Yamagata University
Soft and Wet Matter Engineering Laboratory
Since 2009

YAWARAKA 3D
Soft 3D Co Creation Consortium

3D/4D Printing of Soft Materials

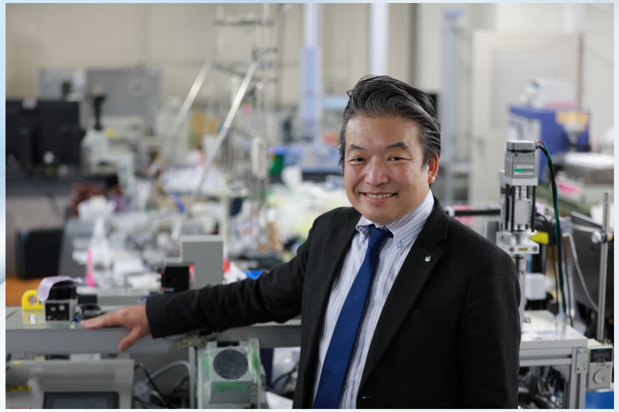
that creates a new world of soft-matter robotics

Hidemitsu Furukawa

Soft & Wet matter Engineering Lab (SWEL)
Department of Mechanical Systems Engineering
Yamagata University

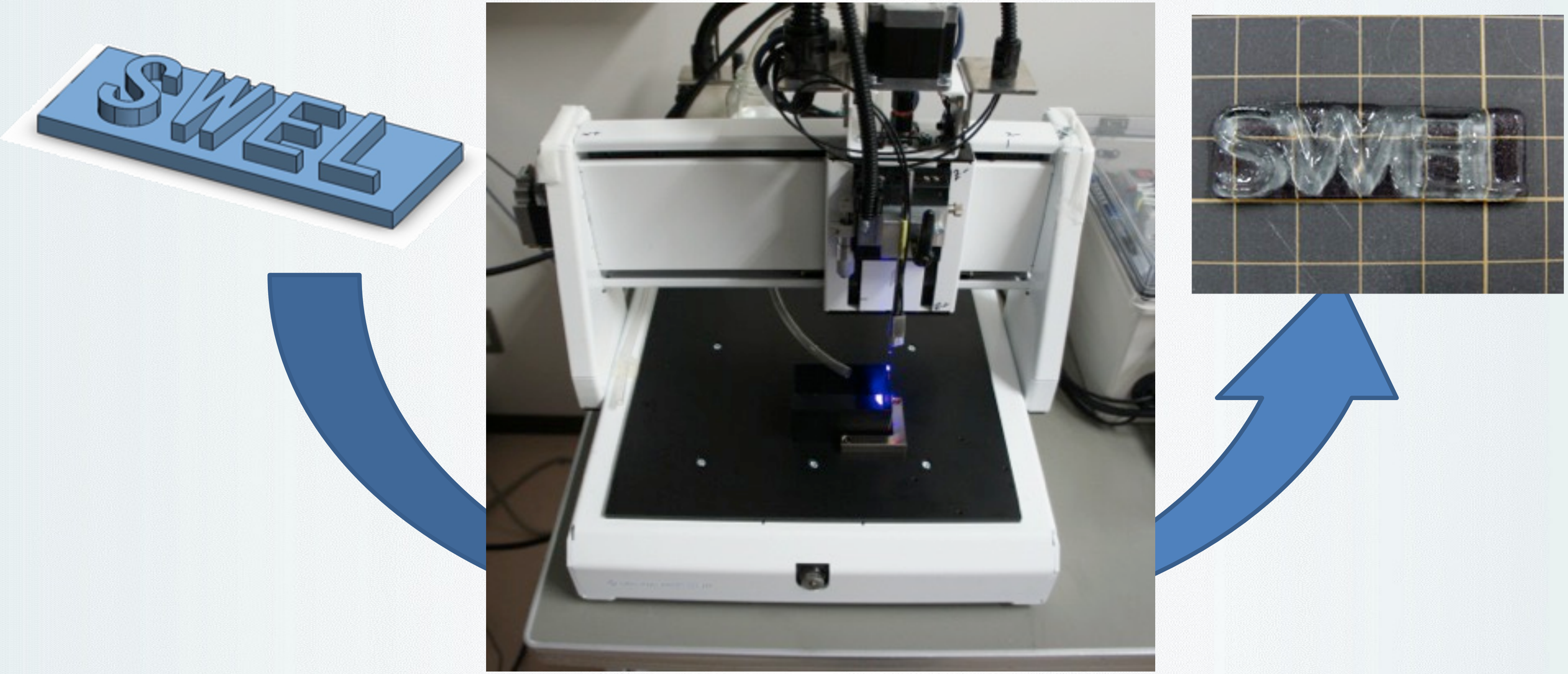
"YAWARAKA 3D" Soft 3D Co-Creation Consortium

Twitter @gelmitsu



https://docs.google.com/document/d/1Oah4ep8CbEe5J-LiUHAcHKDcEElN7mQoCgb6DbFwOqA/edit?usp=sharing

3D Gel Printer（Bathtub Type）

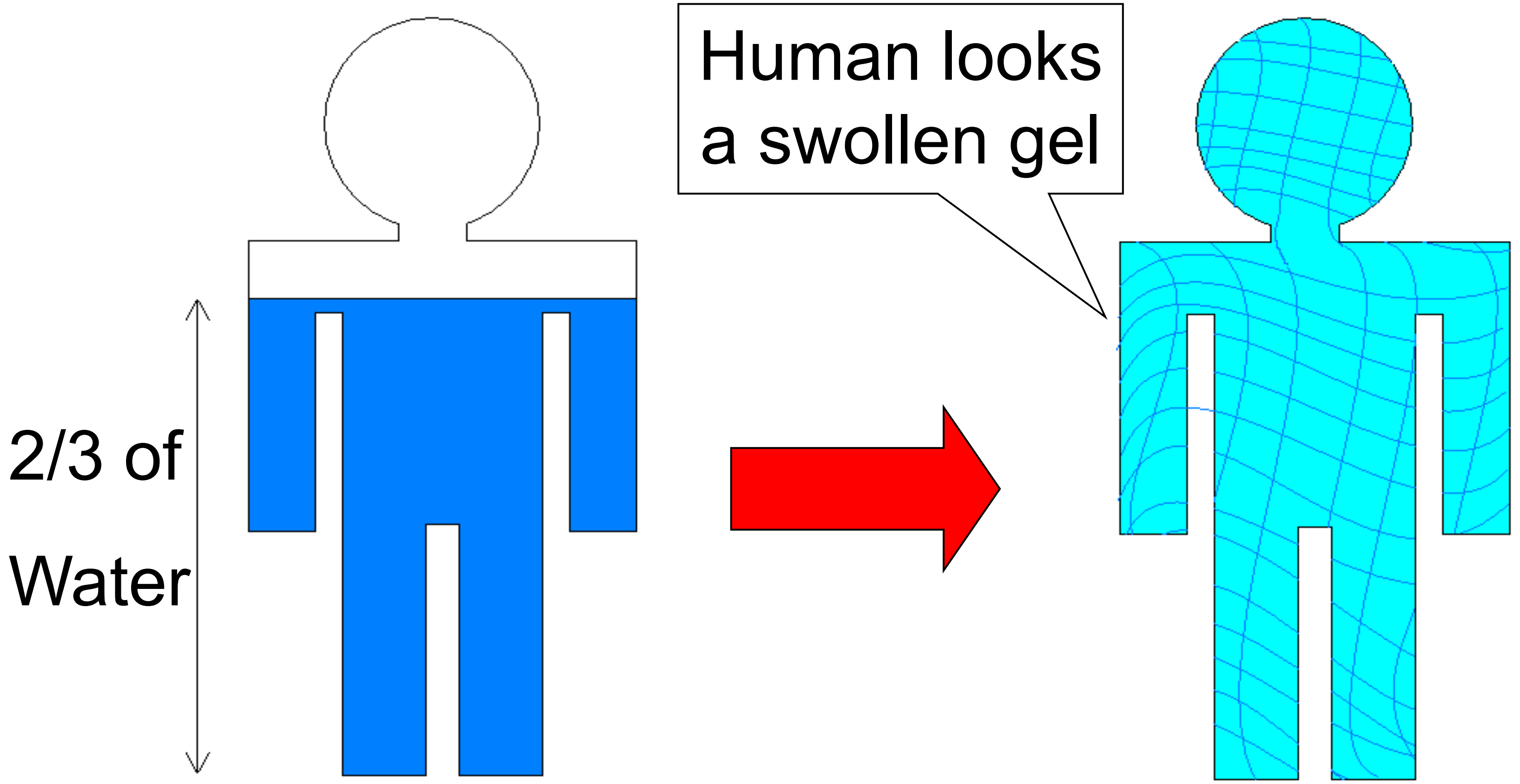


- Bathtub contains pre-gel solution of tough hydrogels (water > 90%).
- The minute fabrication is made by UV irradiation thru optical fiber.
- Free shape fabrication is done by 3-dimentional scanning the fiber.

R. Hidema, K. Sugita, H. Furukwa, ***Trans. J. Soc. Mech. Eng. (A)***, **77**, 1002-1006 (2011)
H. Muroi, J. Gong, H. Furukawa, ***J. Solid Mech. Mater. Eng.***, 2013.

WHY GELS?

Soft and Wet Human



Human expressed in a water content

Human expressed in the network of gels.

Living bodies are made from

soft organisms

except skeletons (bone, teeth, shell, etc.)

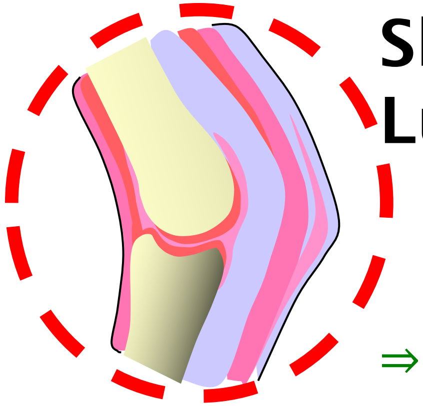
Examples:
blood vessel, muscle
cartilage, tendon,
ligament, etc.

The soft organisms contain 50~80% of water.

They are soft & wet materials.

Specific functions of soft and wet organs

Joint cartilage



Shock absorb ○
Lubrication ○
Low frictional coefficient ~0.001

⇒Smooth motion

Blood vessel

Penetration ○
Lubrication ○

⇒Exchange of materials

Previous artificial organs have been made from **Hard & Dry Materials**: These functions cannot be worked.

Artificial Joint

Shock absorb ×
Lubrication △

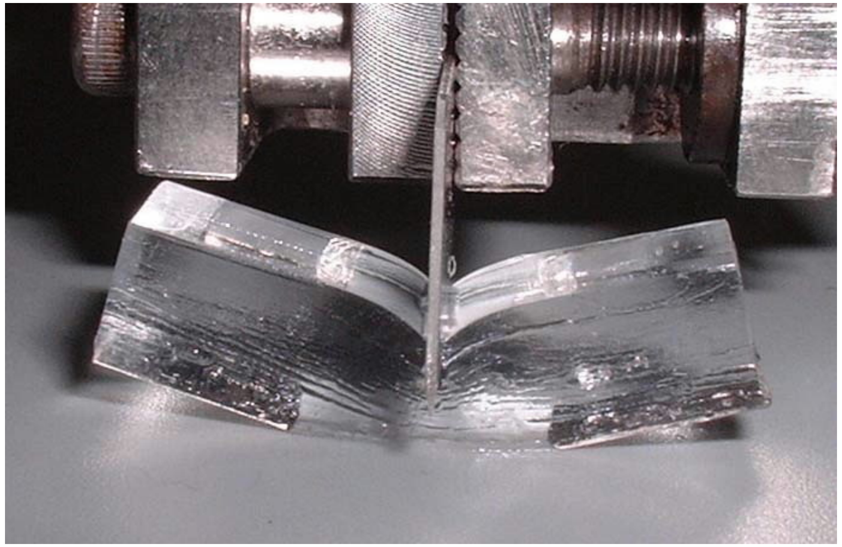
⇒Limitation of motion

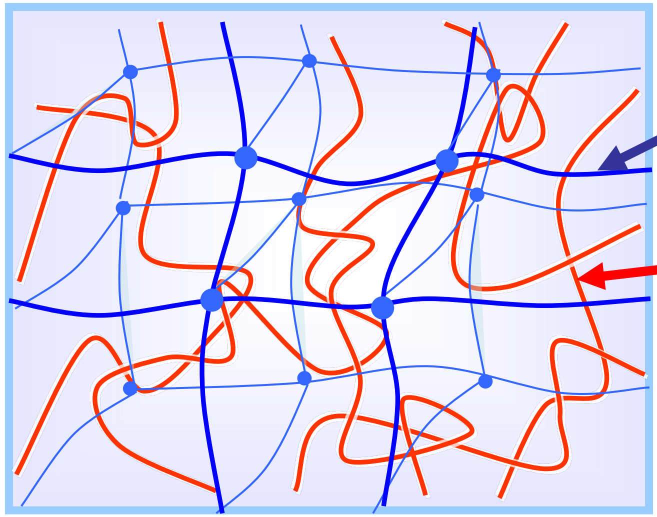
Artificial Vessel

Penetration ×
Lubrication △

⇒Thrombus (Blood clot)

DN gels' fracture energy is 1,000 times higher



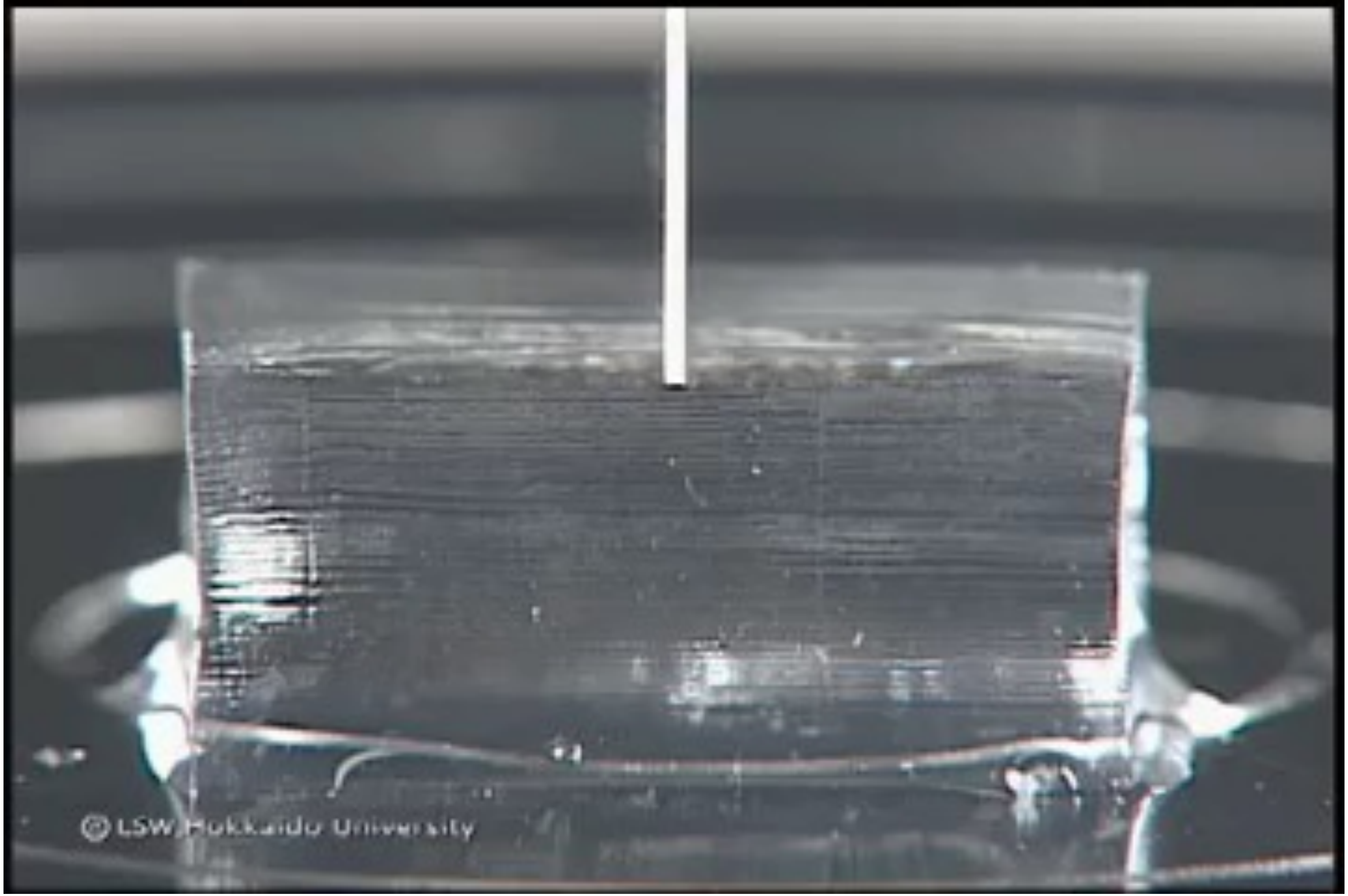


Water content ~ 90%
Compress fracture stress: 10-40MPa
(Can compare with cartilage in joint)

Electrolyte (rigid & brittle)
Neutral (soft & ductile)

PAMPS gel	+	PAAm gel	=	DN gel
Fracture energy ~1J/m^2	+	Fracture energy 10J/m^2	≠	Fracture energy 100～1000J/m^2

Cannot be explained based on the previous theories



Water Content 90%   Breaking Compression 40MPa

J. P. Gong, Y. Katsuyama, T. Kurokawa, Y. Osada, ***Adv. Mater.*** **15**, 1155 (2003)

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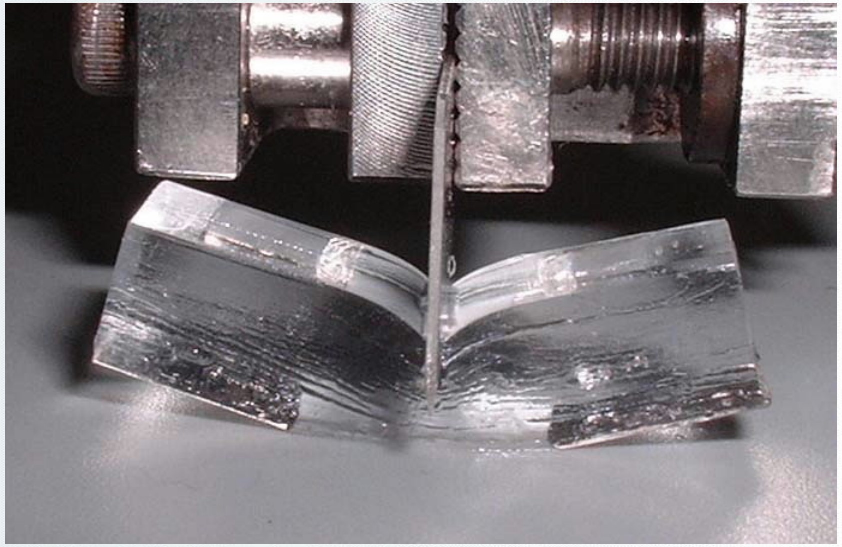

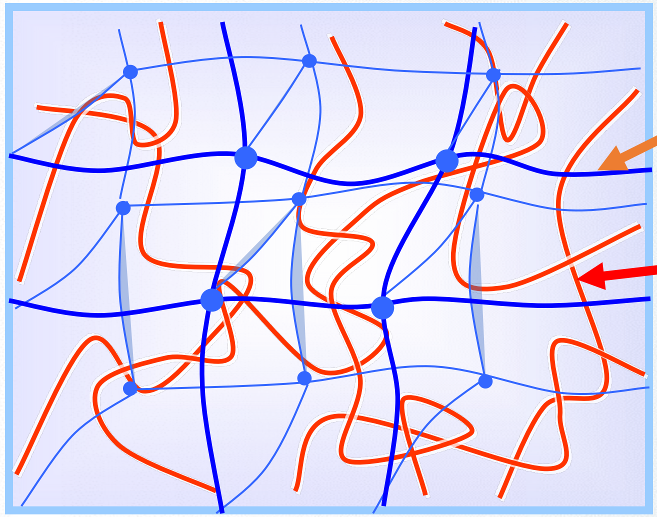

＜1st＞
PAMPS

＜2nd＞
PAAm

Water content ~ 90%
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(Can compare with cartilage in joint)

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PAMPS gel	+	PAAm gel	=	DN gel
Fracture energy ~$1 J/m^2$	+	Fracture energy $10 J/m^2$	≠	Fracture energy **$100 \sim 1000 J/m^2$**

Cannot be explained based on the previous theories

Figure out: Low frictional Tough gels

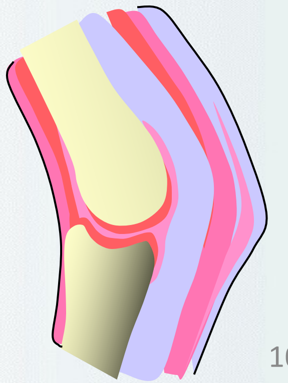
Both

Toughness **40MPa~400kgf/cm^2** and

Low Friction μ≒10^{-4} means…

1cm^2 of the gel sheets withstatnds **400kg** weight and move it by **40g** force!

This situation corresponds to that of knee joint cartilage in our body.



Tough Gel Slider in Lab

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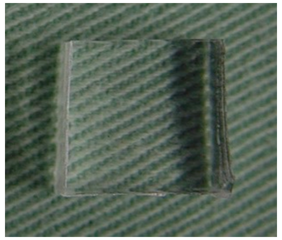
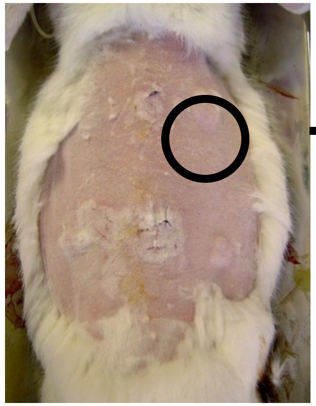
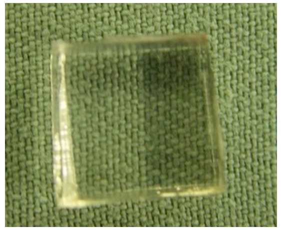
Soft 3D Co Creation Consortium

Biocompatibility of DN Gels



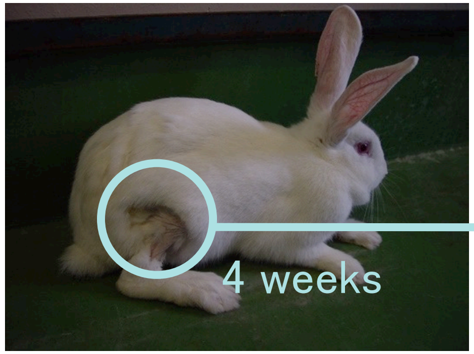
Before Operation

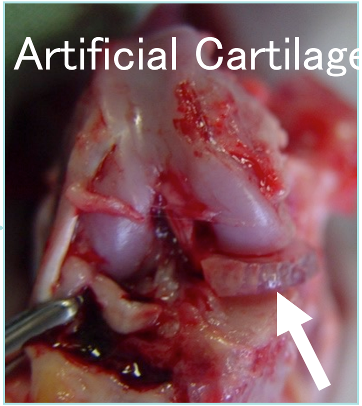


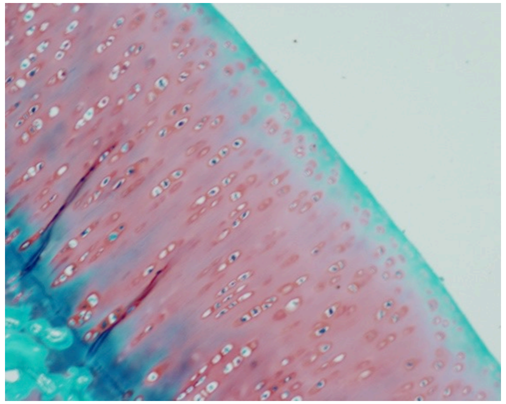


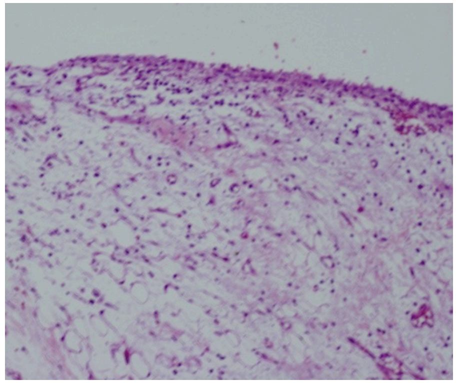
After Operation

Embedded in subcutaneous tissue of rabbit in 6 weeks: No change in appearance









No inflammation and
No degeneration

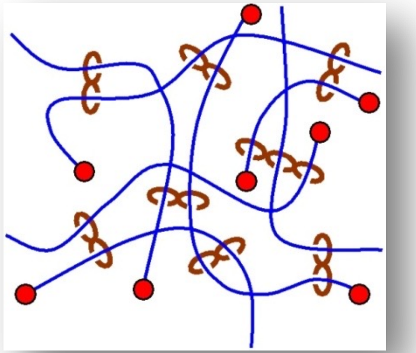
DN gels can be applied for artificial cartilage.

