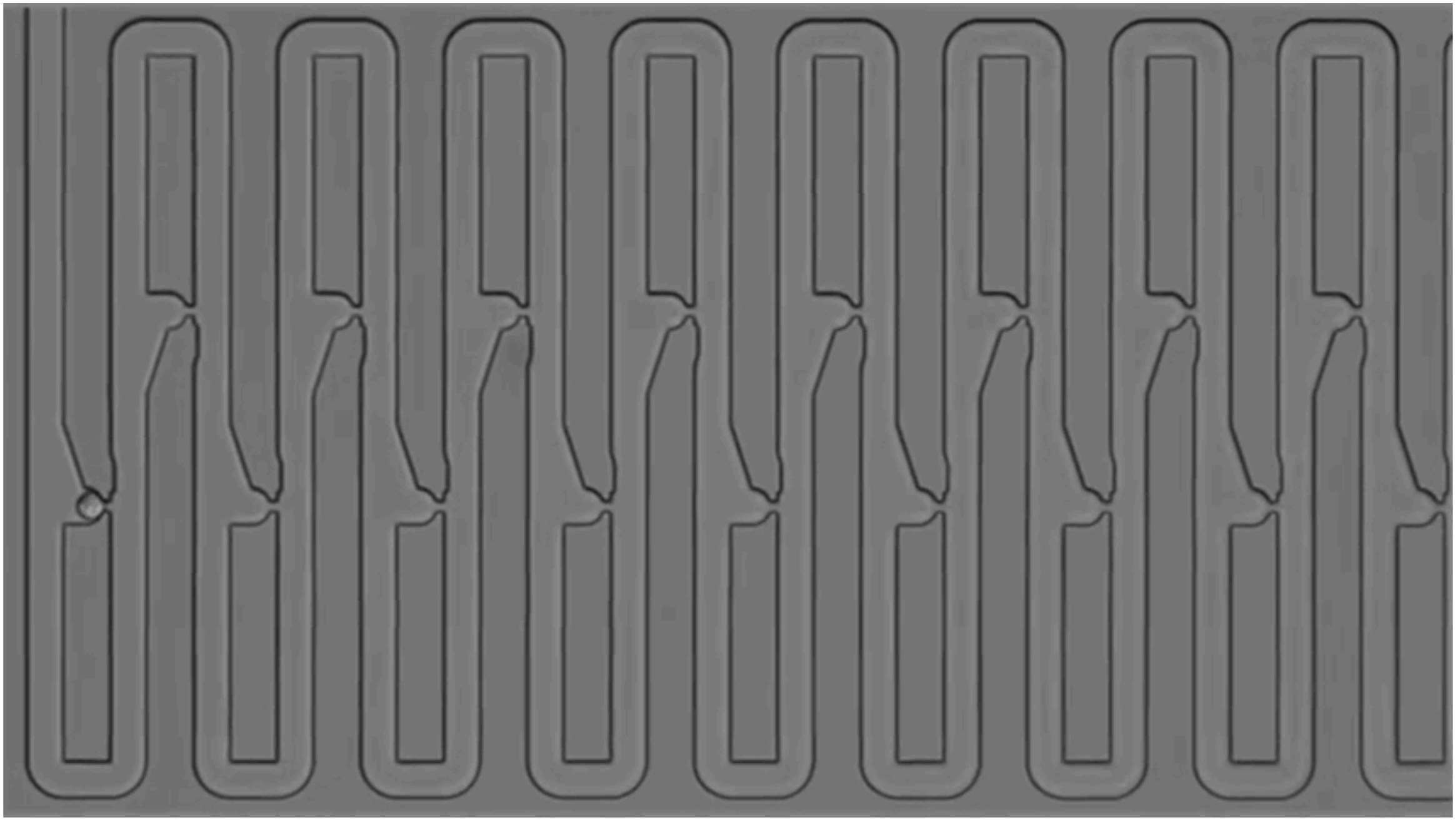
Guasto lab

‘Big data’ in der