Prof. MD. K. Yasuda (Medical department of Hokkaido Univ.)

Lineup of High-Strength Gels, Invented in Japan

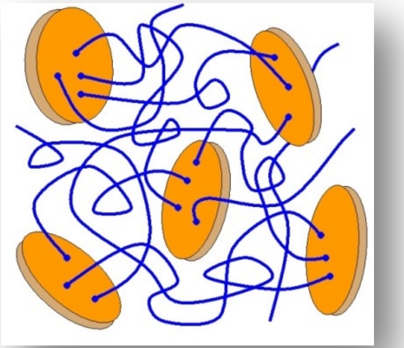
2001 2002 2003

Slide Ring Gel



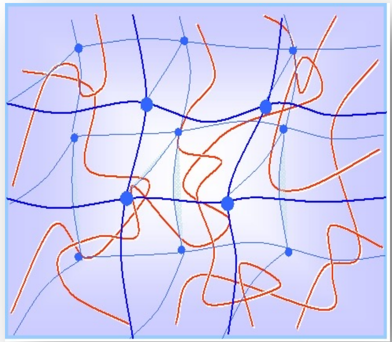
Okumura and Ito

Nanocomposite Gel



Haraguchi

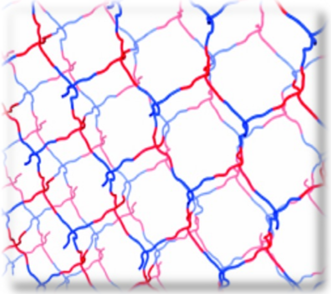
Double-Network gel



Kurokawa, Gong, et al.

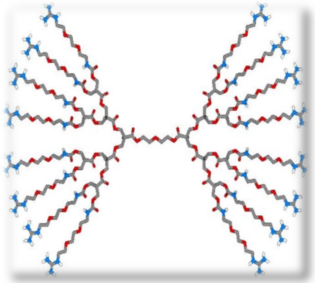
2008 2010 2011

Tetra-PEG gel



Sakai, et al.

Aqua Material



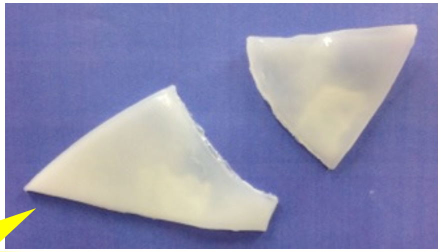
Aida, et al.

Inter-Crosslink Network Gel

Furukawa, Takada, et al.

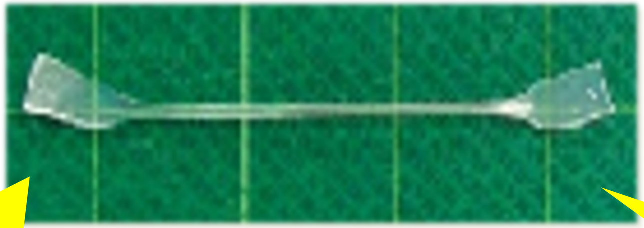
Different approach: To make different structures!

Difficulty of Gel Fabrication



Brittle

Cutting Difficulty



Too soft to mold

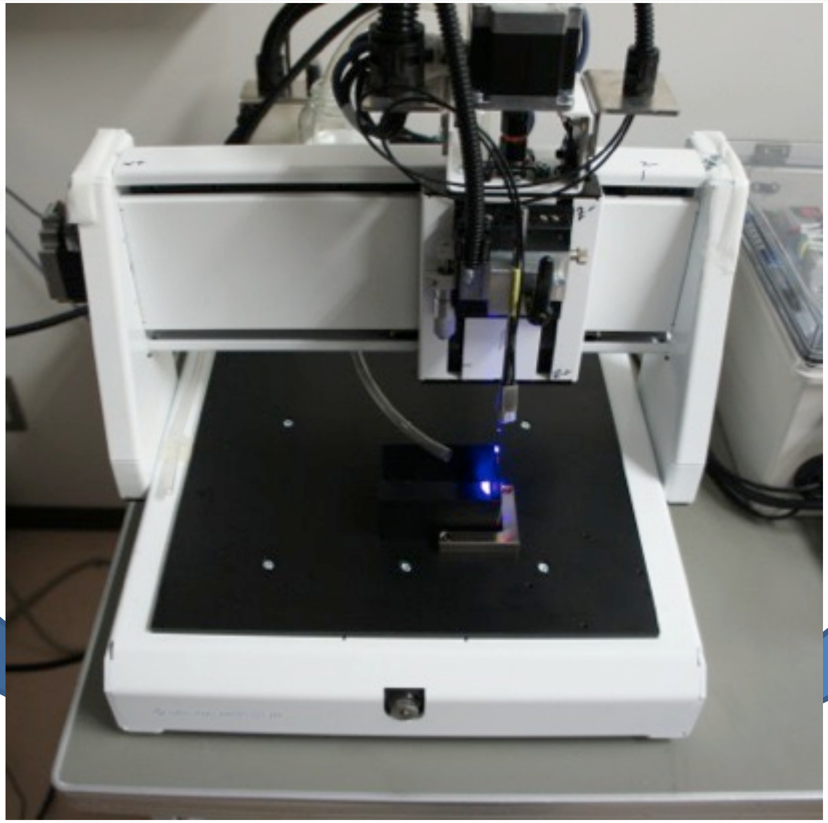
Unstable Shape

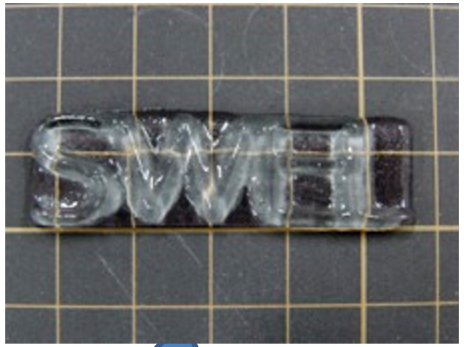
We could not use traditional manufacturing!

3D Gel Printer（Bathtub Type）

Soft & Wet matter Eng. Lab

SWEL





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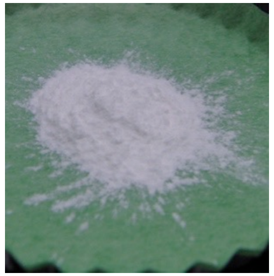
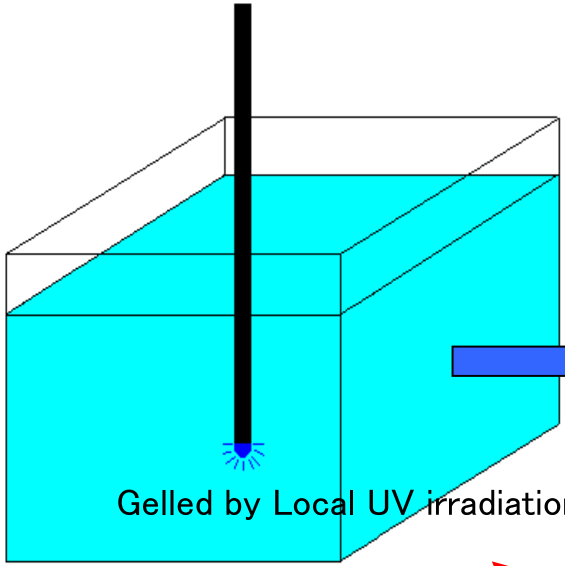
Bathtub type

Particle-DN gel



Particle of 1st gel

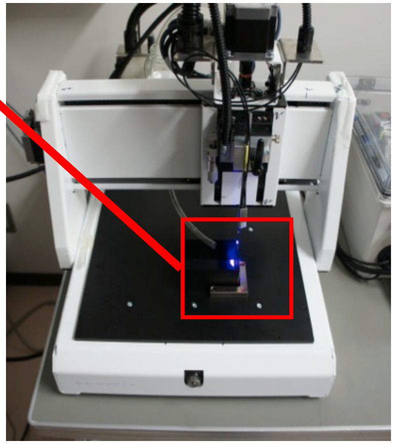
Pregel solution of swollen 1st gel particle in 2nd monomer solution



Bathtub in the printer

Printed High-strength gel

3D-CAD data



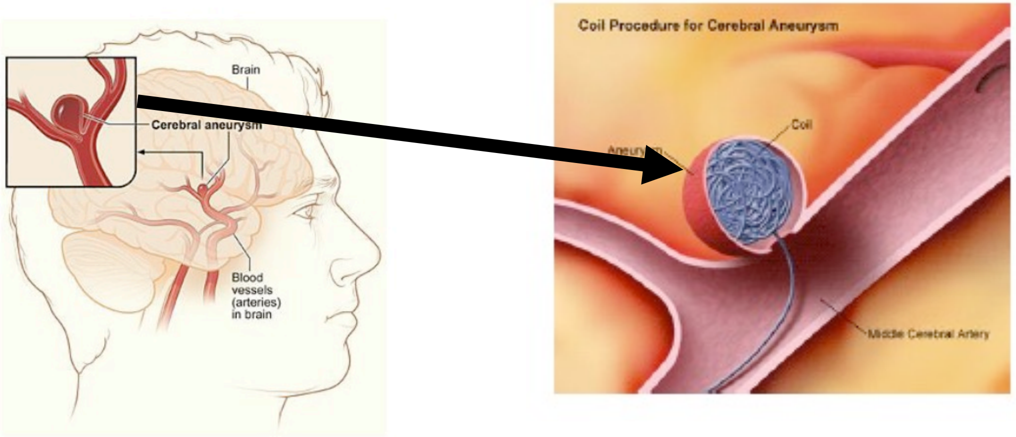
3D Gel Printer

How to use the Gel Printer

Soft & Wet matter Eng. Lab
SWEL

1) If we print blood vessel,…

Coil Stopper Surgery in Head (動脈瘤)



Transparent gel modeling makes head surgery safe and effective!

Printed blood vessel

2) If we print gel foods,…

Improved!

Make them beautiful

17

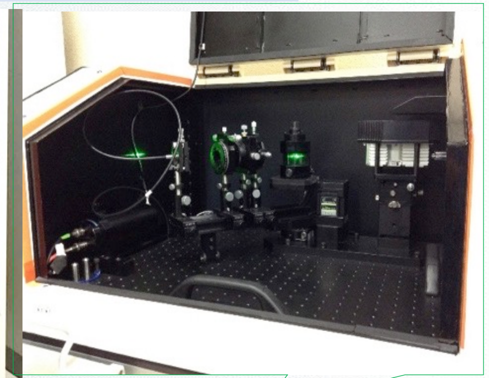

Nice-Step Researchers 2013
Me,
Furukawa
Mr. Hakubun SHIMOMURA
Minister of Education, Culture, Sports,
Science and Technology (MEXT)

High-speed 3D Gel Printer (2017)

3-D Technologies for Gels

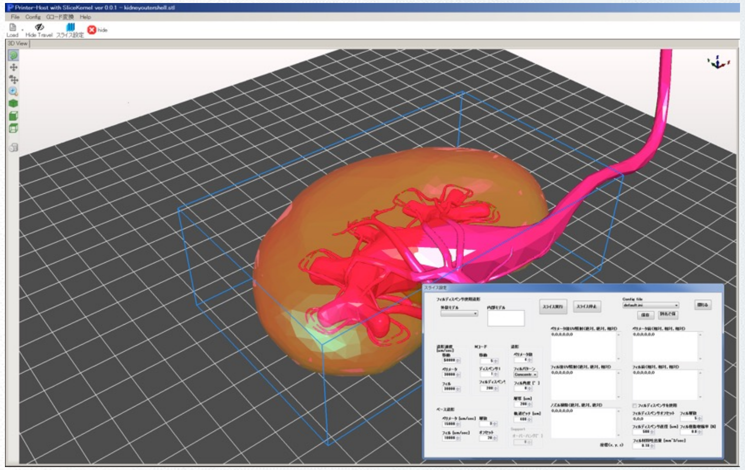
Hardware

3D Gel Printer



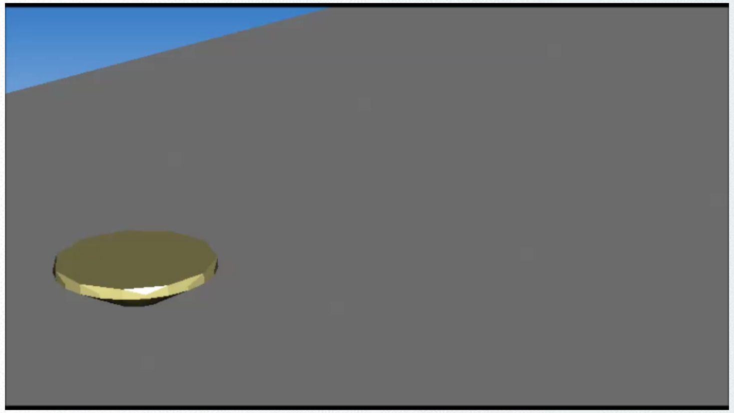
Gel Scanner

Software



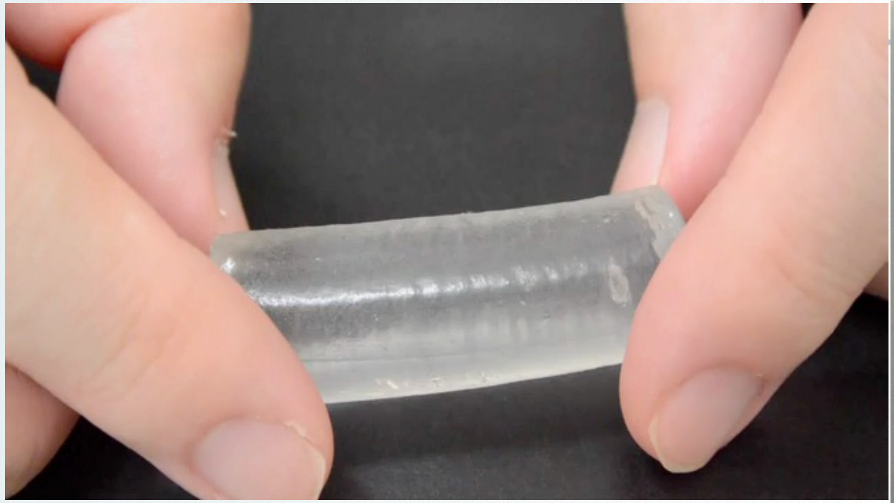
3D Modeling Software for Designable Gel

Simulation of Gel Laminates

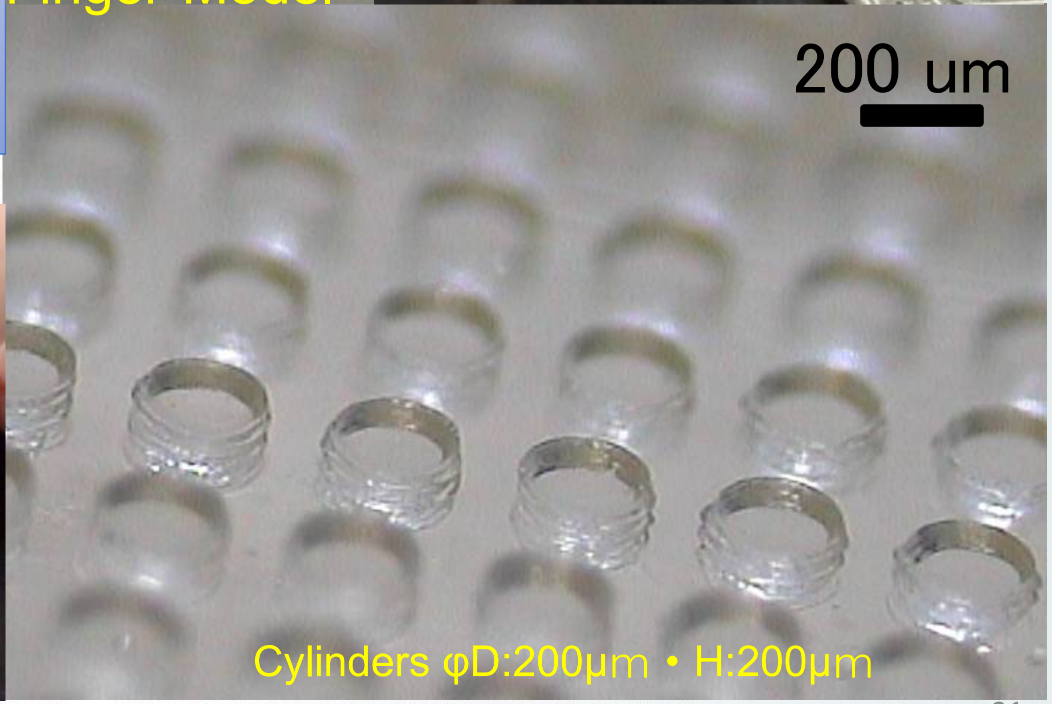


SPH Method：Smoothed Particle Hydrodynamics

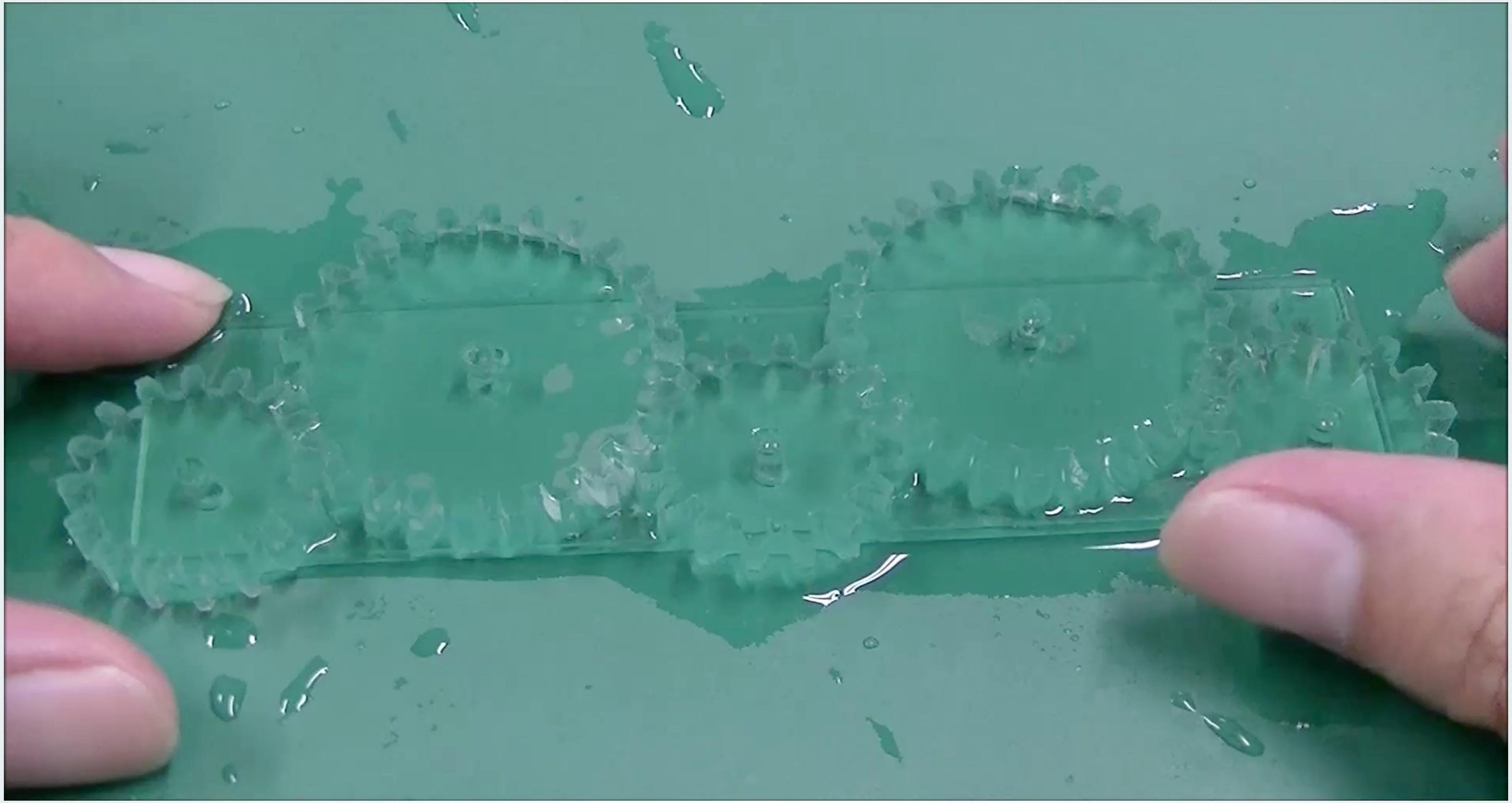
3-D Objects Made of Designable Gels



3D Printing
for Soft & High transparent Gels



Gel Gear

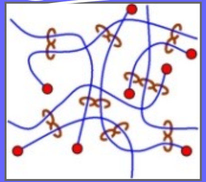


Category of New Tough Gels

New Crosslink

New Mixing

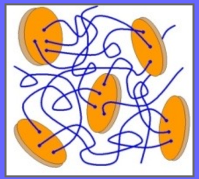
Slide-Ring gel



東京大学 THE UNIVERSITY OF TOKYO

E=1~10[kPa]

Nano Composite gel



KR 一般財団法人 川村理化学研究所

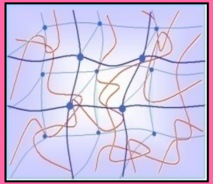
E=0.1~40 [kPa]

山形大学 YAMAGATA UNIVERSITY

Inter-Crosslink Network gel

E=1~30 [kPa]

Double Network gel



北海道大学 HOKKAIDO UNIVERSITY

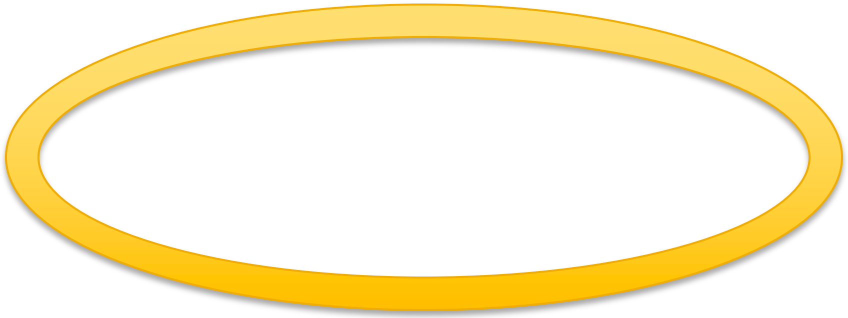
E= ~250[kPa]

- **ICN gel is a hybrid of new crosslink and new mixing. Yamagata University goes with ICN gel technology.**

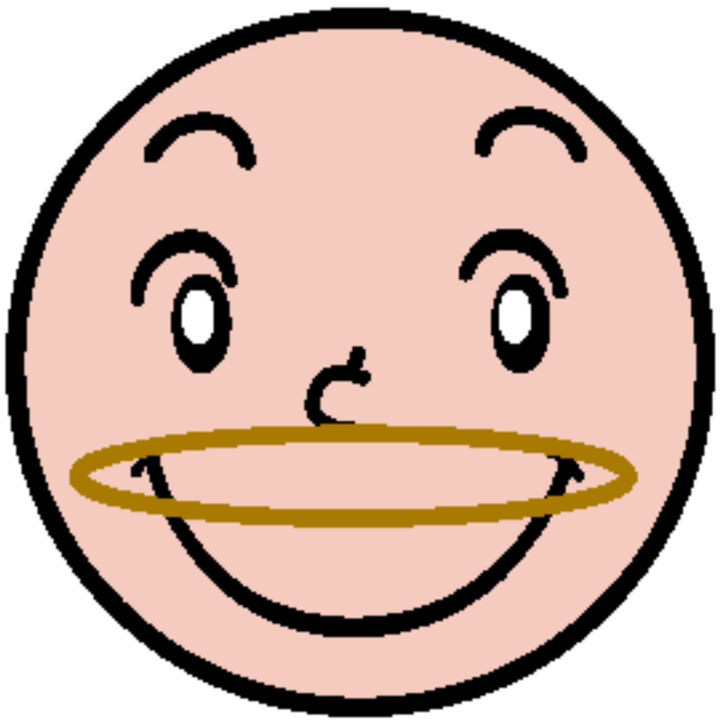
Enjoy! 楽しくやりましょう!

Please take a rubber band

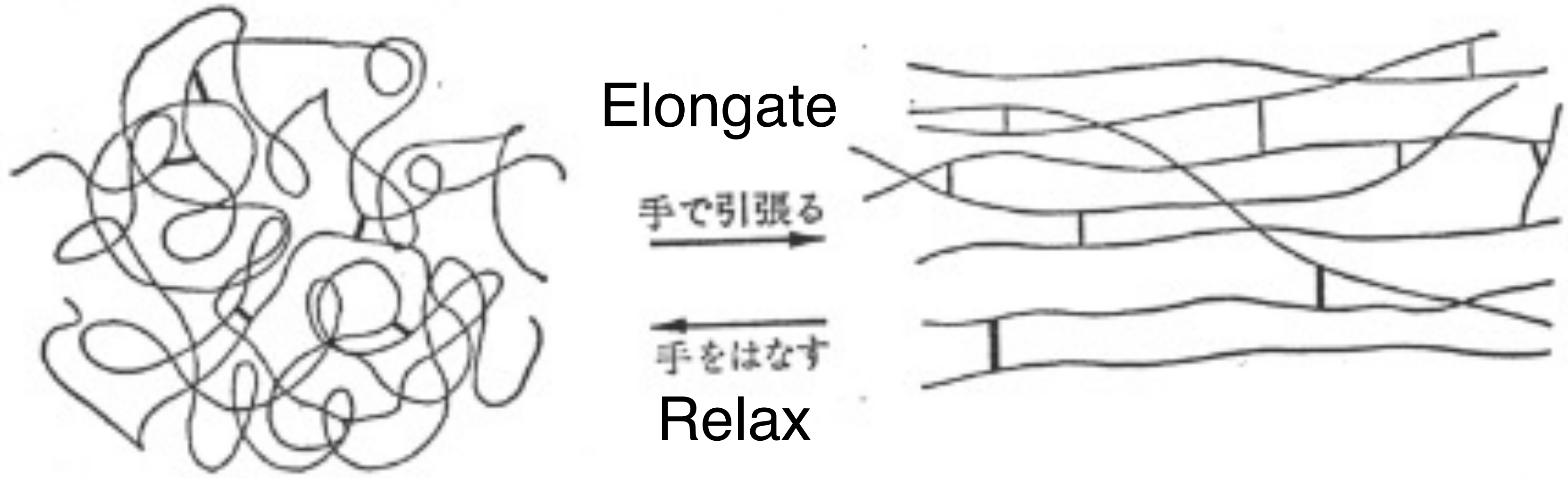
輪ゴム を 取り上げます。



Try this experiment!



1. Touch the rubber band between nose and mouth to feel the worm or cool
2. Sudden elongate the band and touch the band on there. How do you feel?
3. Sudden relax the band to return it to be its original length. How do you feel?
4. Caution: If you elongate the band too much, you sometimes feel pain. Take care of it!



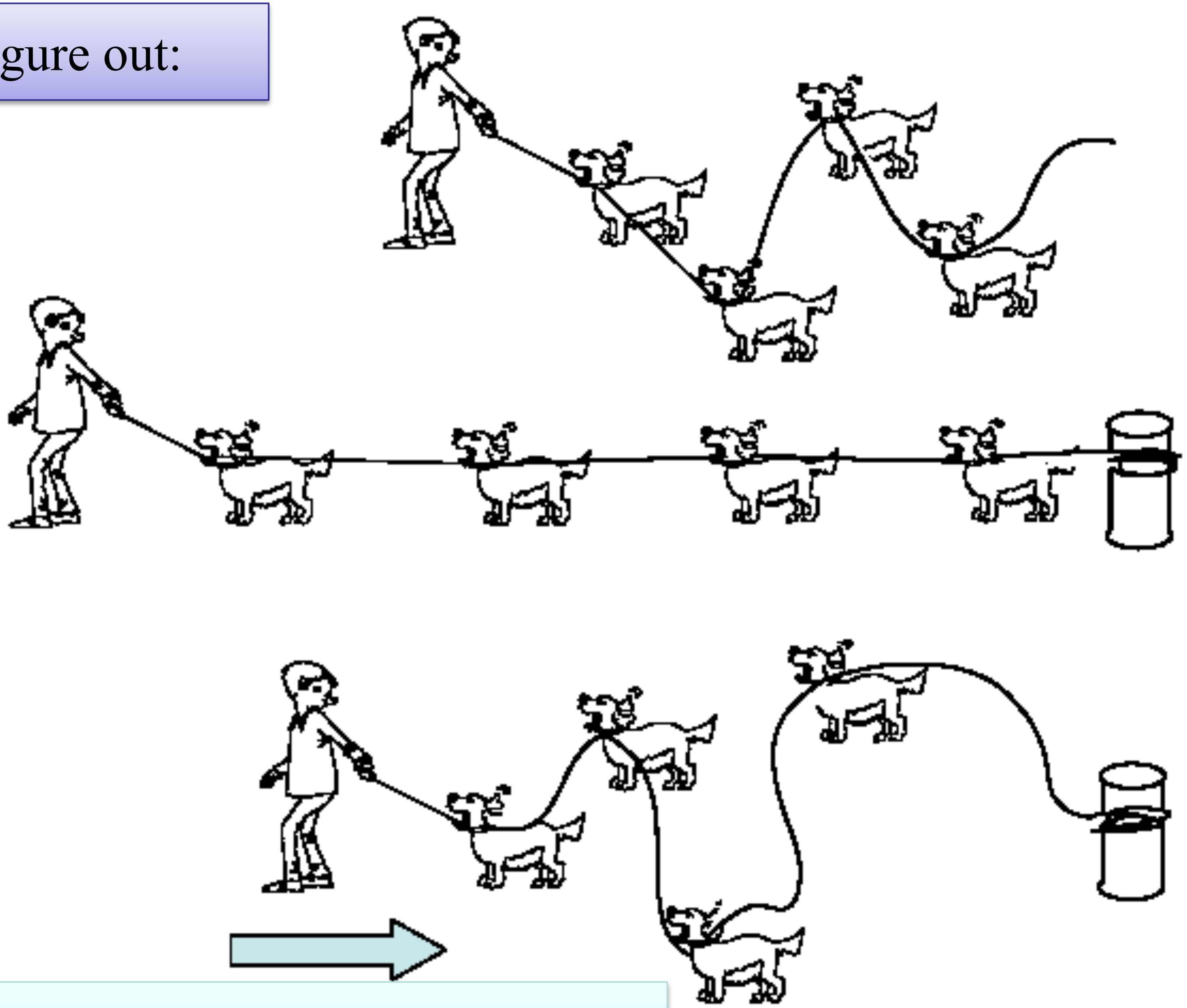
Random → High Entropy

Getting heat in

Ordered → Low Entropy

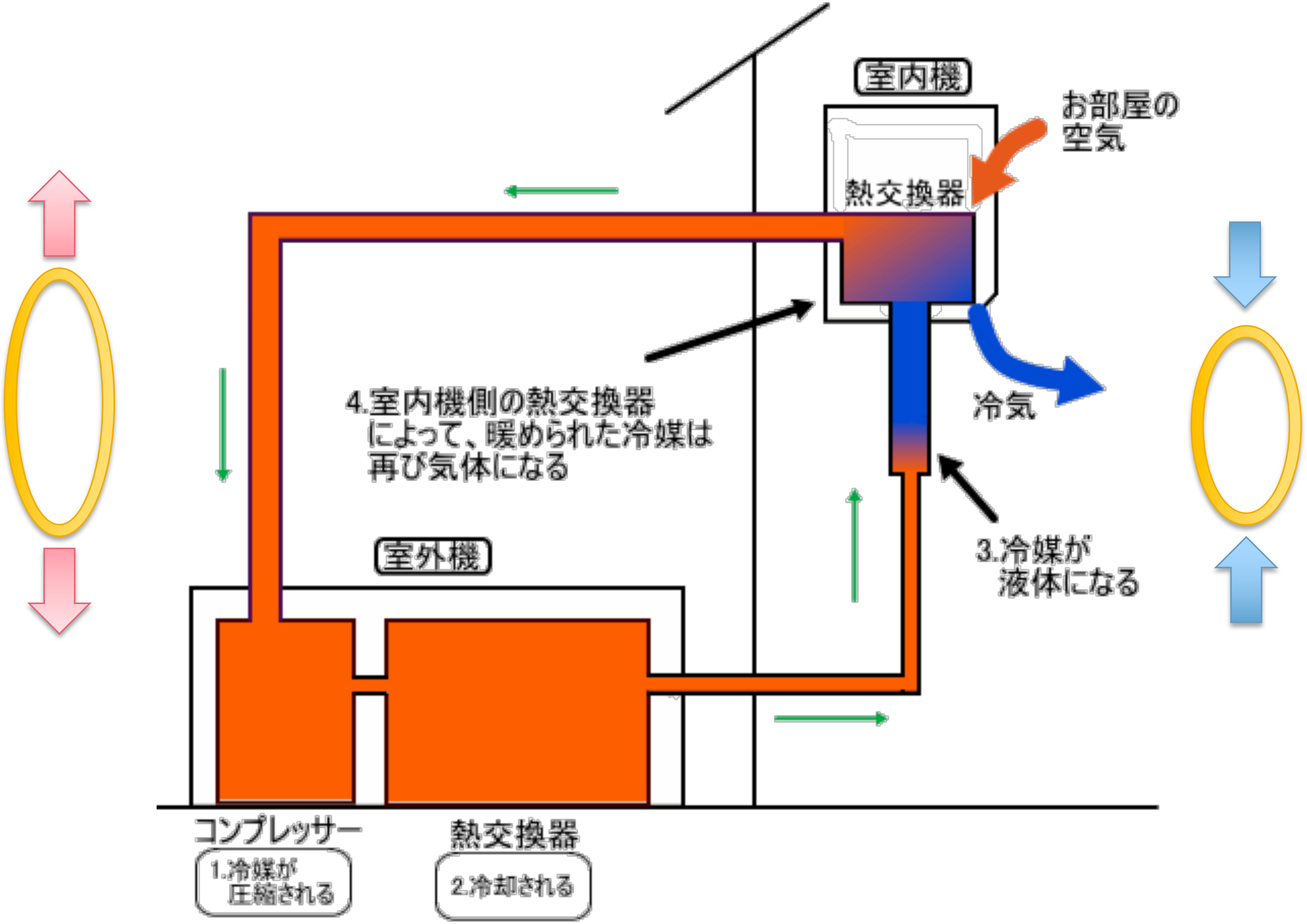
Leaving heat off

Figure out:



The heated dogs pull the guy.

Stupid innovation: Rubber air conditioner
珍発明: 輪ゴムエアコン



Estimation of the Young's modulus *E* of a rubber band (ヤング率*E*のみつもり)

Stress (応力) $\sigma = E\varepsilon$ Strain (ひずみ)

$$E = \frac{\sigma}{\varepsilon} = \frac{\frac{F}{A}}{\frac{l - l_0}{l_0}}$$

Exercise

Please calculate *E* (Pa) in the following situation:

F: force, 100gf ≈ 1N

A: area, 2mm^2 = 2 x 10^{-6}m^2

(1Pa = 1N/m^2)

Strain: ε=5

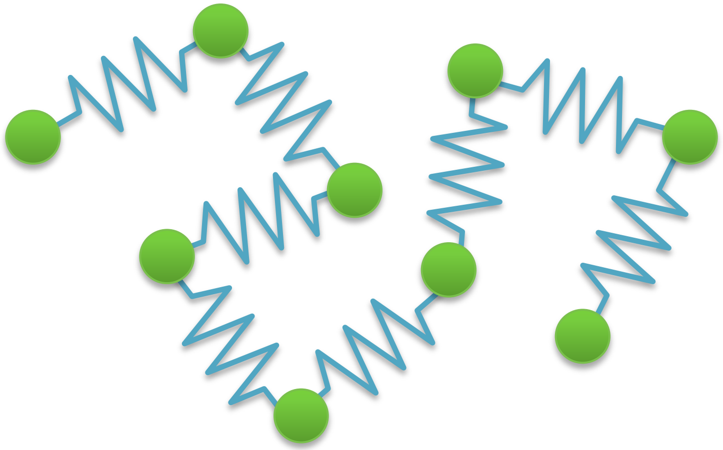
Answer:

$$E = \frac{\sigma}{\varepsilon} = \frac{1\mathrm{N} / 2 \times 10^{-6}\,\mathrm{m}^2}{5} = 0.1\mathrm{MPa}$$

Entropy elasticity: Gaussian chain model
エントロピー弾性: ガウス鎖モデル

Distribution fn. of a Gaussian chain in λ elongation ratio.
伸張率λの1本のガウス鎖の分布関数:

$$P(\lambda)=\left(\frac{3}{2\pi R_0^2}\right)^{3/2}\exp\left[-\frac{3}{2}\left(\lambda_x+\lambda_y+\lambda_z\right)^2\right]$$



Free energy of the Gaussian chain:
1本のガウス鎖の自由エネルギー:

$$F(\lambda)=-TS(\lambda)=-k_BT\ln P(\lambda)$$

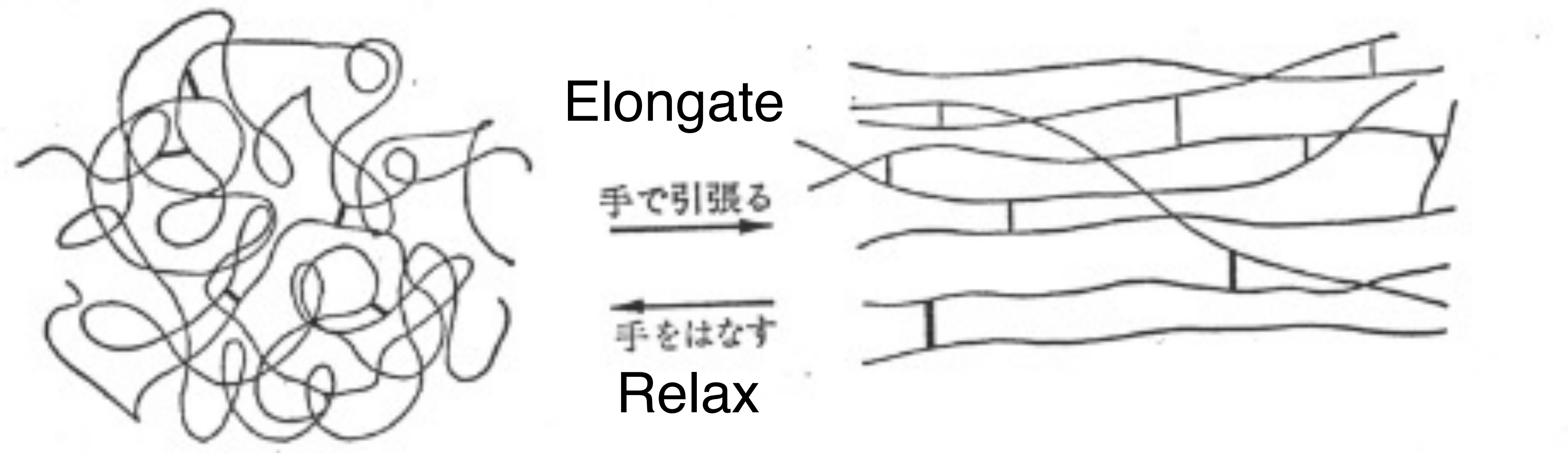
$$\sigma_x=\frac{1}{\lambda_y\lambda_z}\frac{\partial}{\partial\lambda}F(\lambda)=k_\mathrm{B}T\left(\lambda^2-\frac{1}{\lambda}\right)$$

$$\lambda_x=\frac{1}{\lambda},\quad \lambda_y=\lambda_z=\frac{1}{\lambda}$$

$$\sigma_x=k_\mathrm{B}T\left(\lambda^2-\frac{1}{\lambda}\right)=k_\mathrm{B}T\left[\left(1+\varepsilon\right)^2-\frac{1}{\left(1+\varepsilon\right)}\right]\cong 3k_\mathrm{B}T\cdot\varepsilon$$

Young’s modulus of a Gaussian chain:
1本のガウス鎖のヤング率:

$$\boxed{E=3k_\mathrm{B}T}$$



Young's modulus of a Gaussian chain:
1本のガウス鎖のヤング率:

$$\boxed{E = 3k_{\mathrm{B}}T}$$

Young's modulus of Ideal rubber:
理想ゴムのヤング率:

$$\boxed{E = 3\nu k_{\mathrm{B}}T}$$

ν: Chain density per unit volume 単位体積あたりの鎖の密度

If there were a chain in 1nm^3, (1nm^{3}当り1本とすると)

$$E = 3 \cdot \frac{1}{\left(10^{-9}\,\mathrm{m}\right)^3} \cdot 1.38 \times 10^{-23}\,\mathrm{J} \cdot \mathrm{K}^{-1} \cdot 300\mathrm{K} \cong 12\mathrm{MPa}$$

Young's modulus of Ideal rubber:
理想ゴムのヤング率:

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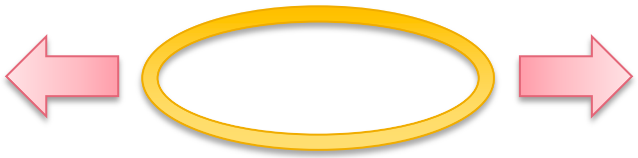
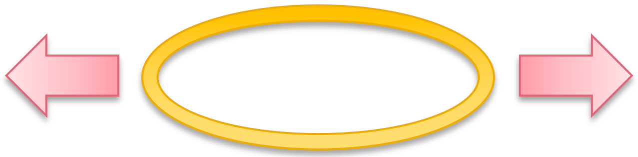


$$\boxed{E = \frac{\sigma}{\varepsilon} = \frac{1\mathrm{N} \big/ 2 \times 10^{-6}\,\mathrm{m}^2}{5} = 0.1\mathrm{MPa}}$$

The rubber band contains about 1 chain per 100nm^3.



The rubber band contains 1 chain per 10nm^3.