Biologie



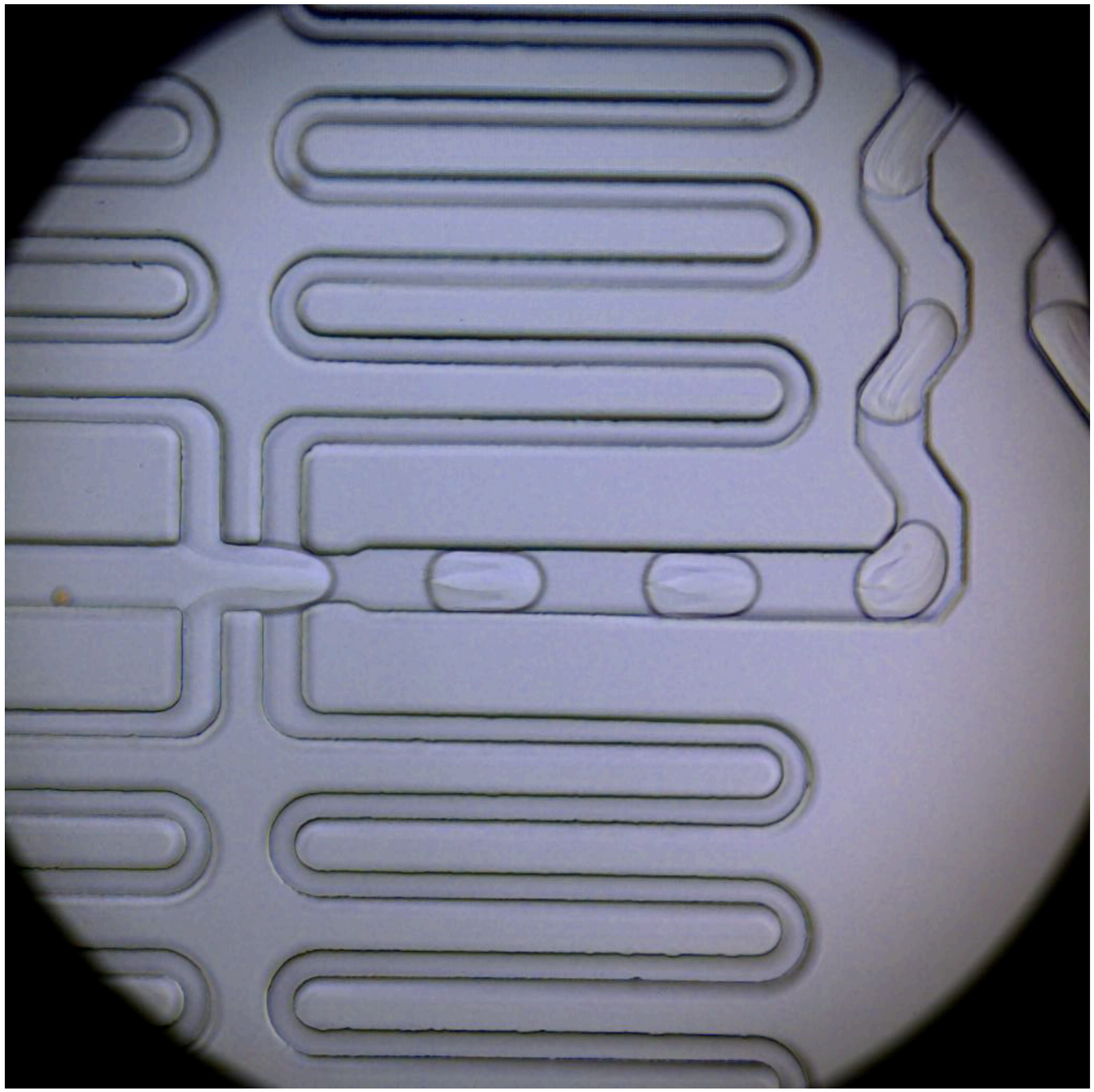
(… und anderswo)

Mikrofluidische ‘Revolution’:
Einzel-Zell Studien

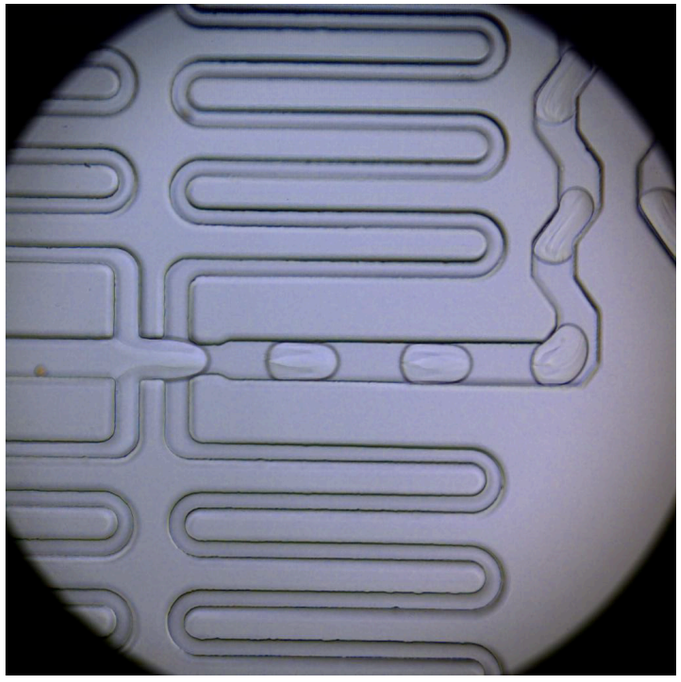


Manalis lab (MIT)

Einzelne Zellen in Mikrotropfen

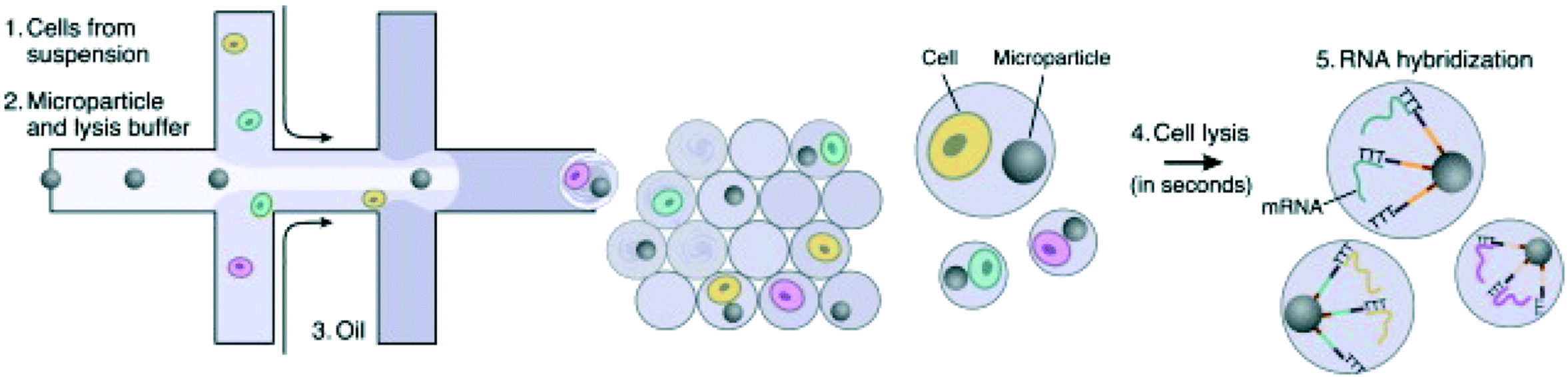


Macosko *et al*, Cell 161 (2015)