Exercise

Density of the rubber: 0.68 g/cm^3
Estimate the <u>molecular weight</u> of the chain in the rubber band:

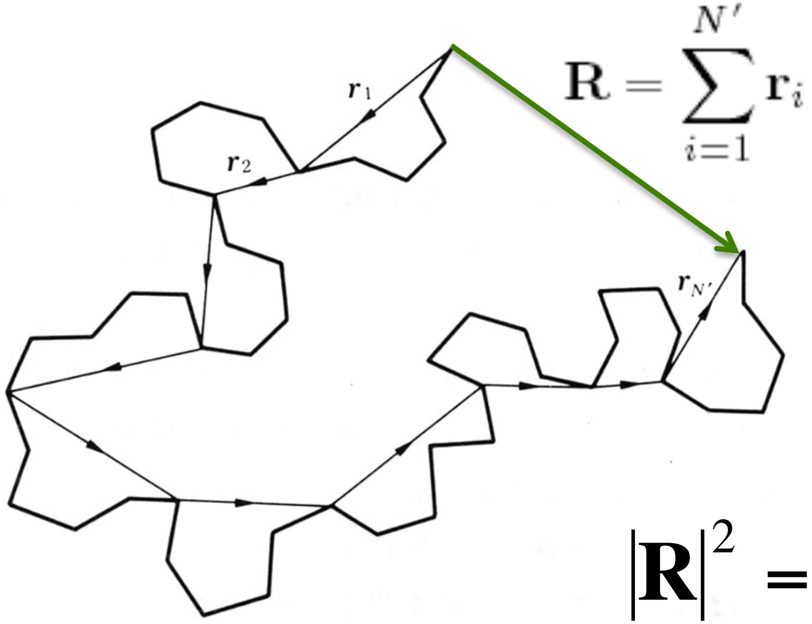
$$M_W = 10\mathrm{nm}^3 \times 6 \times 10^{23}/\mathrm{mol} \times 0.68\mathrm{g/cm}^3$$
$$\cong 10 \times 10^{-27}\mathrm{m}^3 \times 6 \times 10^{23}/\mathrm{mol} \times 0.7\mathrm{g}/10^{-6}\mathrm{m}^3$$
$$= 4200\mathrm{g/mol}$$

Exercise

Molecular weight of isoprene (C_5H_8) ≈ 68 g/mol
Estimate the <u>polymerization degree</u> of the rubber band:

$$N = {}^{4200\mathrm{g/mol}}\!\big/_{68\mathrm{g/mol}} \approx 60$$

Size of Chain in solution: Random Walk model



N' Flexible segments made by n_c units.

$$N' = \frac{N}{n_c}$$

$$|\mathbf{R}|^2 = (\mathbf{r}_1 + \mathbf{r}_2 + \cdots + \mathbf{r}_{N'})^2$$

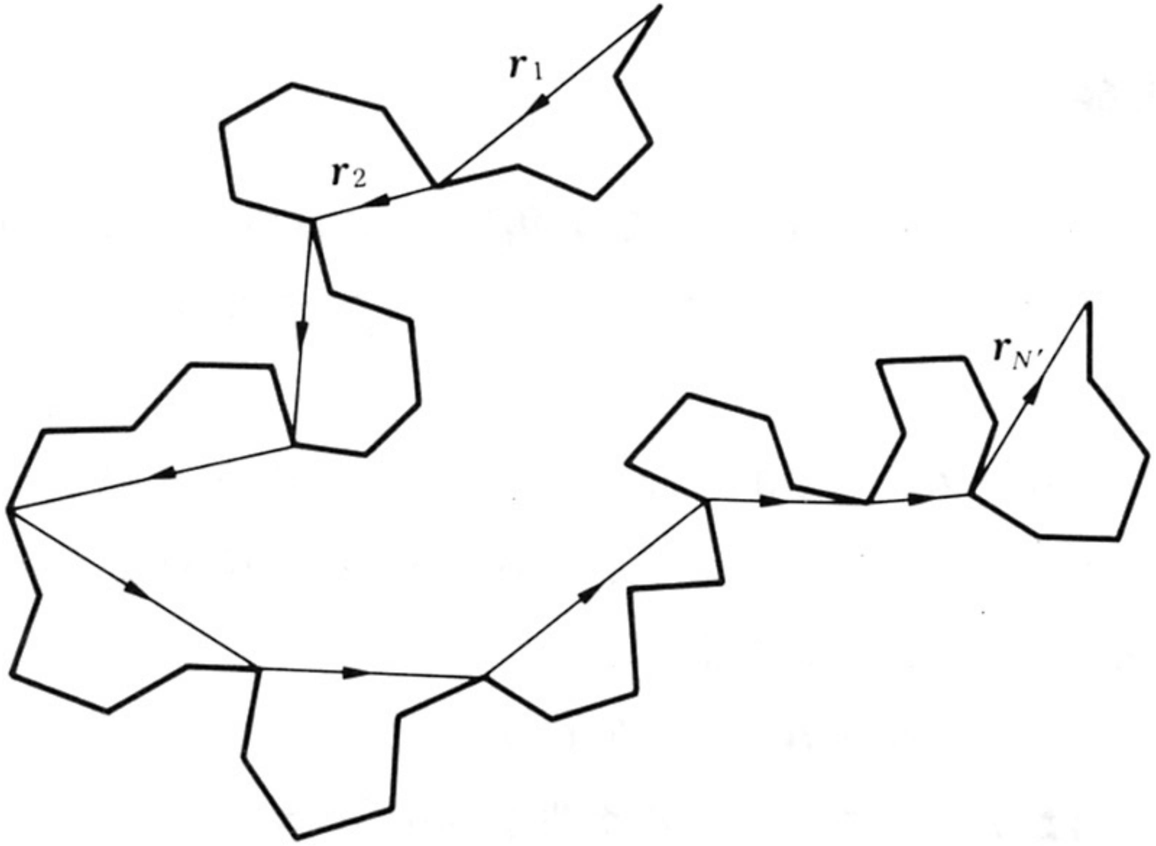
$$= \mathbf{r}_1^2 + \mathbf{r}_2^2 + \cdots + \mathbf{r}_{N'}^2 + 2\mathbf{r}_1 \cdot \mathbf{r}_2 + \cdots$$

$$\langle \mathbf{r}_1 \cdot \mathbf{r}_2 \rangle = 0$$

$$\langle |\mathbf{R}|^2 \rangle = \langle \mathbf{r}_1^2 \rangle + \langle \mathbf{r}_2^2 \rangle + \cdots + \langle \mathbf{r}_{N'}^2 \rangle$$

$$= b^2 N'$$

Radius of the ideal chain based on the random walk model



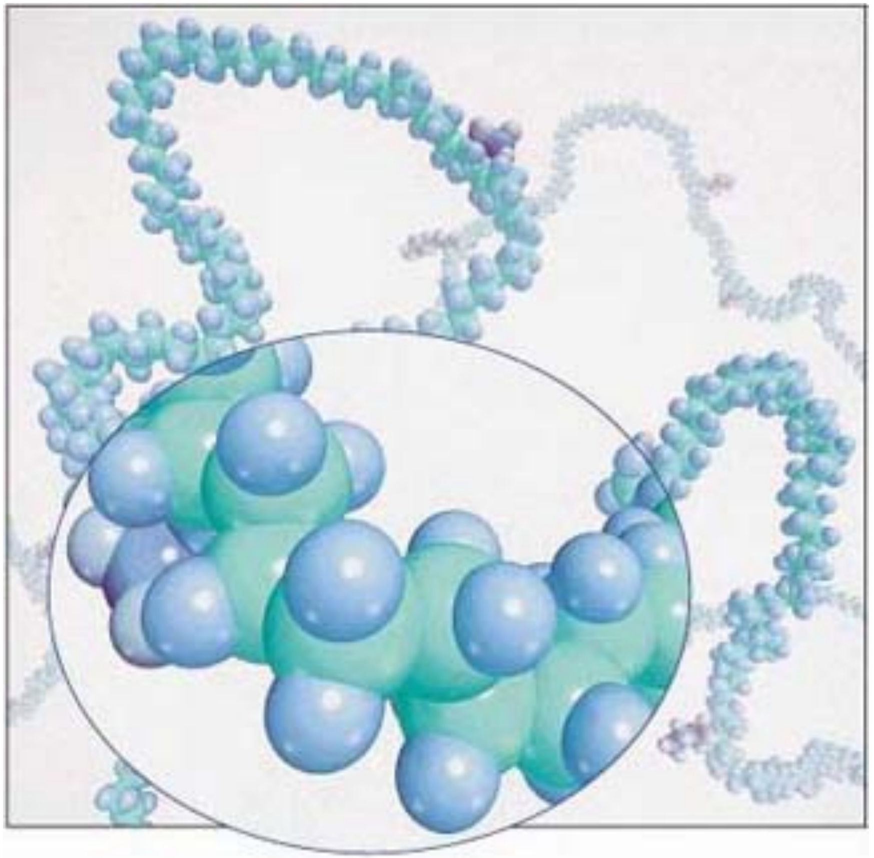
$$\boxed{R = \sqrt{N}a = aN^{1/2}}$$

R: Radius of chain, *N*: Polymerization degree, *a*: segment size

IDEAL CHAIN

$$\boxed{R = aN^{1/2}}$$

R: Radius of chain,
N: Polymerization degree,
a: segment size

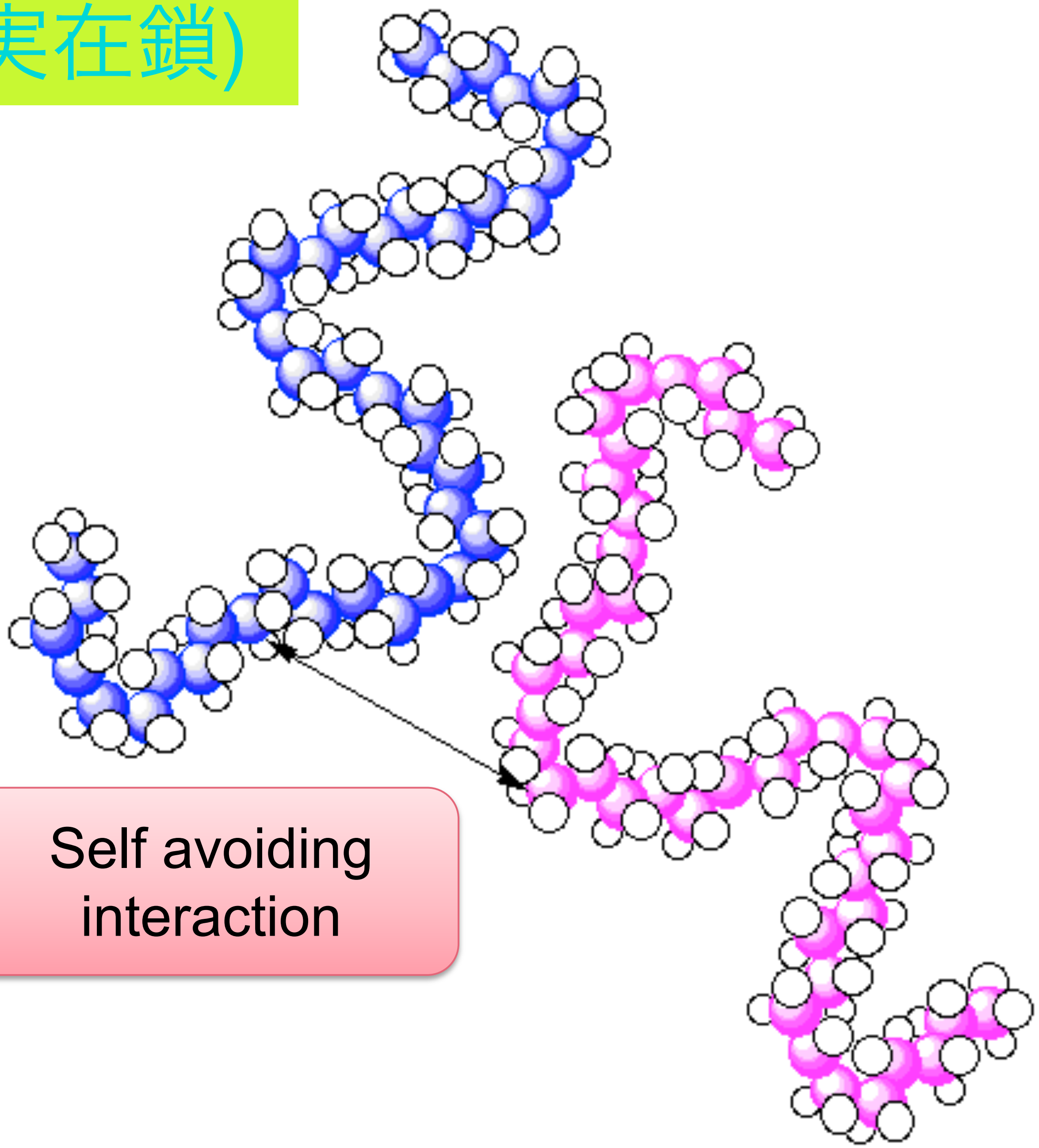


Exercise

Estimate the radius of the chain in the rubber band swollen in toluene based on the ideal chain model, where N=100 and segment size a=0.3nm.

Answer: $R = \sqrt{100} \times (0.3\text{nm}) = 3\text{nm}$

REAL CHAIN(実在鎖)



Self avoiding interaction

The real chain expands in solution lager than the ideal chain.

$$\boxed{R_{\mathrm{F}} = aN^{3/5}}$$

R_{F}: the radius of the real chain →Flory's radius
N: Polymerization degree
a: segment size

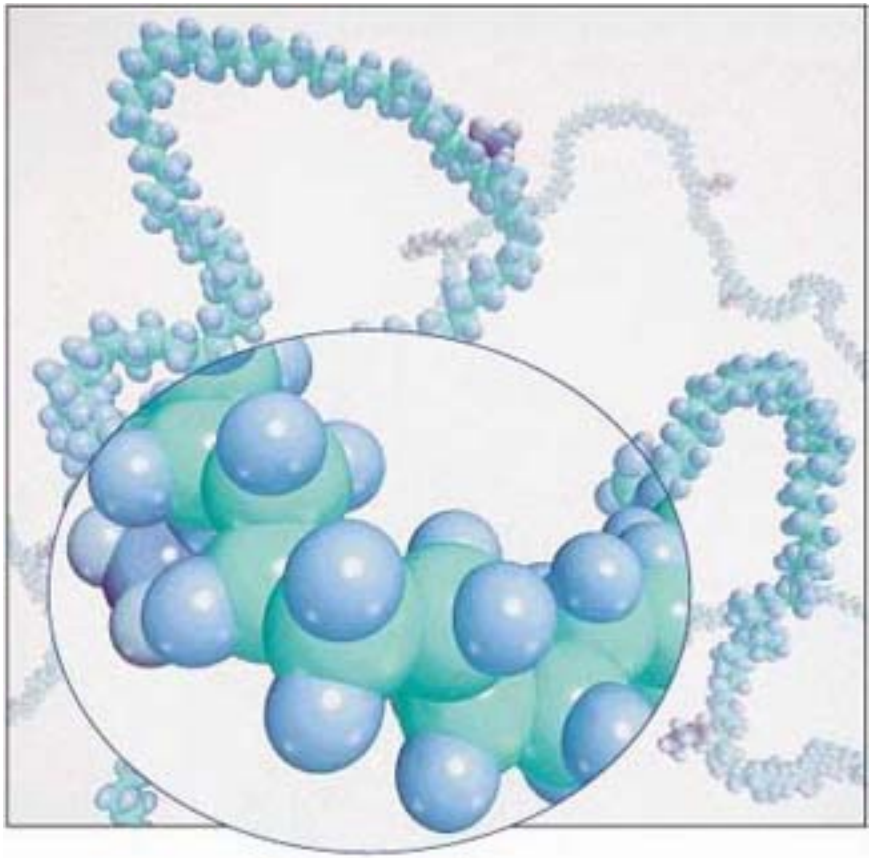
P. J. Flory, (1910-1985)

State of Chain	Quality of Solvent
Real chain (実在鎖) $R \propto N^{3/5}$	Good solvent (良溶媒)
Ideal chain (理想鎖=ガウス鎖) $R \propto N^{1/2}$	Theta solvent (Θ溶媒)
Globule chain, Collapsed chain (収縮鎖) $R \propto N^{1/3}$ ($\because V \propto N$)	Poor solvent (貧溶媒)

REAL CHAIN

$$R = aN^{3/5}$$

R: Radius of chain,
N: Polymerization degree,
a: segment size



Exercise

Estimate the radius of the chain in the rubber band swollen in toluene based on the *real* chain model, where N=100 and segmeng size a=0.3nm.

Answer: $R = 100^{0.6} \times (0.3\text{nm}) = 4.75\text{nm}$

1.5 times larger than the ideal chain.

Polyelectrolyte gels extends larger than the real chain.

REAL CHAIN

$$\boxed{R_\mathrm{F} = aN^{3/5}}$$

EXTENDED CHAIN

$$\boxed{R_\mathrm{E} = aN^{\nu_\mathrm{E}}}$$

$$\frac{3}{5} \le \nu_\mathrm{E} \le 1$$

Exercise

Estimate the radius of the charged chain in fully swollen state in solution based on the *extended* chain model, where we assume N=100, segment size a=0.3nm, and the exponent ν_E=1.

Answer:

$$R = 100^1 \times (0.3\mathrm{nm}) = 30\mathrm{nm}$$

10 times larger than the ideal chain.

Developing Next Gels with Different Structures

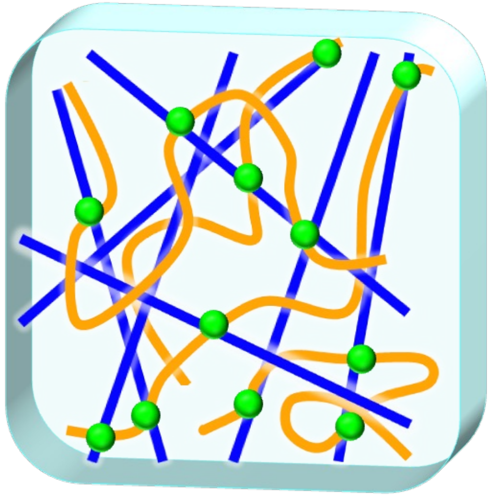
Inter-Crosslinking Network (ICN) structure


Flexible polymer

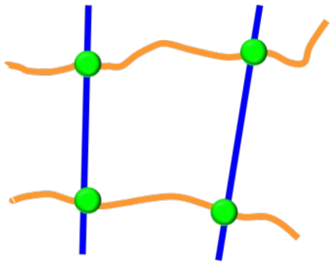
Rigid polymer

Crosslinker

ICN Gel



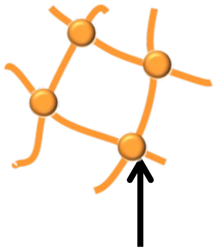
Several polymer



Crosslinking exists only between the different types of the polymer chains.

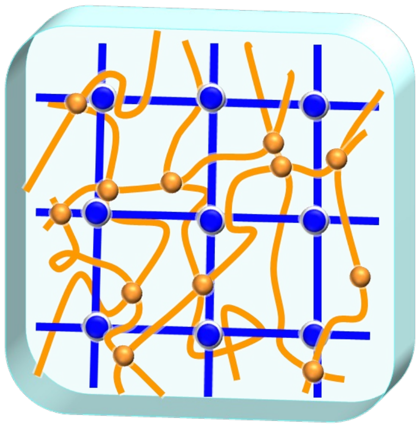
Common Gel

Single polymer

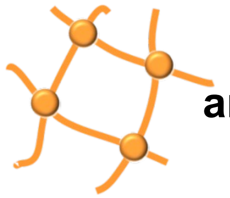
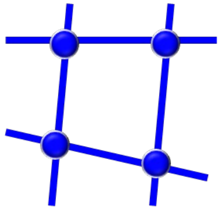


Crosslinking

Composite Gel



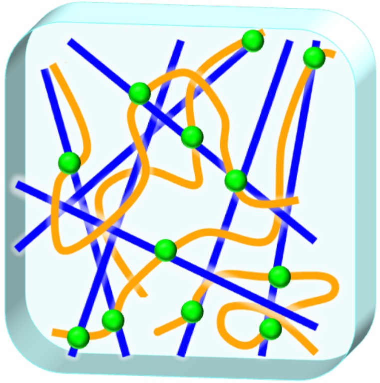
Several polymer


and


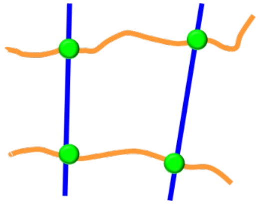
Crosslinking exists only between the same type of the polymer chains.

Tensile test of the ICN gels

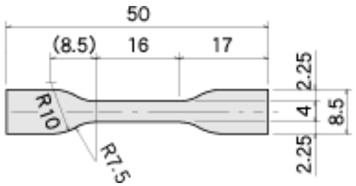
ICN Gel



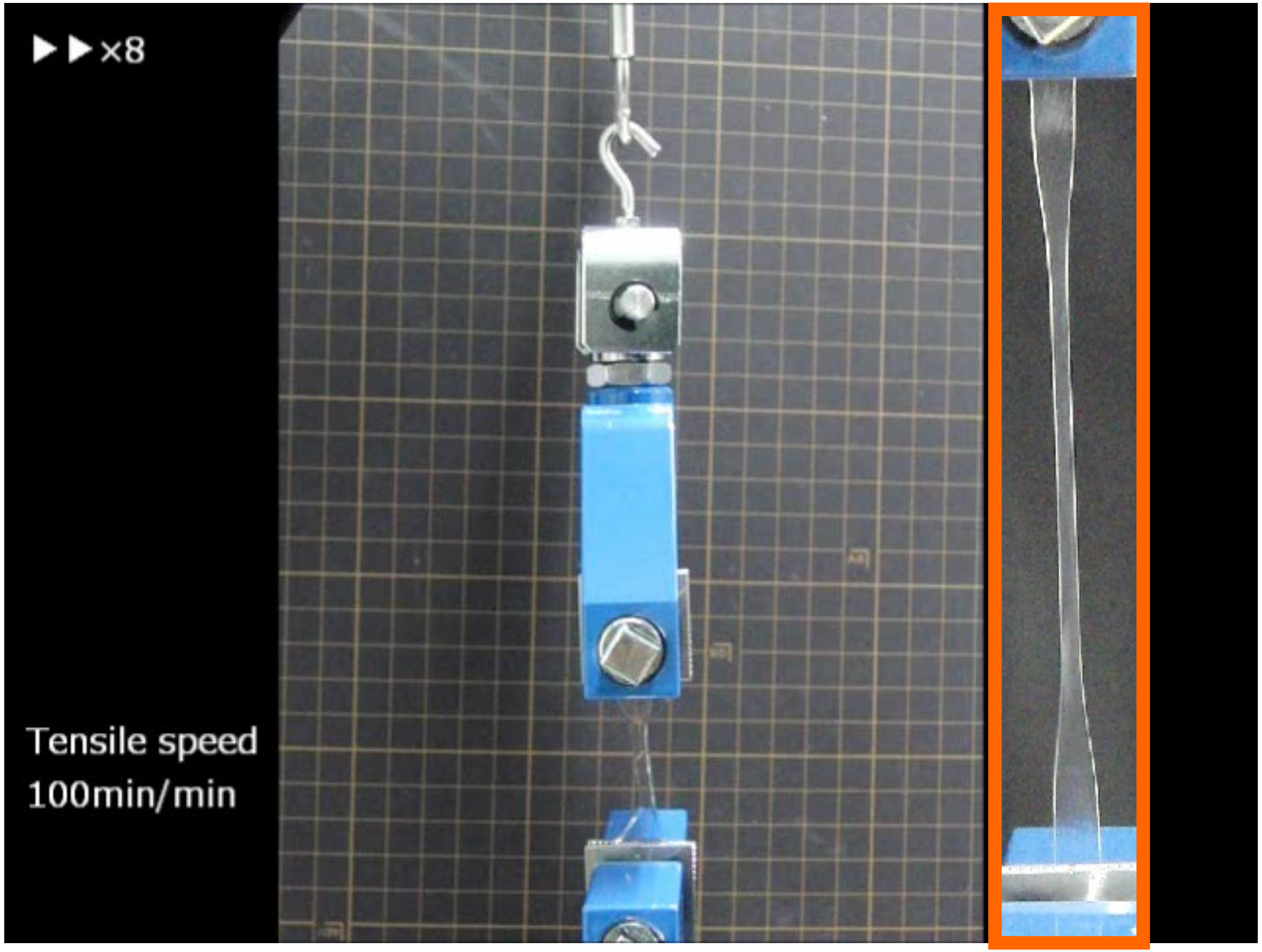
Several polymer



Crosslinking exists only between the <u>different types</u> of the polymer chains.

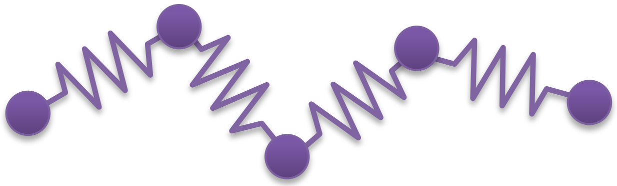


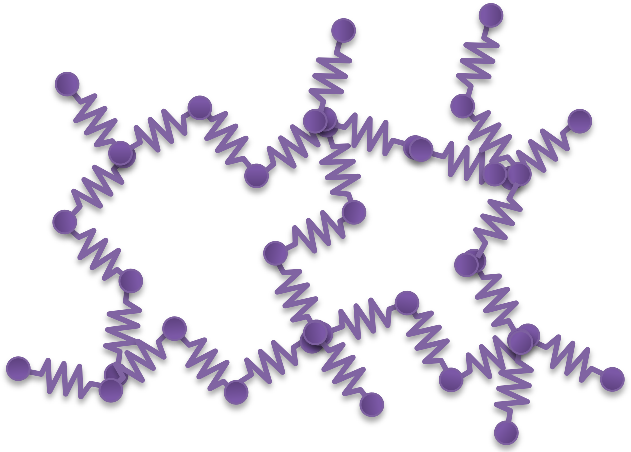
98% water content



Why the ICN gels can be elongated so long?