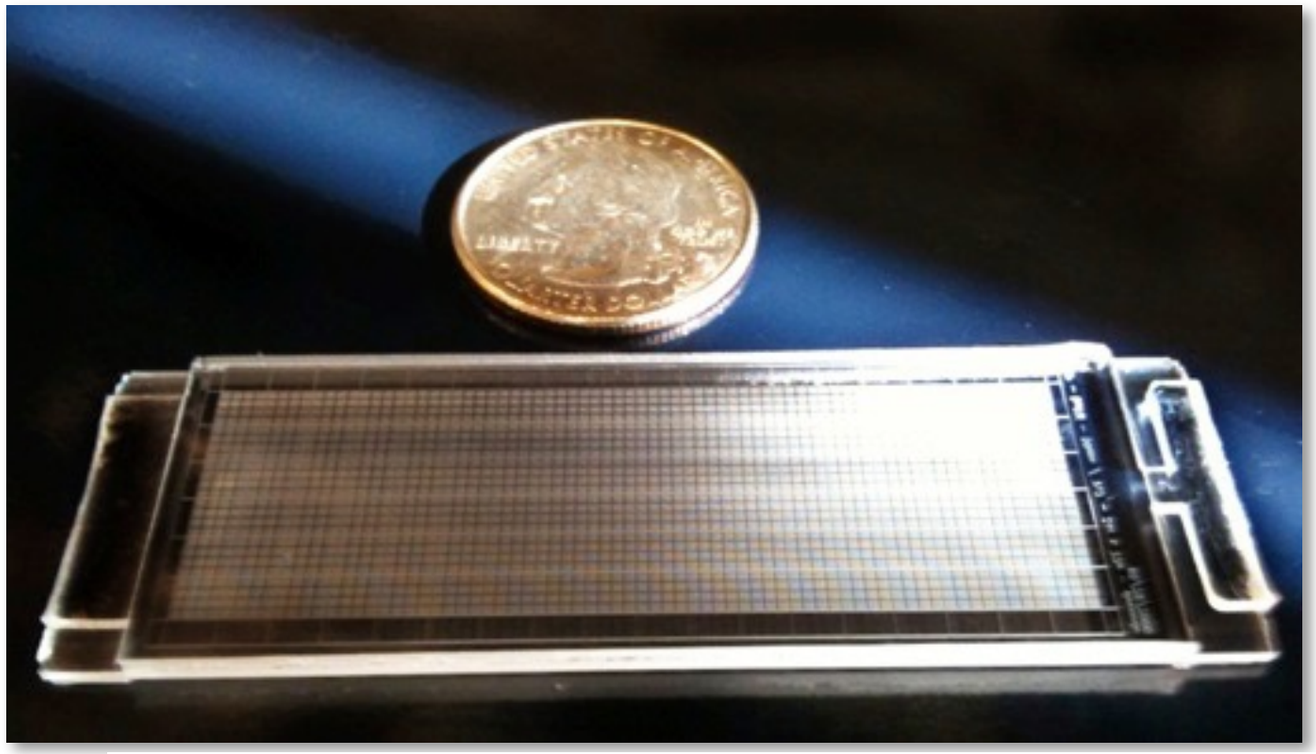
Zellen in Tropfen
+
RNA Sequenzierung

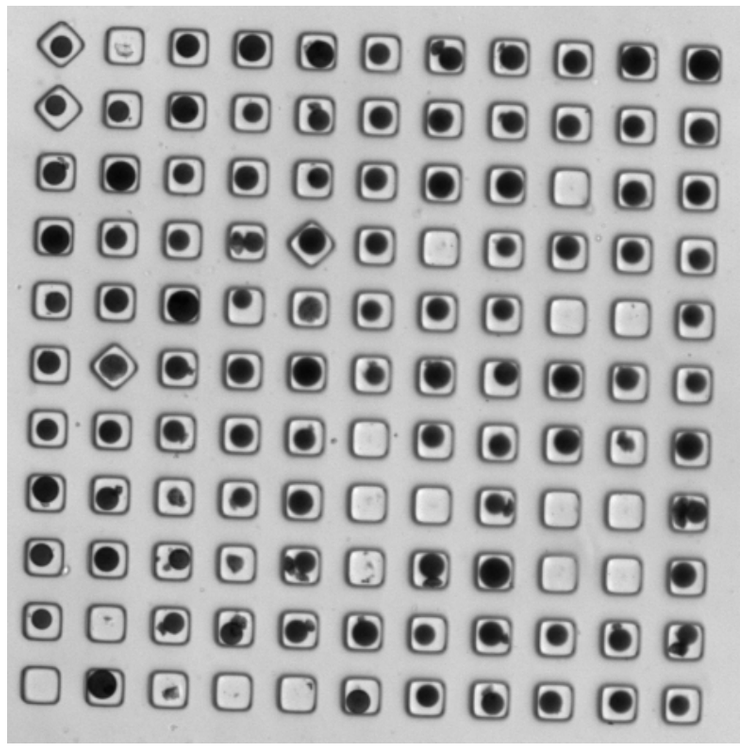
(Drop-Seq)