Gauss Model of polymer gels





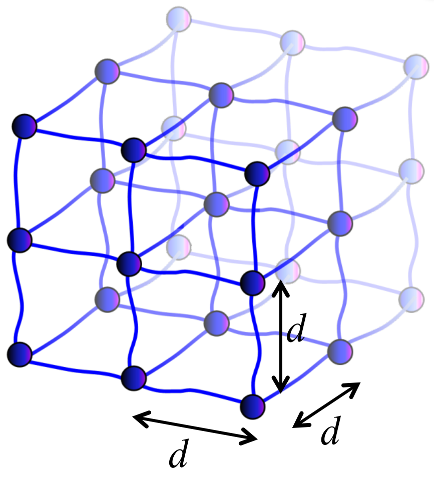
Young's Modulus of a chain:

$$E = 3k_{\mathrm{B}}T$$

Young's Modulus of gel:

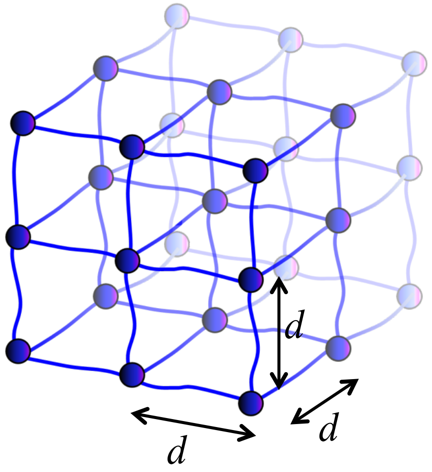
$$E = 3\nu k_{\mathrm{B}}T$$

ν: Chain density

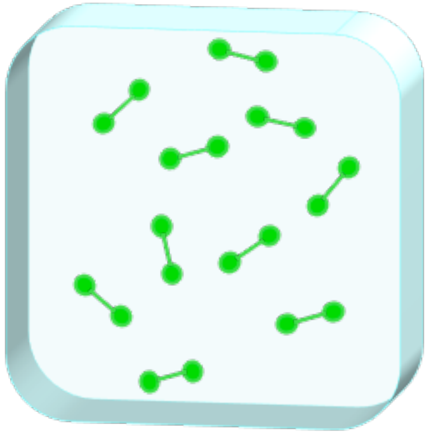


$$\nu \cong \frac{1}{R_0^3}$$

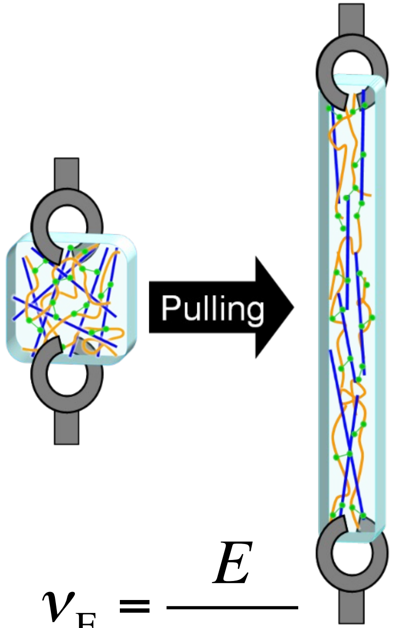
Chain density definitions in gels ν



$$\nu_{\mathrm{S}} = \frac{1}{d^3}$$



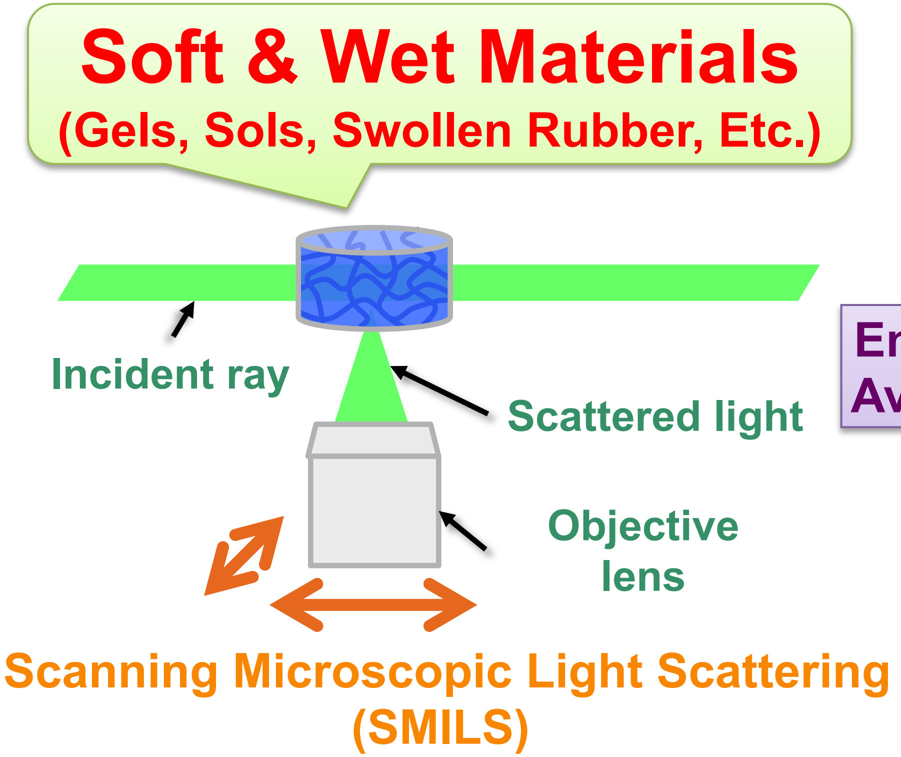
$$\nu_{\mathrm{W}} = \frac{(f/2)n_{\mathrm{C}}}{V} = \frac{N_{\mathrm{A}}\rho_{\mathrm{W}} f}{2M_{\mathrm{C}}}\psi_{\mathrm{C}}\left(1-\phi_{\mathrm{W}}\right)$$



$$\nu_{\mathrm{E}} = \frac{E}{3k_{\mathrm{B}}T}$$

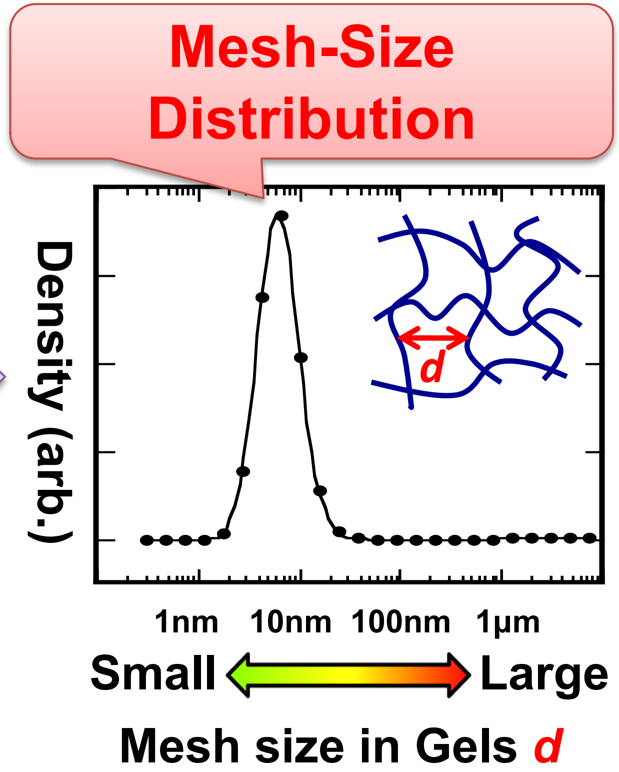
Sample name	d (nm)	ν_{S} (1/m³)	ν_{W} (1/m³)	ν_{E} (1/m³)
ICN Gel No.1	13.1	4.45×10^{23}	5.01×10^{23}	8.73×10^{23}
ICN Gel No.2	16.4	2.27×10^{23}	3.19×10^{23}	3.87×10^{23}
PDMAAm Gel	8.08	19.0×10^{23}	1.66×10^{23}	10.8×10^{23}

*Scanning Microscopic Light Scattering (SMILS)**
- A new apparatus for characterizing gels -



COMMERCIARIZED BY HORIBA

Ensemble Averaging



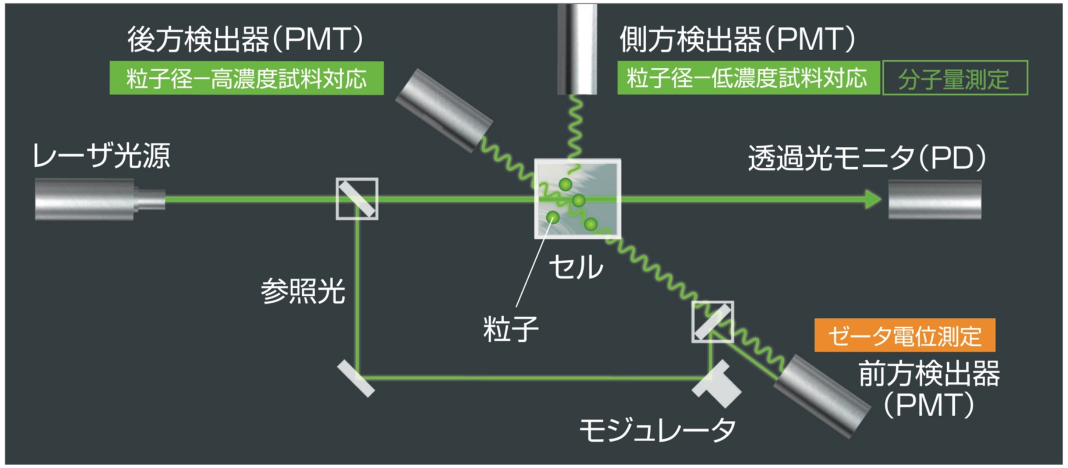
Network structure is easily characterized and quantified with mesh size d.

Young's Modulus of gel: $E = 3\nu k_B T$ ⇐ Sub-chains density $\nu = 1/d^3$

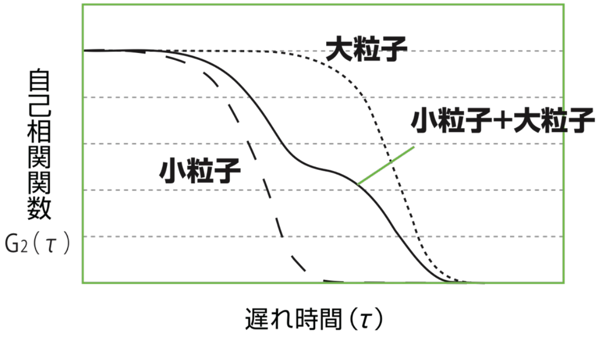
*H. Furukawa et al., *Phys. Rev. E*, **68**, 031406 (2003)

■ 粒子径: 高濃度・低濃度試料に幅広く対応できる独自の光学系

～ NEDOの「ナノ粒子プロジェクト」で高精度・高速コリレータを共同開発 ～



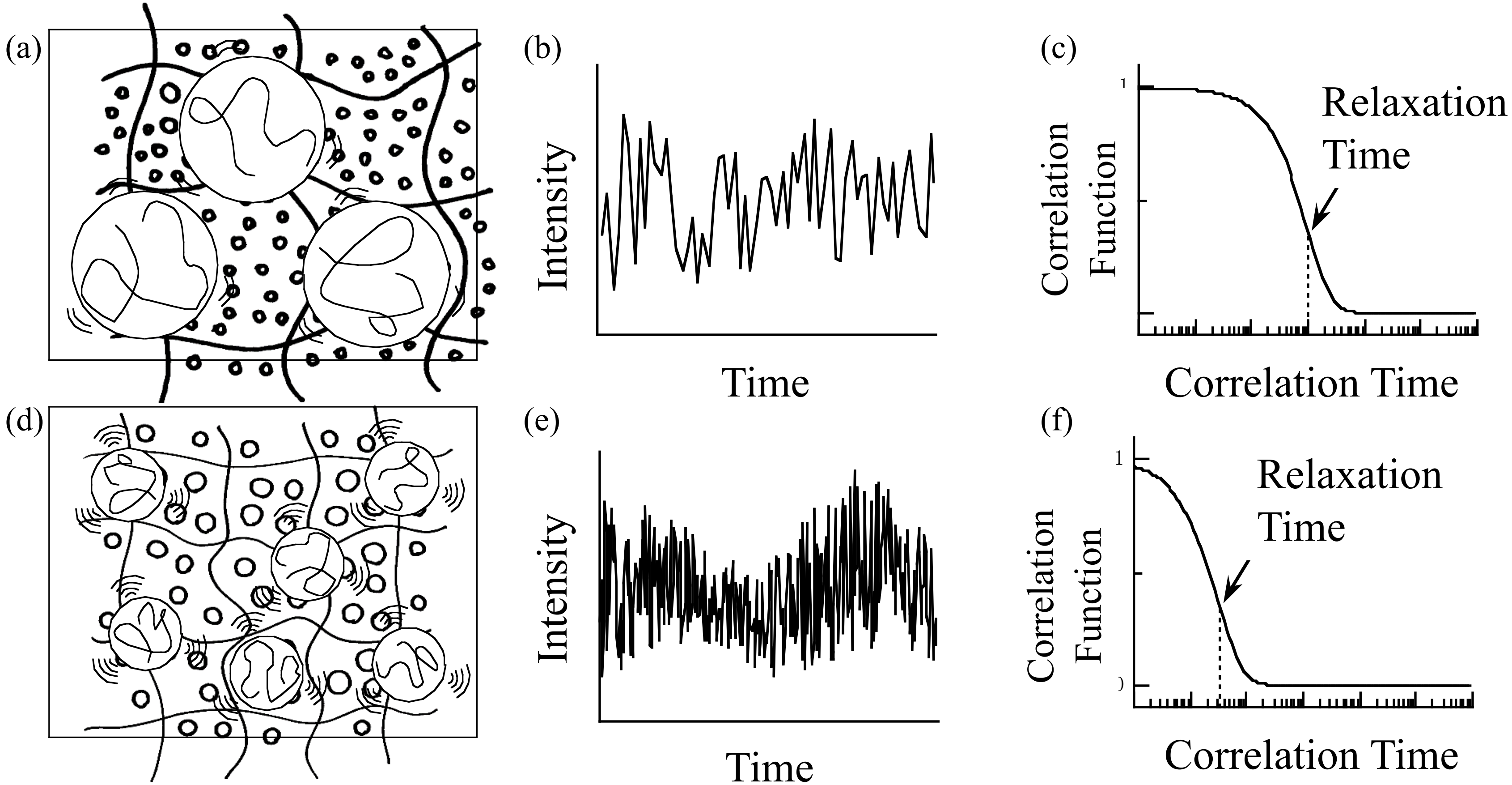
● 自己相関関数と粒子径の関係



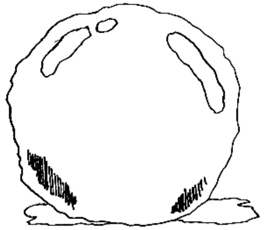
❶ 高感度光学部品の採用で、シングルナノ粒子の測定精度を向上

❷ 最適測定条件の自動選択機能により、測定濃度レンジを拡大

Nano-scale fluctuation observed by Dynamic Light Scattering

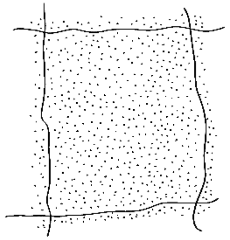


Network Structures in Gels: If nano-scales are enlarged to earth-scales, …



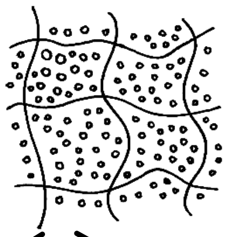
1.2cm

Small Gel Ball



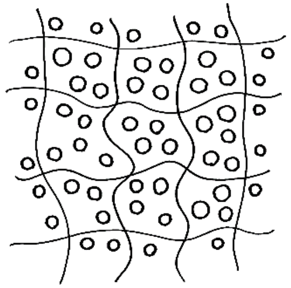
~100nm

Water-absorbent Fabric
Nata de coco



~30nm

Ion-exchange Resin
High Water-absorption Resin
(Polyelectrolyte Gels)



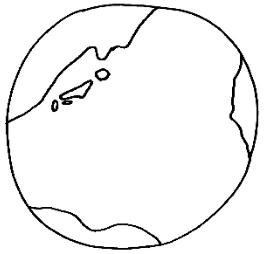
2~3nm

Solvent Molecular Size ~ **0.3nm**

Electrophoresis Gels
(Neutral Gels)

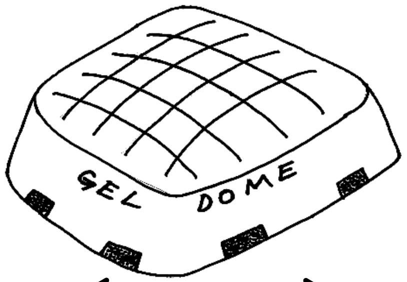
x 10^{9}
Enlargement

x 10^{-9}
Reduction



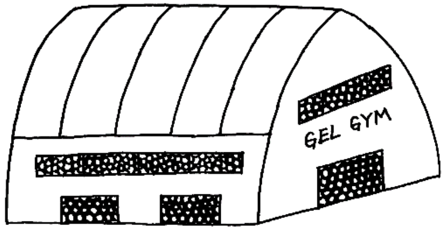
12,000km

Earth



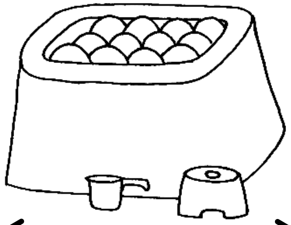
~100m

Ballpark Dome
Filled with Footballs



~30m

Gymnasium Filled With Footballs



2~3m

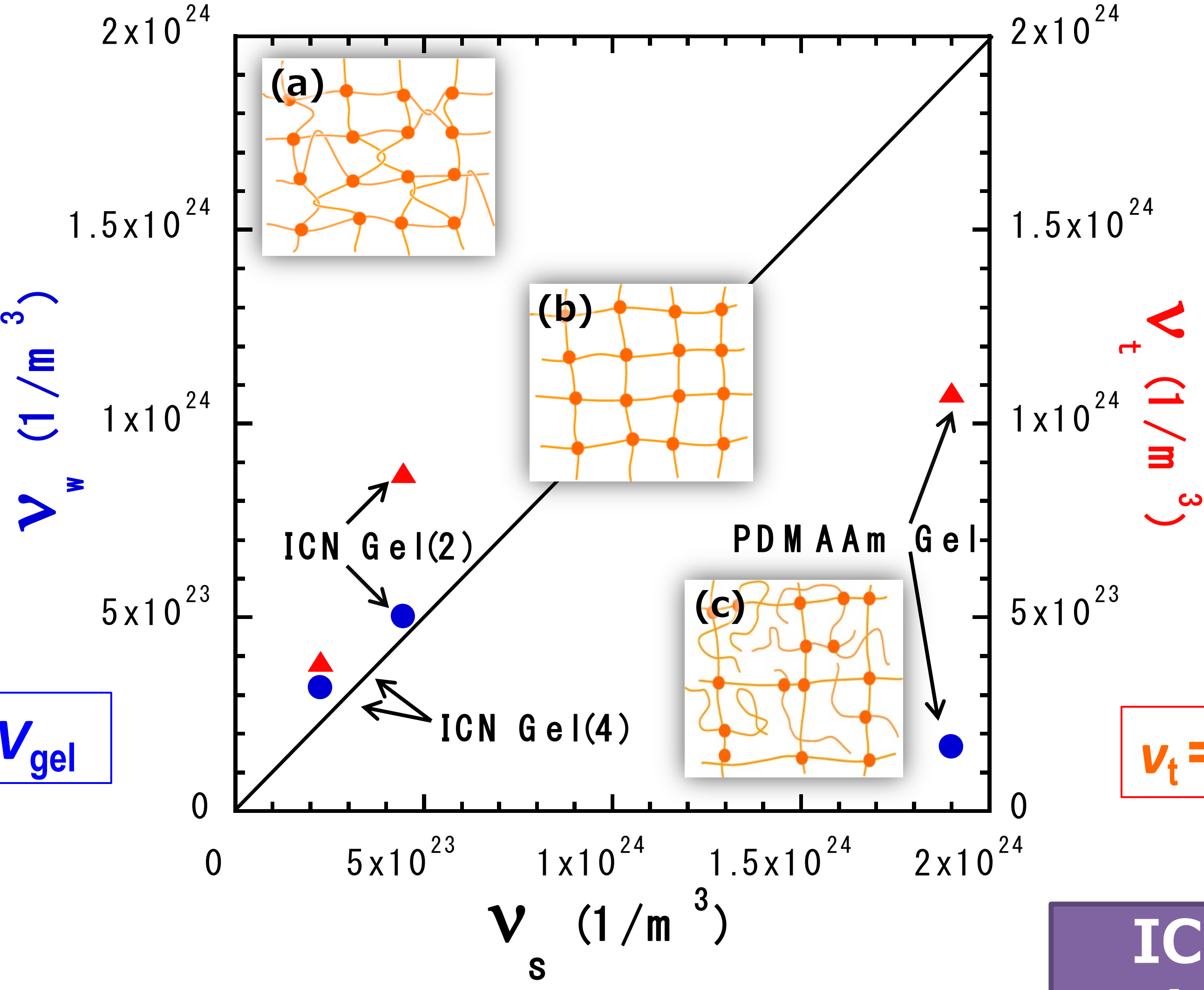
Football Size ~ **0.3m**

Bath Filled With Footballs

Comparing the Different Chain Densities

From Water Content

$v_s = 2n_{icn} / V_{gel}$



From Young's Modulus

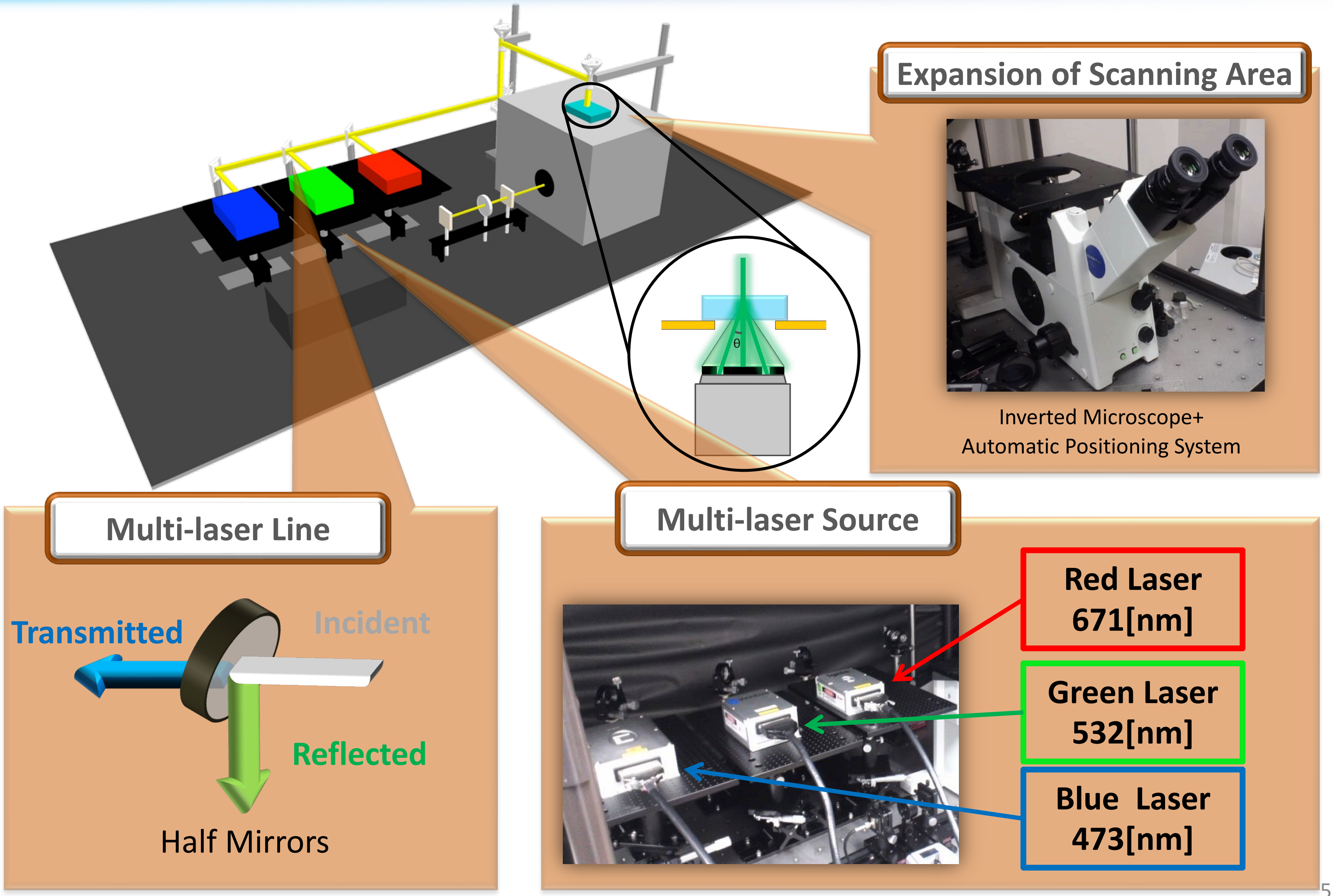
$v_t = E / (3k_B T)$

From Light Scattering (SMILS)