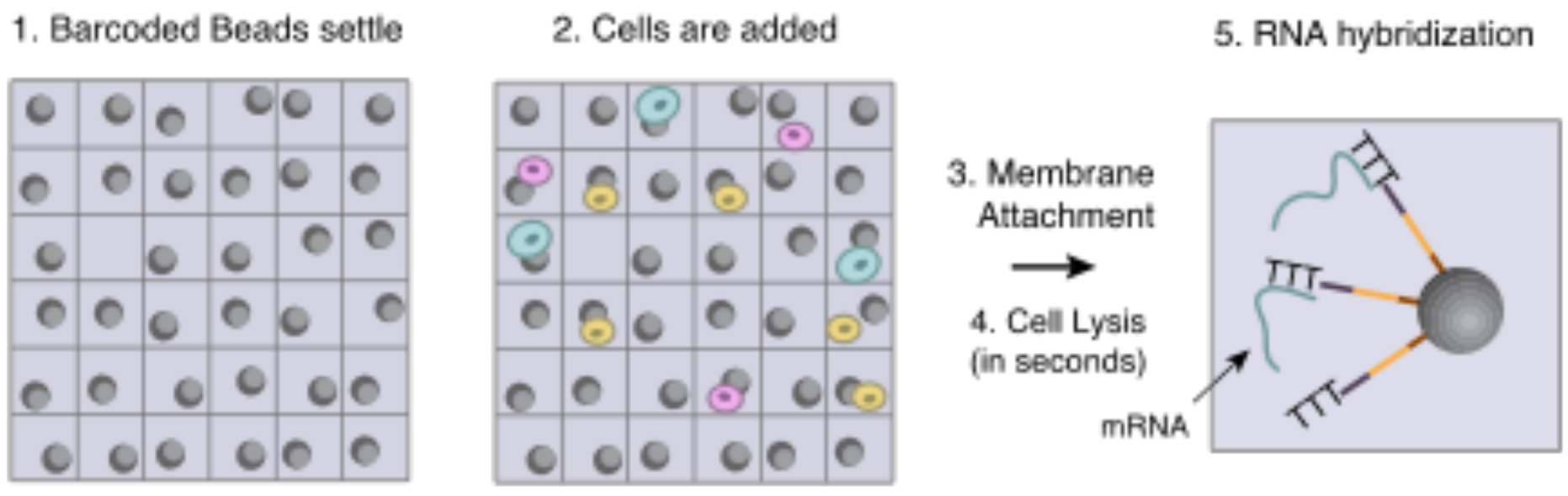


Macosko *et al*, Cell 161 (2015)

Zellen in Mikrokammern (Seq-Well)