$v_s = 1 / d^3$

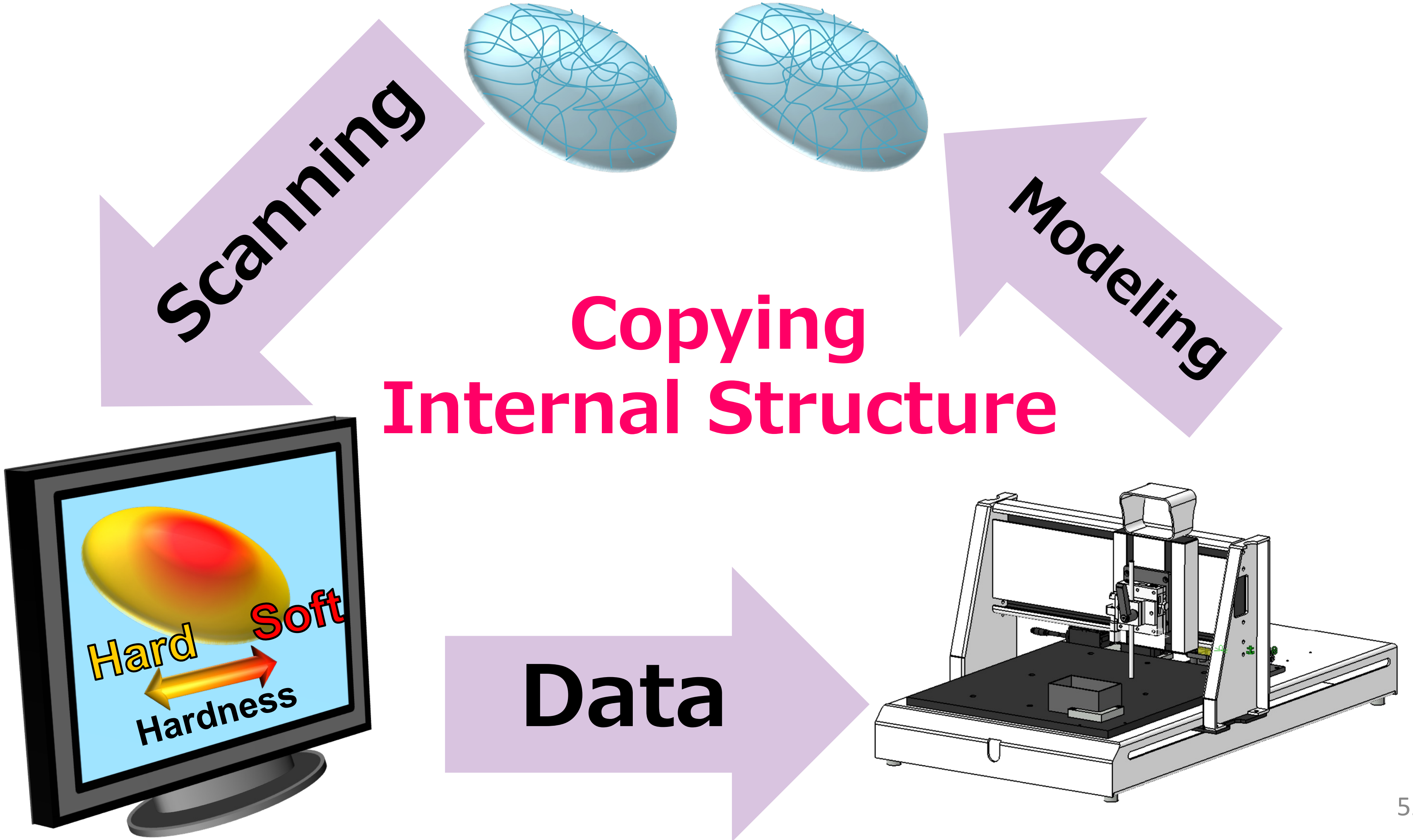
ICN gel looks Very ideal!

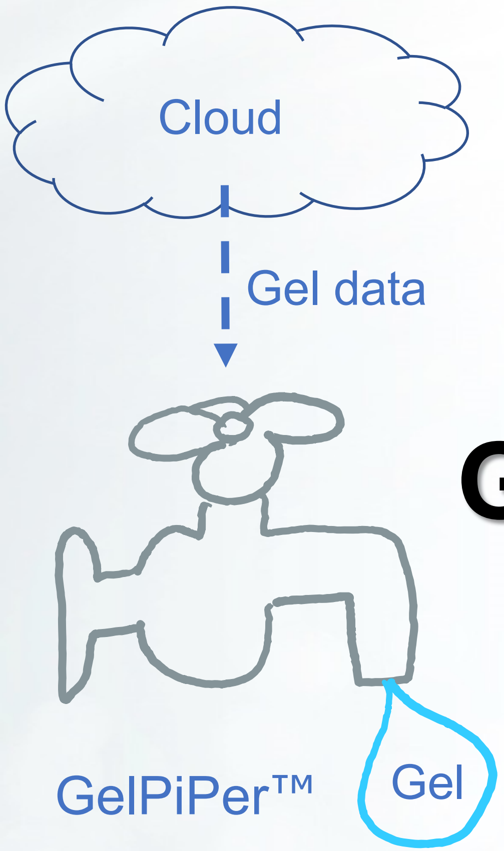
3D Gel Scanner



Gel-Dup

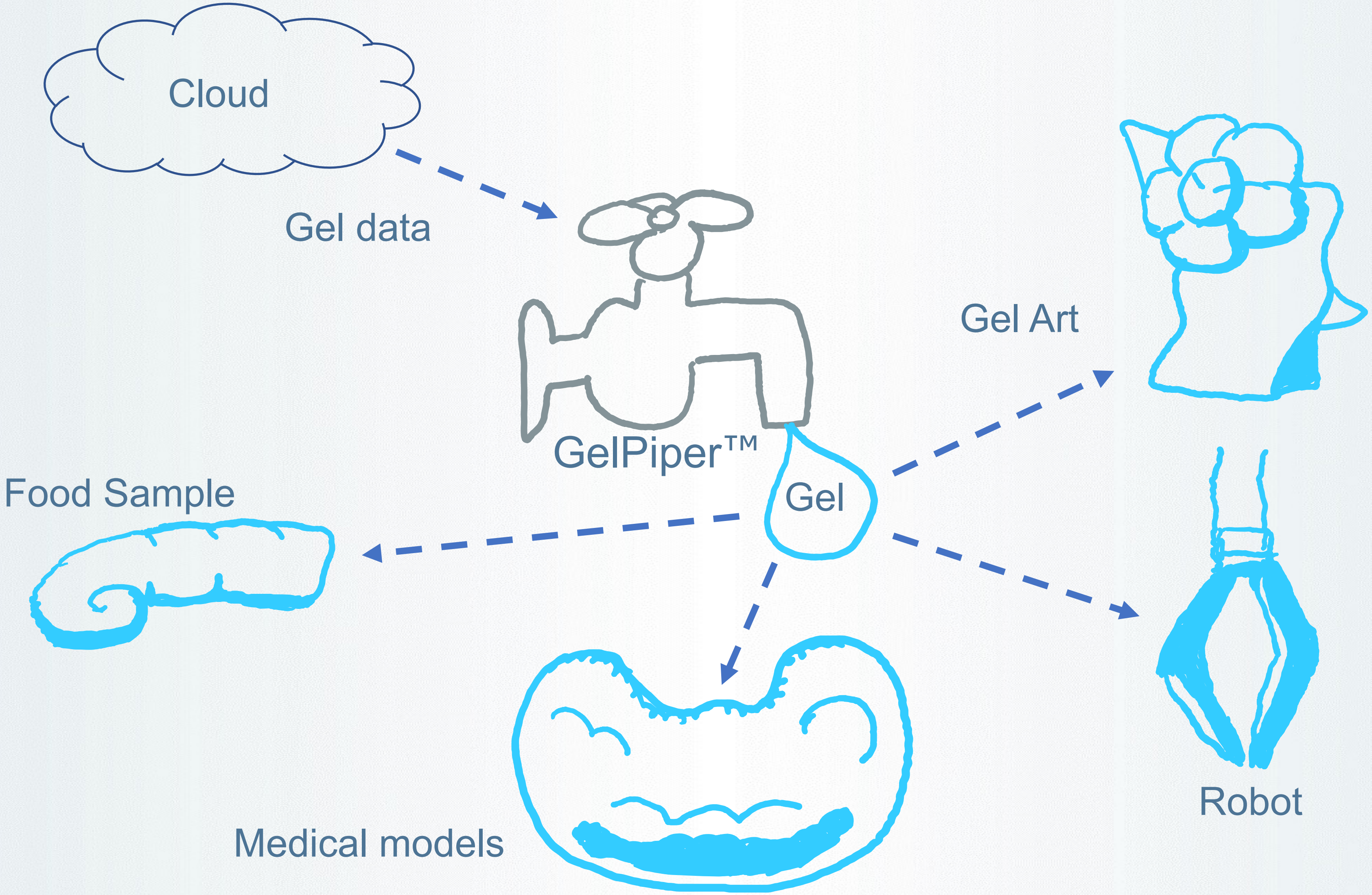
Gel CT × 3D Gel Printer



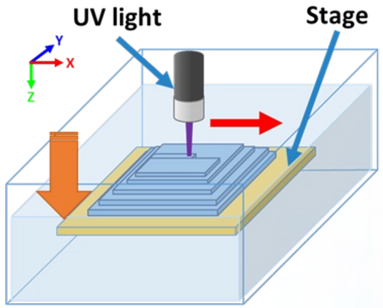


GelPiPer™ Program

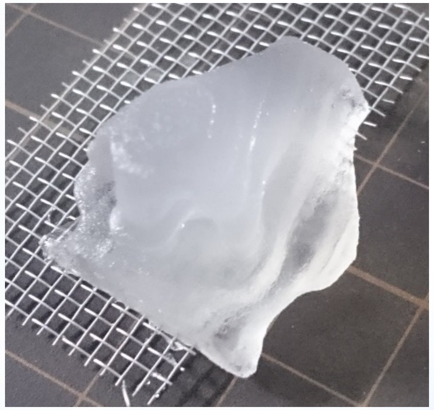
GelPiper™ "Digital Pipeline of Gel"