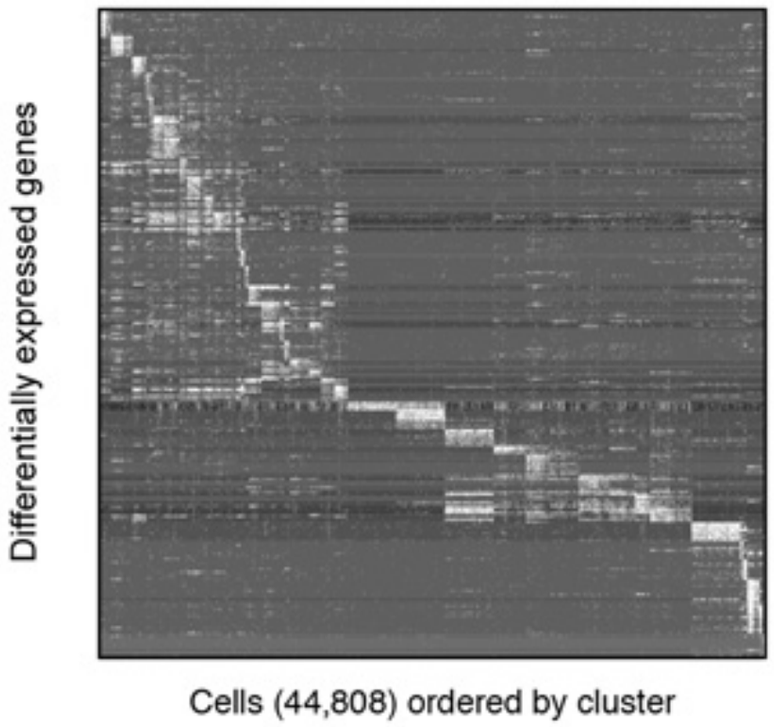


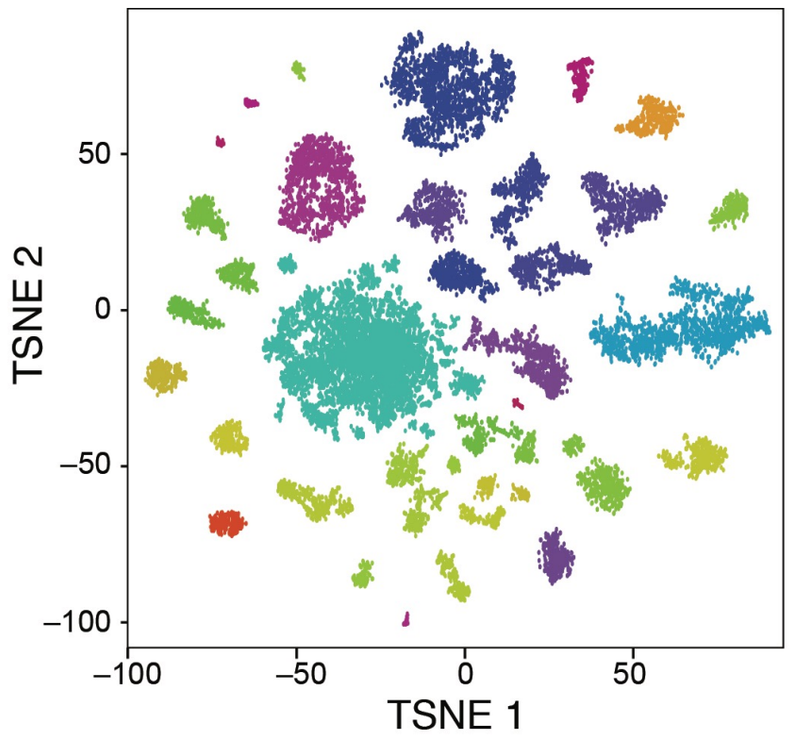
Love lab (MIT Chemical engineering)

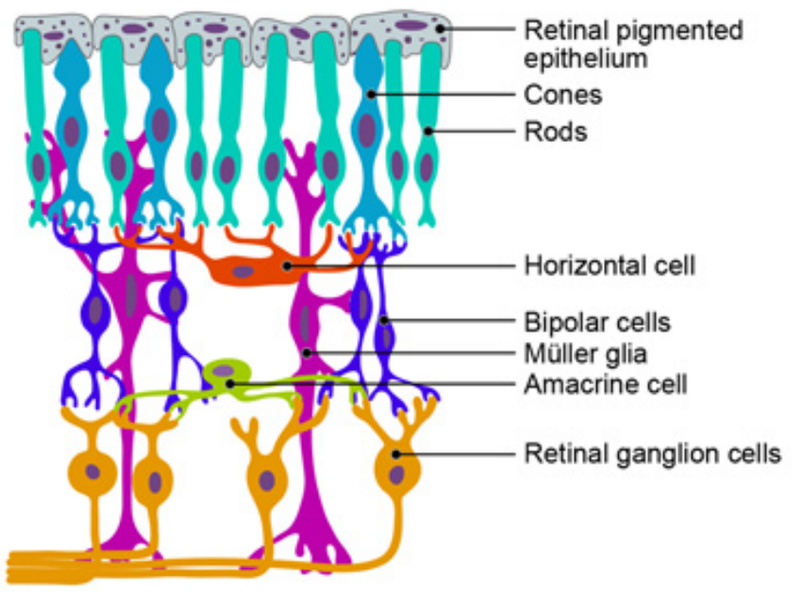
Data example

Drop-Seq: ~50k cells from dissociated mouse retina (P14) (~15k reads per cell)

Computational pipeline: Select 25% best coverage cells, Dimensionality reduction (PCA+tSNE), Project remaining cells, Identify cell types (density clustering), Refine clusters (differential expression)







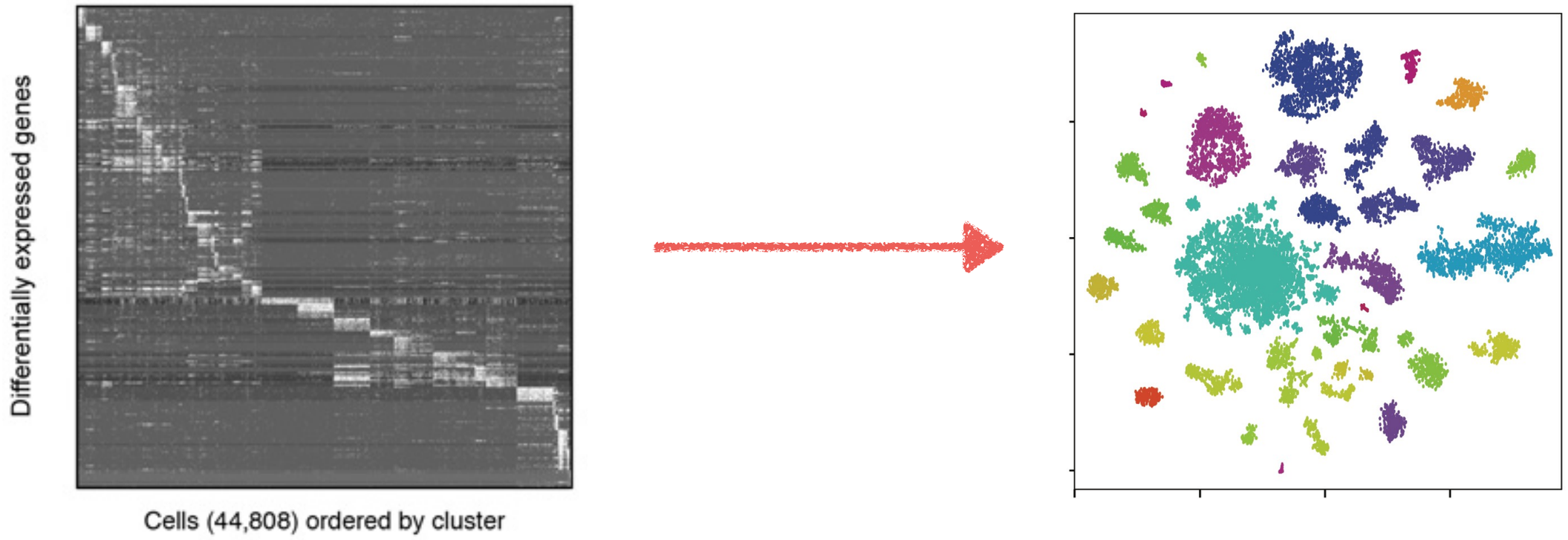
>1000 Dimensionen

2 Dimensionen

Macosko *et al*, Cell 161 (2015)

Mathematische Fragen

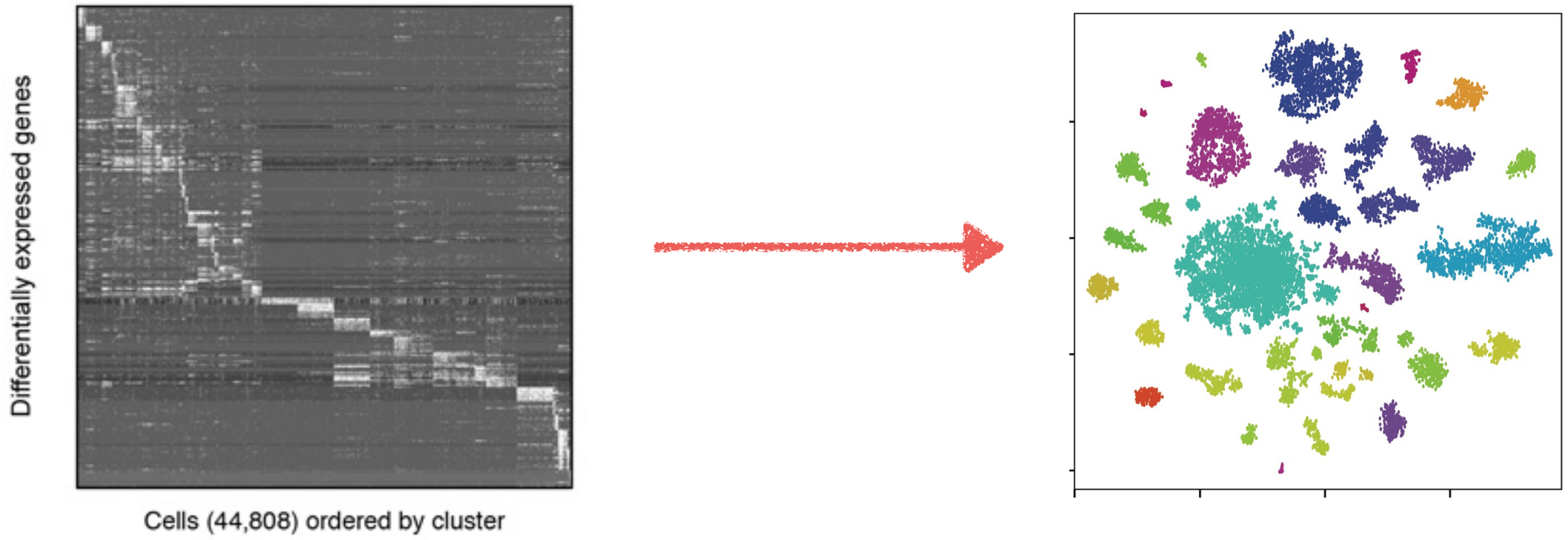
- robuste(re) Dimensionsreduzierung
- Kostenoptimierung: wieviele Zellen wie tief sequenzieren ?
- topologische Strukturen in Daten erkennen (Zellzyklen)