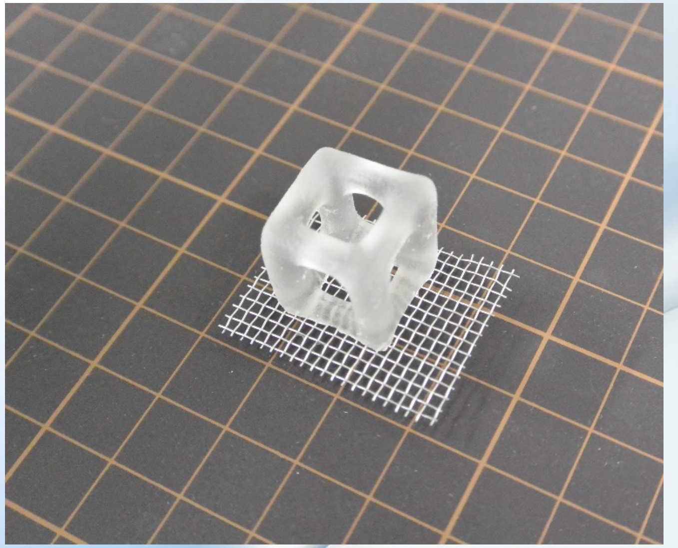
Modeling samples



Gel Ear Model

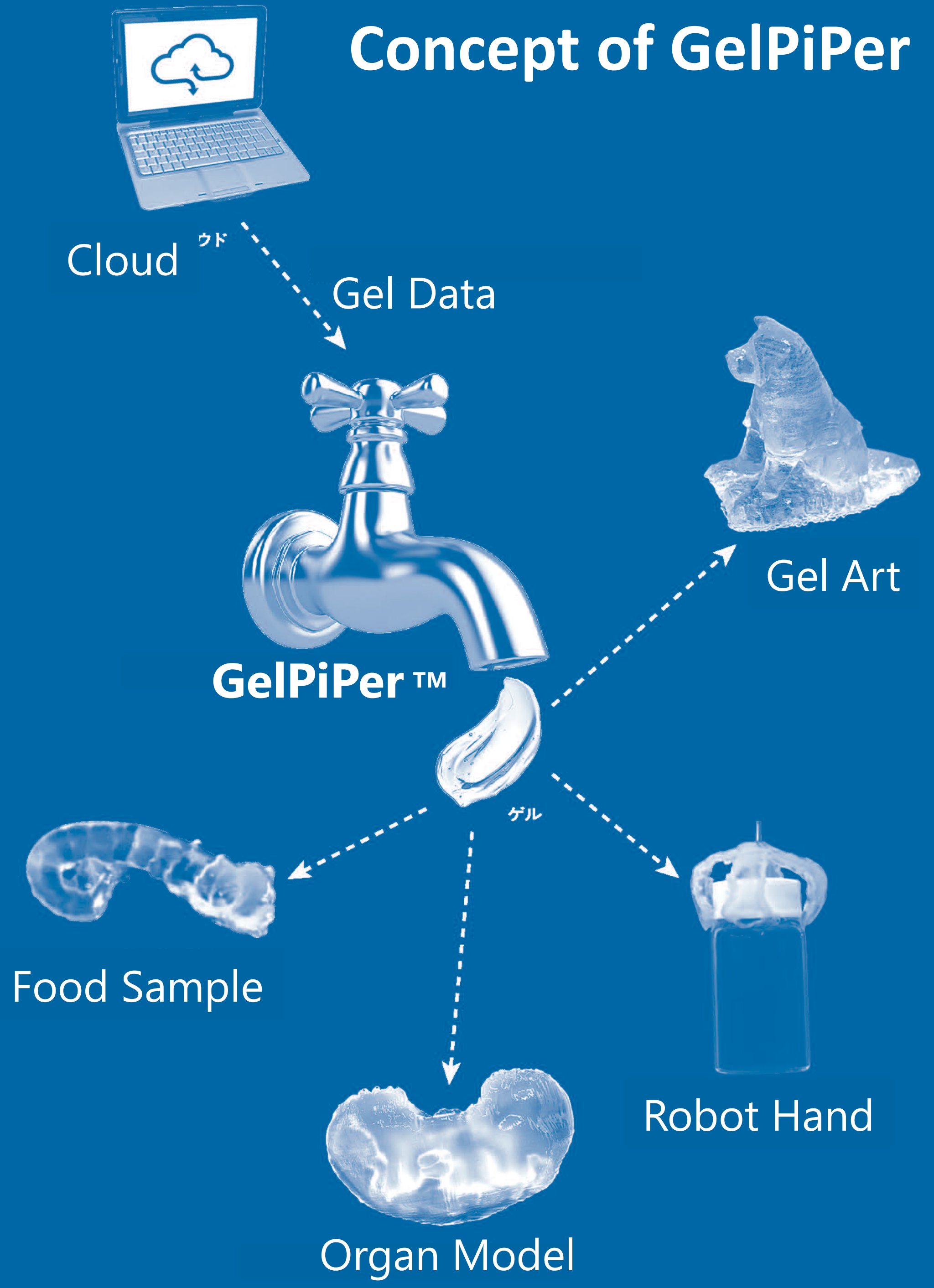


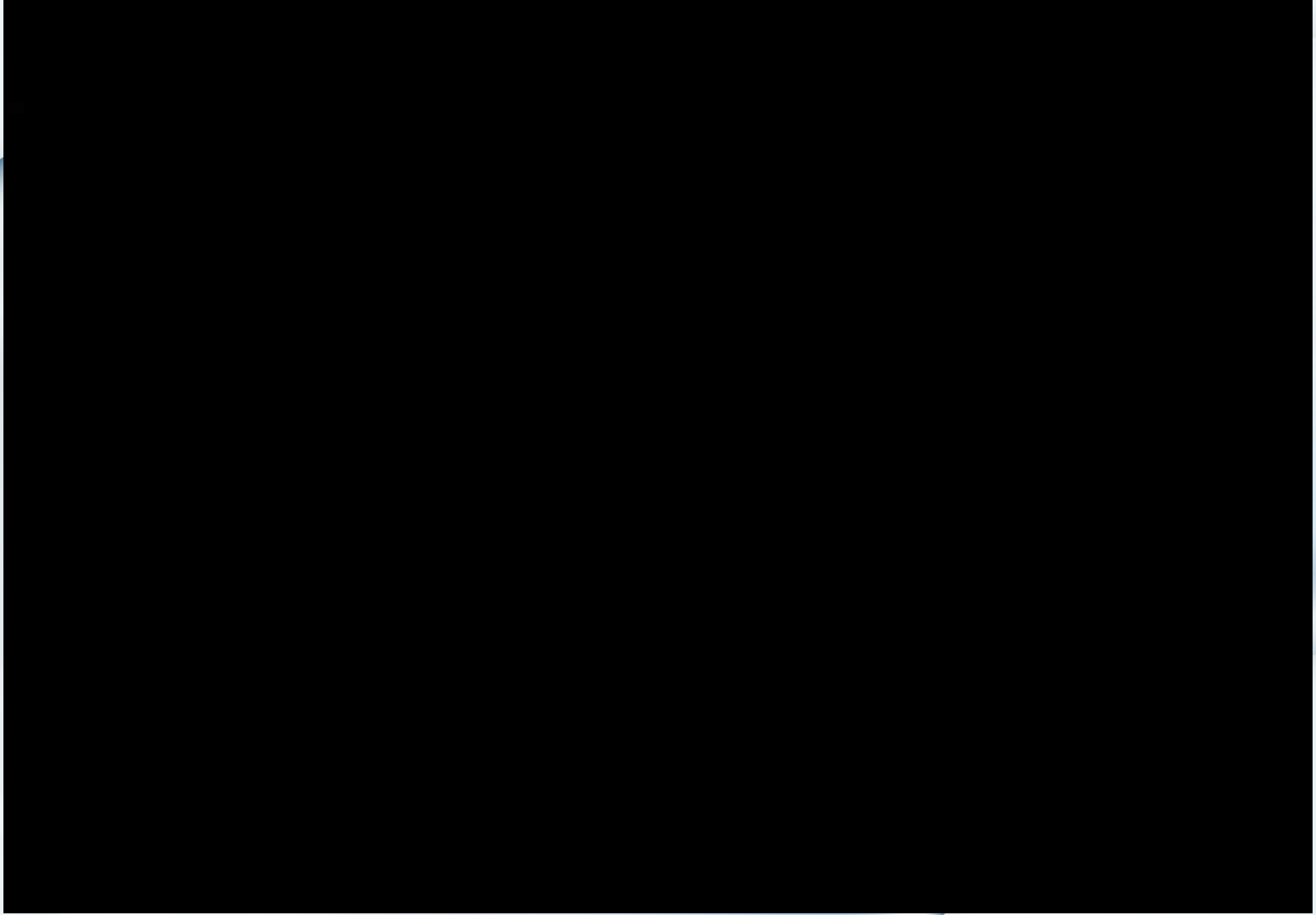
Gel Nose Model

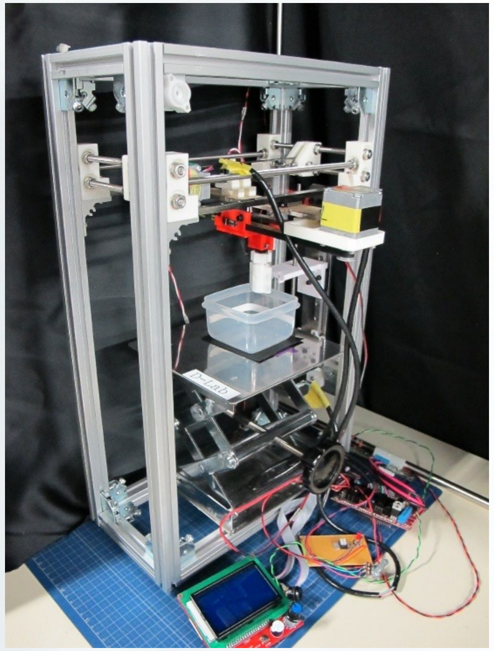


Lattice shaped Gel

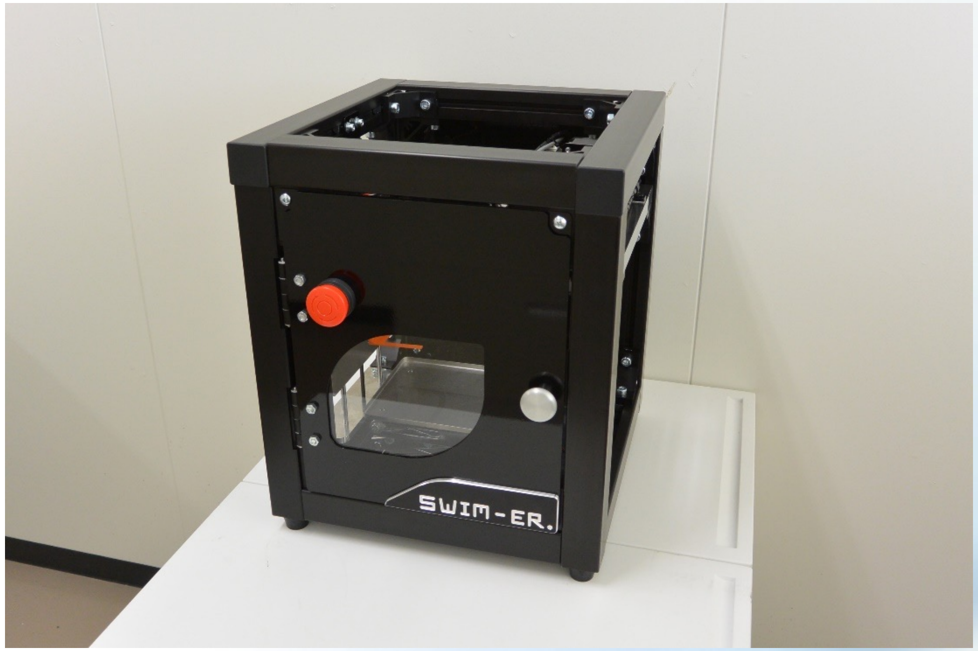
Concept of GelPiPer



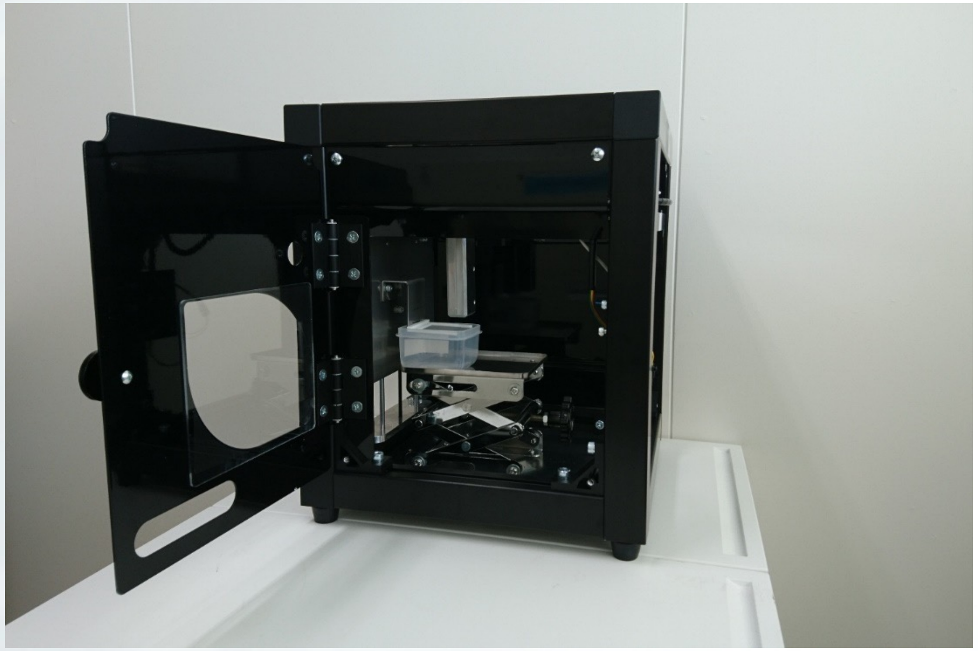




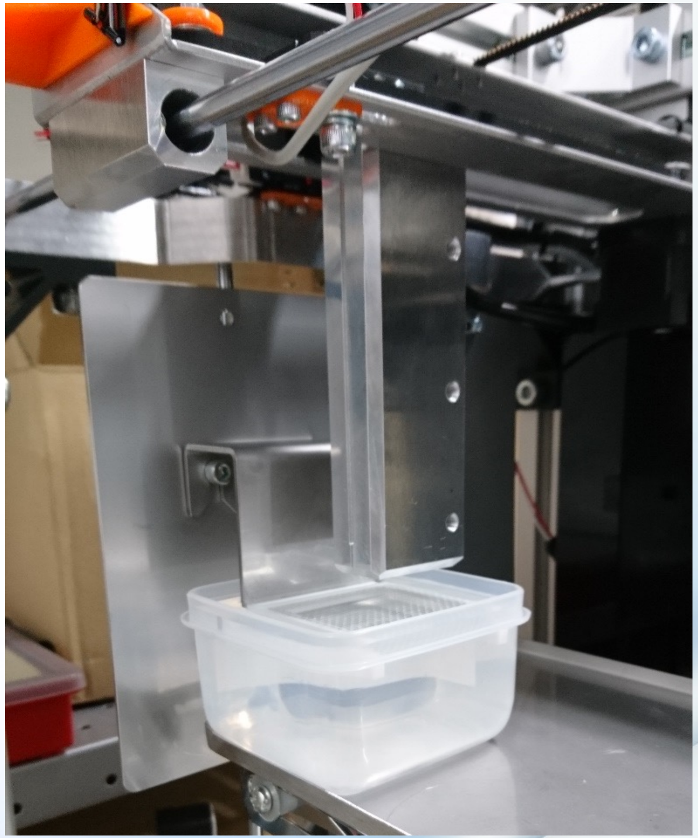
Prototypes



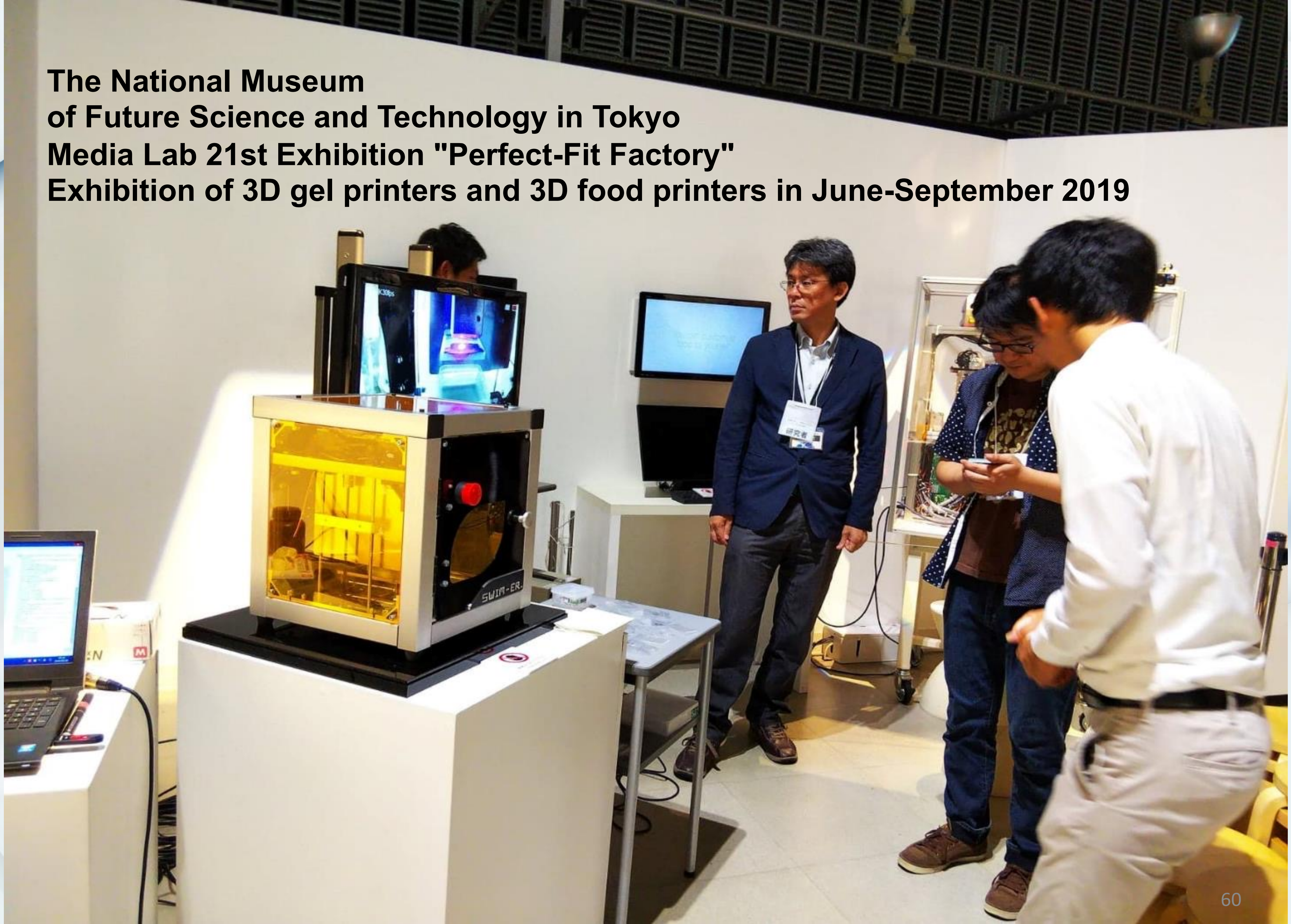
Equipment exhibited at The National Museum of Future Science and Technology



Opening the door



Enlargement of
the modeling part



**The National Museum
of Future Science and Technology in Tokyo
Media Lab 21st Exhibition "Perfect-Fit Factory"
Exhibition of 3D gel printers and 3D food printers in June-September 2019**

3D Gel Printer

3D Food Printer
(Dual nozzle type)

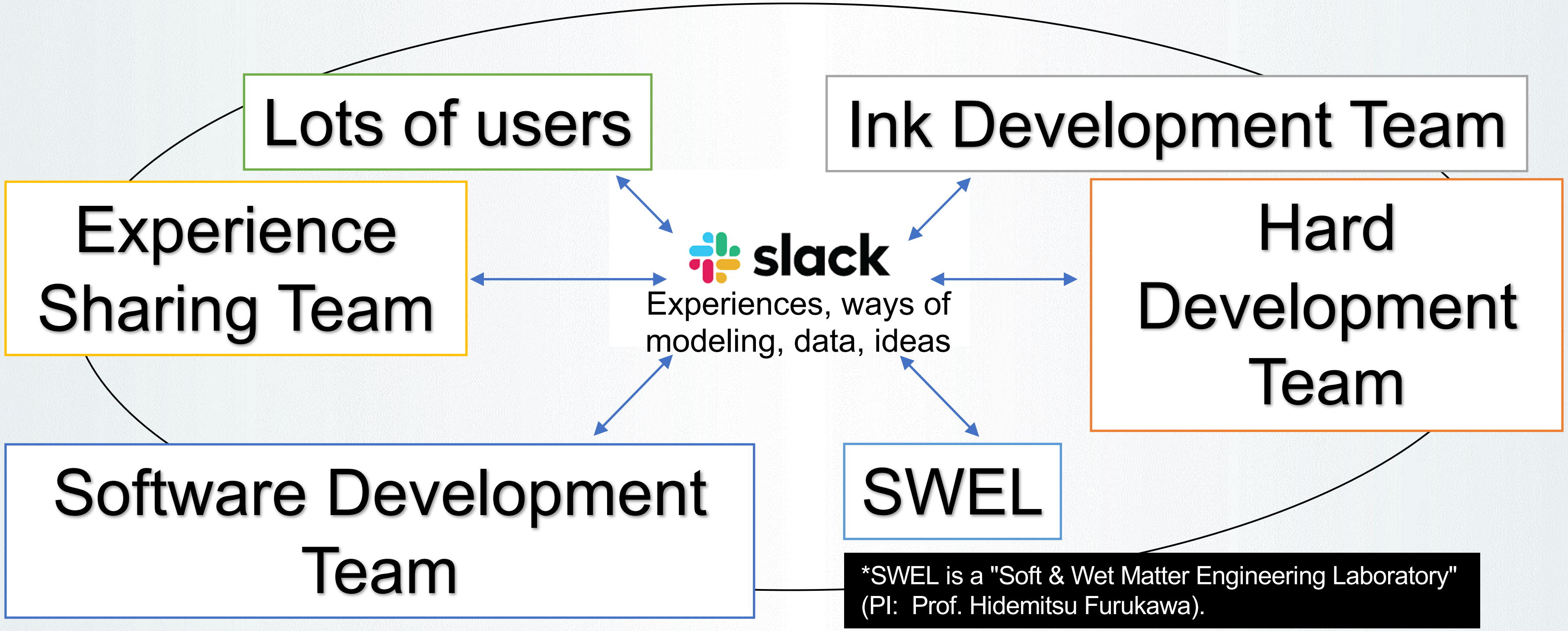
Soft Robot (AI)
Gerhachiko

Gel Jellyfish
Robot

Monodzukuri World 2nd Next Generation 3D Printer Exhibition @ Makuhari Messe
February 26-28, 2020 Soft 3D Co-Creation Consortium

GelPiper Program Overview

Open Innovation Community
→ Soft 3D Co-Creation Consortium Members and University Labs

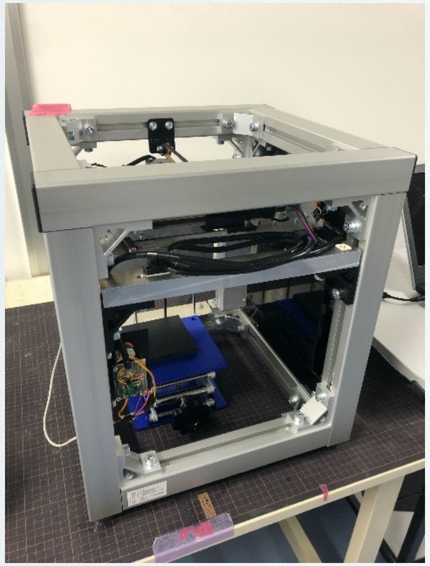


Users and development teams share experiences, molding methods, data, and ideas with each other. We aim to co-create hardware, software, ink, and content.

About the offer set

Image of the offer set

GelPiper™ 1 × unit



Ink 300ml×1,2 pieces

<u>Rental period</u>

No particular settings. At first, it's about 1-3 months.

<u>GelPiper™</u>

<u>Size of the device body</u>

Width: 380mm

Depth: 355mm

Height: 430mm

<u>Size of the model (maximum)</u>

150mm×150mm×150mm

<u>Molding method:</u> Light curing and bathtub method using low-power laser

<u>Software:</u> Use RepRap open source

YAWARAKA 3D
Soft 3D Co Creation Consortium

GelPiper™ "Digital Pipeline of Gels"

A future where everyone can use "**soft manufacturing**".

This program aims to co-create this realization.

As if water were coming out **when I turned on the faucet of the water supply**,

GelPiper provides gels at the user's fingertips. What will happen then?

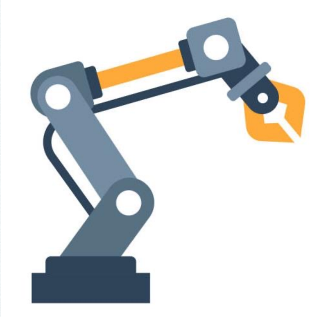
"Oh, gel is like this!" "It's not what I thought!" "It may be convenient"

Like this, a lot of **"!"** I think that happens.

Share that experience, what happened. From there, I noticed **"!"** I hope that it will spread.

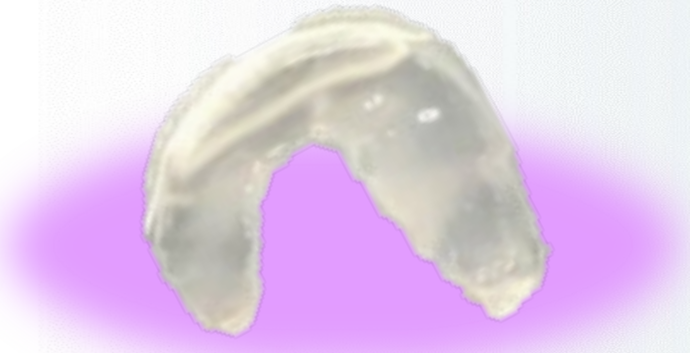
Companies and university labs in the Soft 3D Co-Creation Consortium will try GelPiper. There are a lot of **"!"** While enjoying with everyone, we aim to co-create the future where everyone can use soft manufacturing. **Thank you for your cooperation.**

Case Study of GelPiper's use



1) Food sample (created with ICN gel)
→ practice of robot for food pick-up
(Ritsumeikan University)

Gel Octopus Model



Gel Shrimp Model

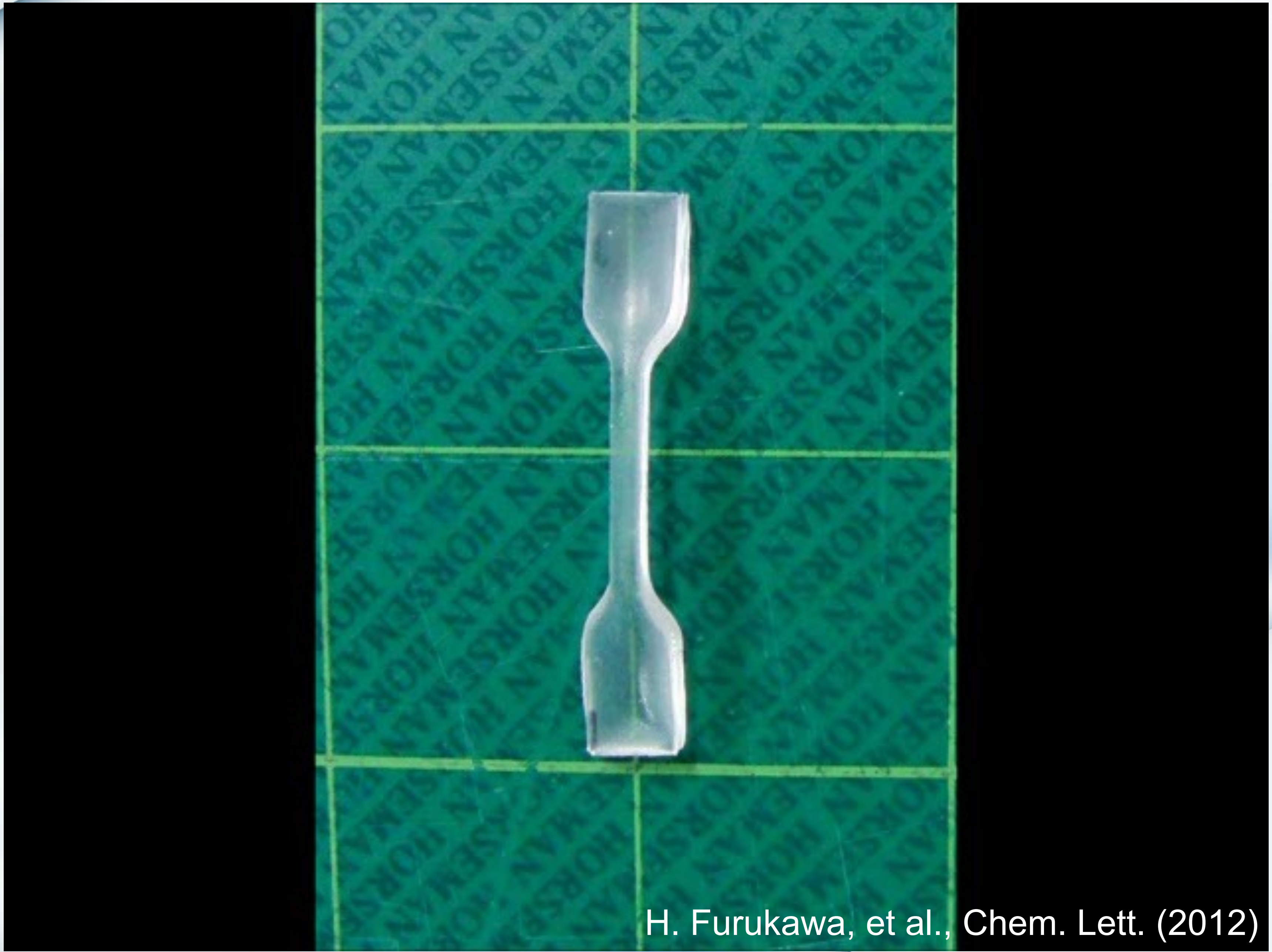
Example of "!" we noticed: It is better to be hard to grasp with a sly. People wants a variety. It leads to the device how to grasp it so that it does not crack if it is easy to crack.

2) Kidney model (created with P-DN gel) (Jikei Medical University Hospital)

Gel Kidney Model

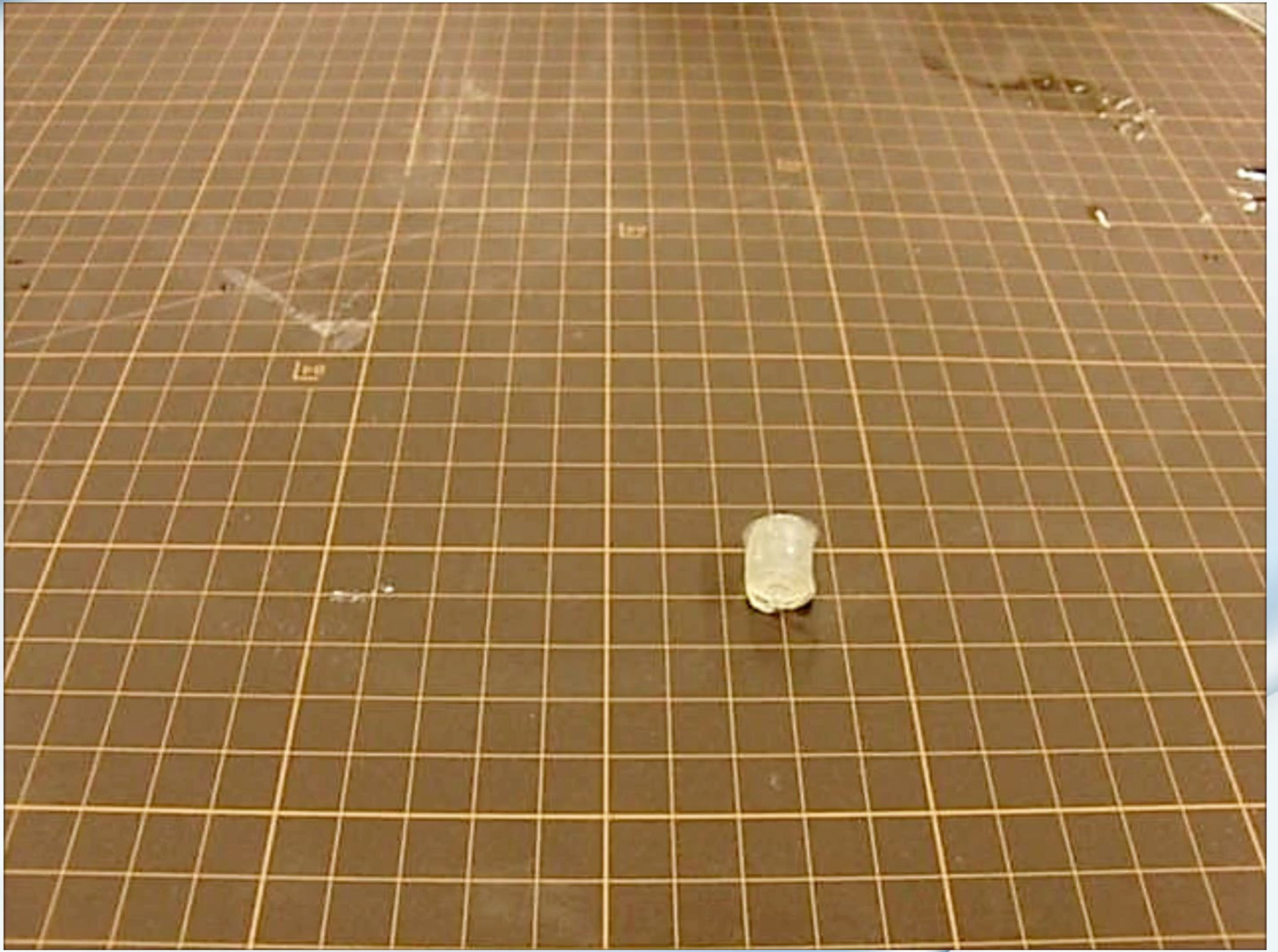
Example of “!” we noticed: It is good to cut with a scalpel casually. It doesn't matter what size you like. In some cases, it becomes large or deformed. If it is fragile, personal information will not be leaked.