Kollaboration mit Shalek lab (MIT Chem)

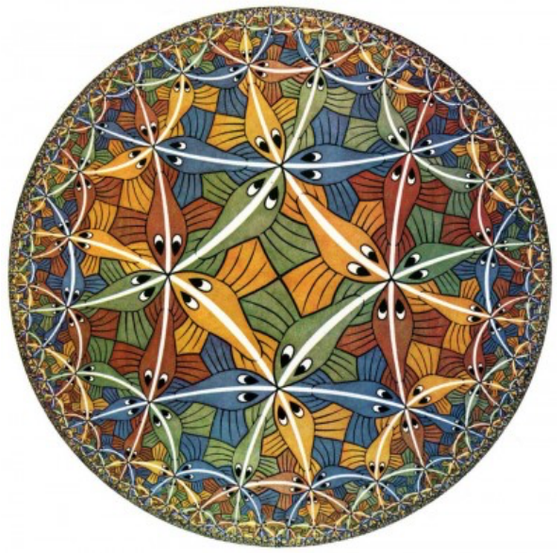
Biologische Fragen

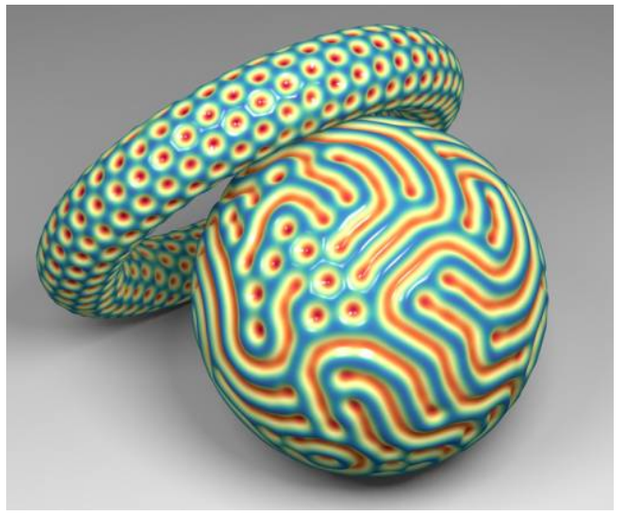
- inhaltsbasierte Definition von Zelltypen
- Wechselwirkung von bestimmten Zellarten & Genen (Korrelationen)
- Tumorzellen vs. gesunde Zellen
- Reaktion auf Medikamente, …



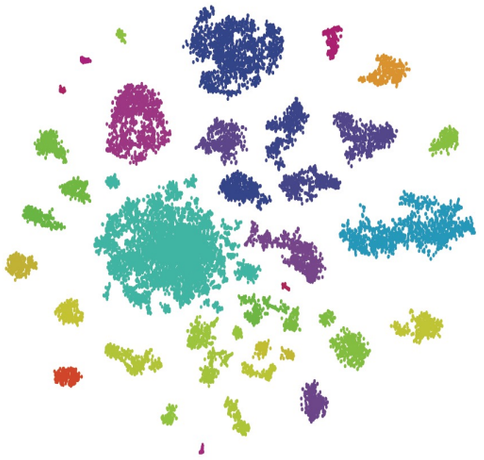
Kollaboration mit Shalek lab (MIT Chem)

Warum Mathematik ?

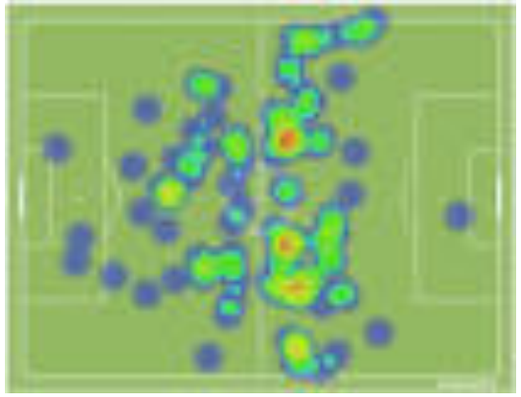






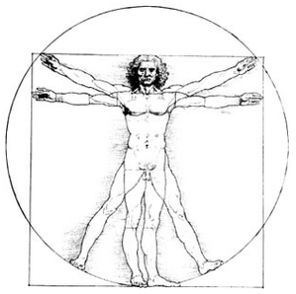








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Math is beautiful