Shape Memory Gels



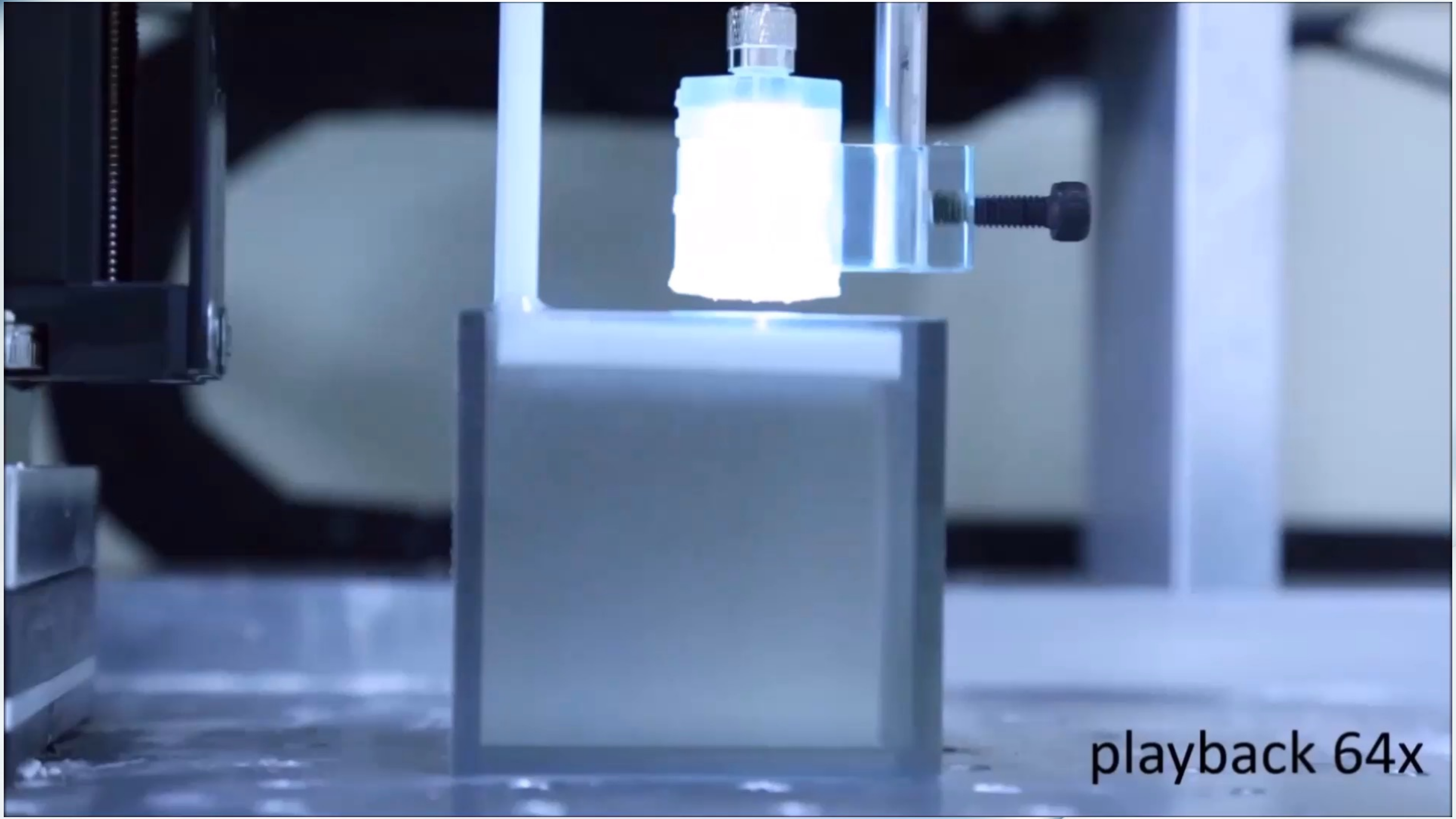
H. Furukawa, et al., Chem. Lett. (2012)

Gel Bandage



H. Furukawa, et al., Chem. Lett. (2012)

4D printing of Shape Memory Gels



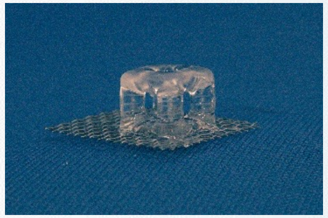
4D printing of Shape Memory Gels

Composition of two layers

Gel	DMAAm (M)	SA (M)	MBAA (mol%)	α-keto (mol%)	Kemisorp 11S (wt%)
SMG70-SA30	0.70	0.30	0.05	0.60	0.05
SMG90-SA10	0.90	0.10	0.05	0.60	0.05

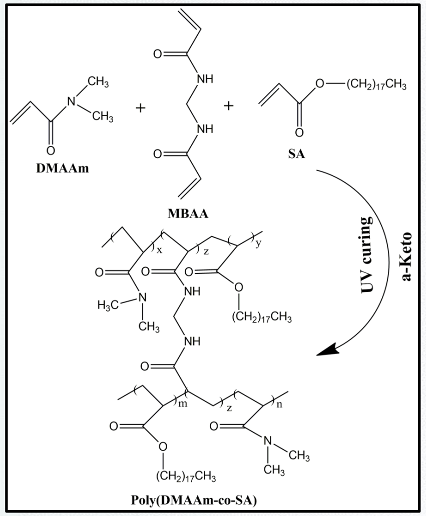
3D printing of Shape Memory Gels:
SMG70-SA30 and SMG90-SA10

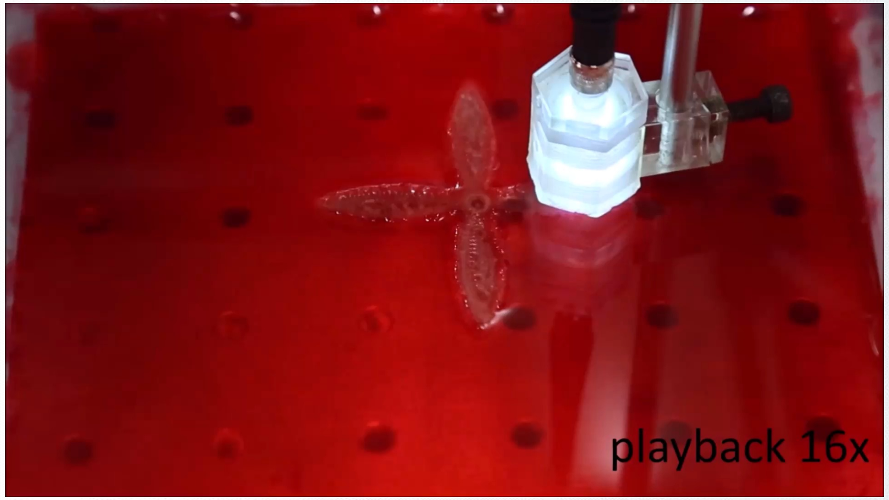
SMG70-SA30



SMG90-SA10

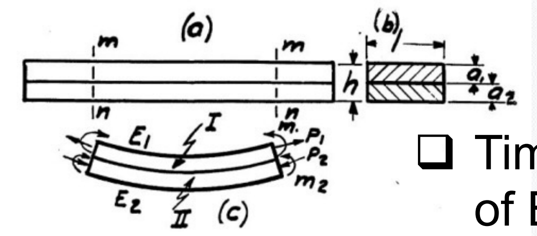
Reaction mechanism





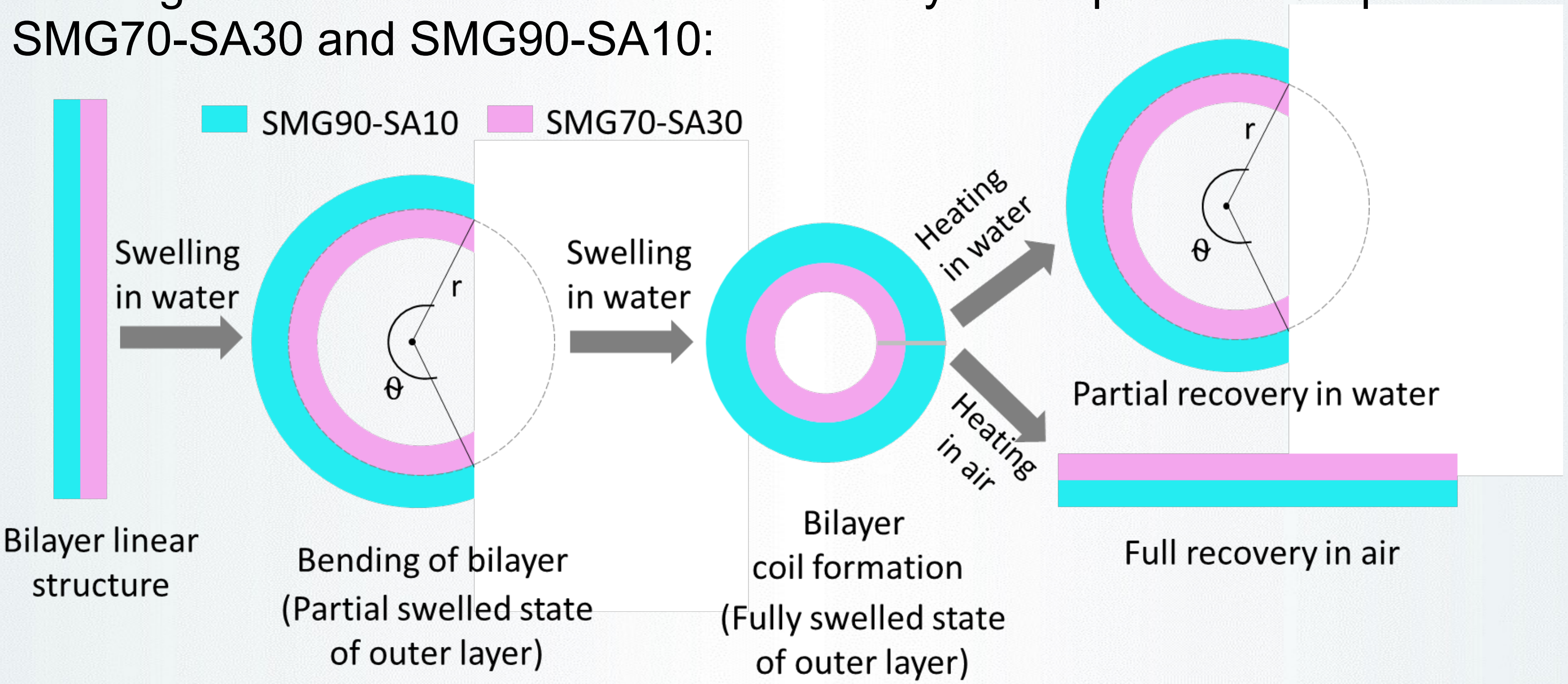
MD Nahin Islam Shiblee, Kumkum Ahmed, Masaru Kawakami, Hidemitsu Furukawa, "4D Printing of Shape Memory Hydrogels for Soft-Robotic Functions", *Adv. Mater. Technol.*, **4**, 1900071 (2019)

4D printing of Shape Memory Gels



- Timoshenko Model: 1925, Analysis of Bi-Metal Thermostats

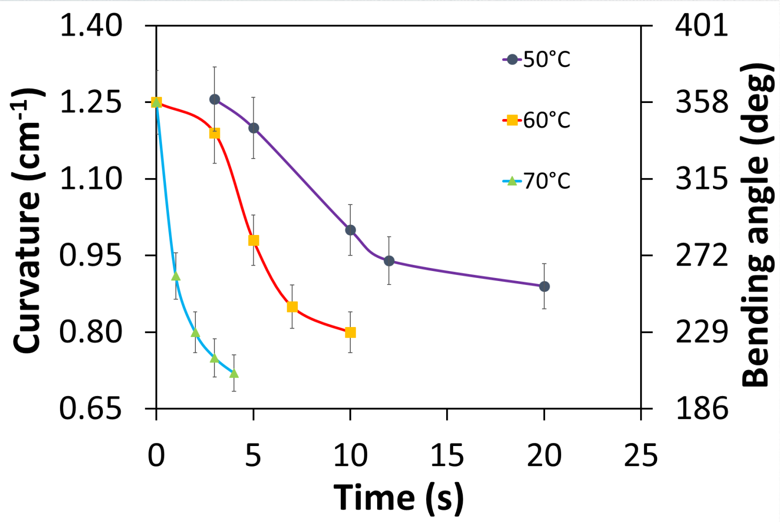
- Bending deformation mechanism of the bilayer composed of 3D printed SMG70-SA30 and SMG90-SA10:



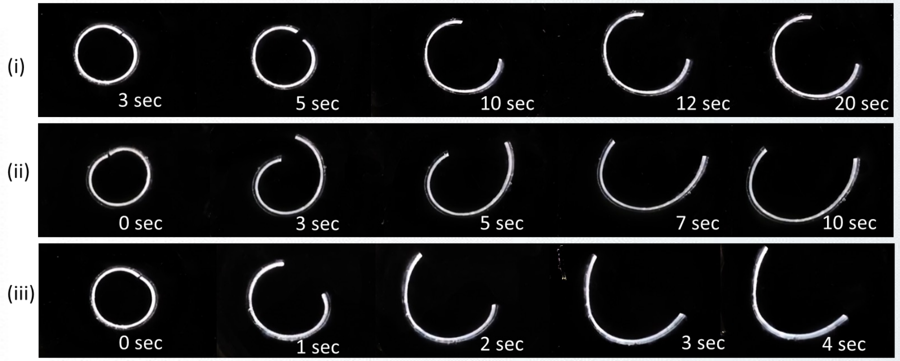
MD Nahin Islam Shiblee, Kumkum Ahmed, Masaru Kawakami, Hidemitsu Furukawa, "4D Printing of Shape Memory Hydrogels for Soft-Robotic Functions", *Adv. Mater. Technol.*, **4**, 1900071 (2019)

Behavior of 3D-Printed Bilayer Gels

Temperature dependent curvature during recovery as a function of time

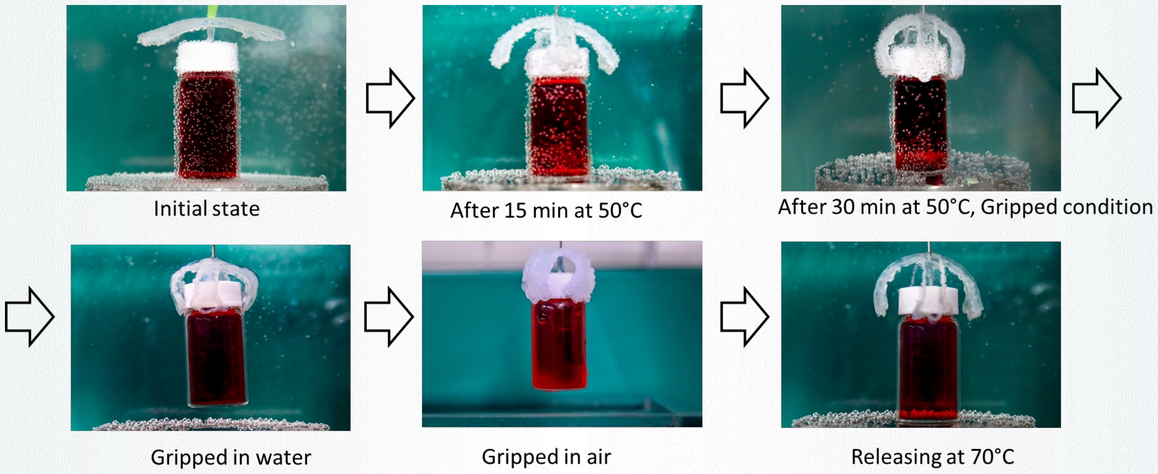


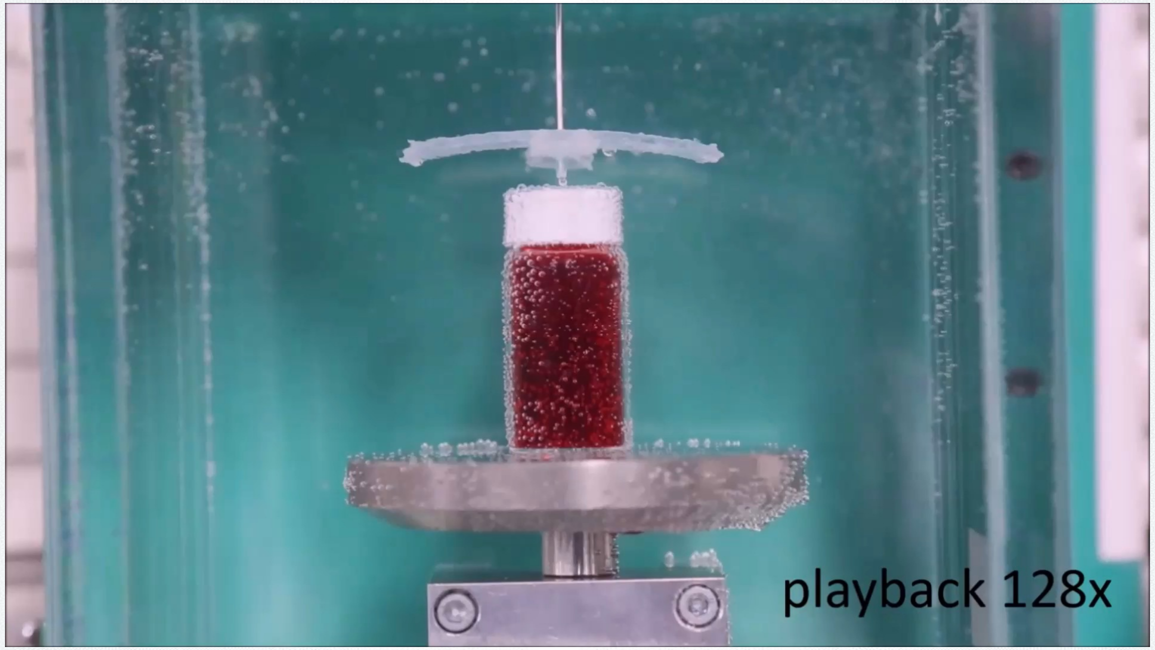
Recovery process of bilayer in water
i) 50 ℃ ii) 60 ℃ and iii) 70 ℃



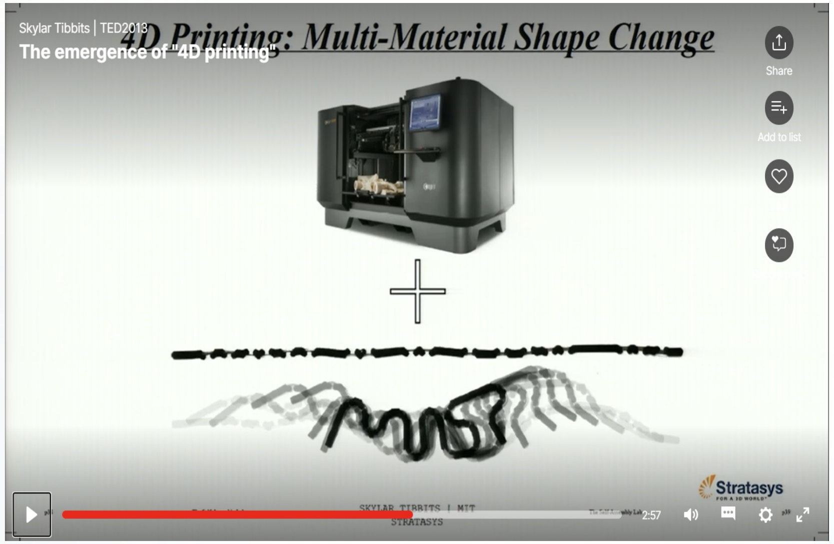
MD Nahin Islam Shiblee, Kumkum Ahmed, Masaru Kawakami, Hidemitsu Furukawa, "4D Printing of Shape Memory Hydrogels for Soft-Robotic Functions", *Adv. Mater. Technol.*, **4**, 1900071 (2019)

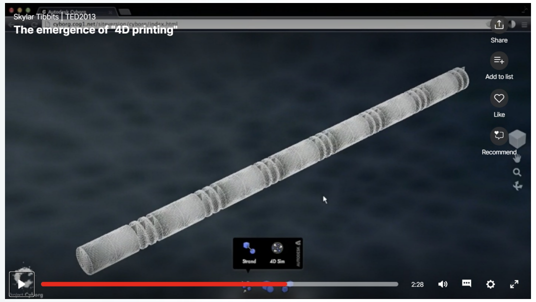
4D-Printed Gel Gripper

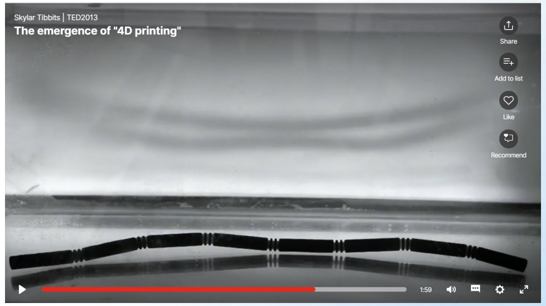


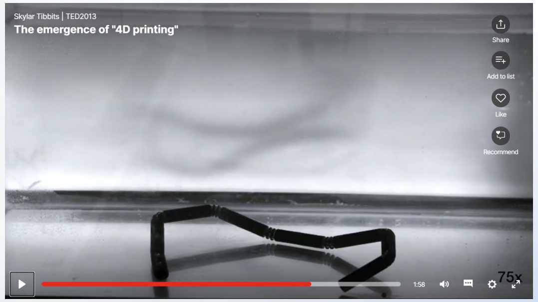


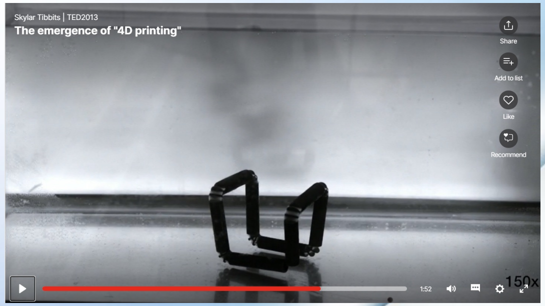
MD Nahin Islam Shiblee, et al., *Adv. Mater. Technol.*, **4**, 1900071 (2019)











https://www.ted.com/talks/skylar_tibbits_the_emergence_of_4d_printing

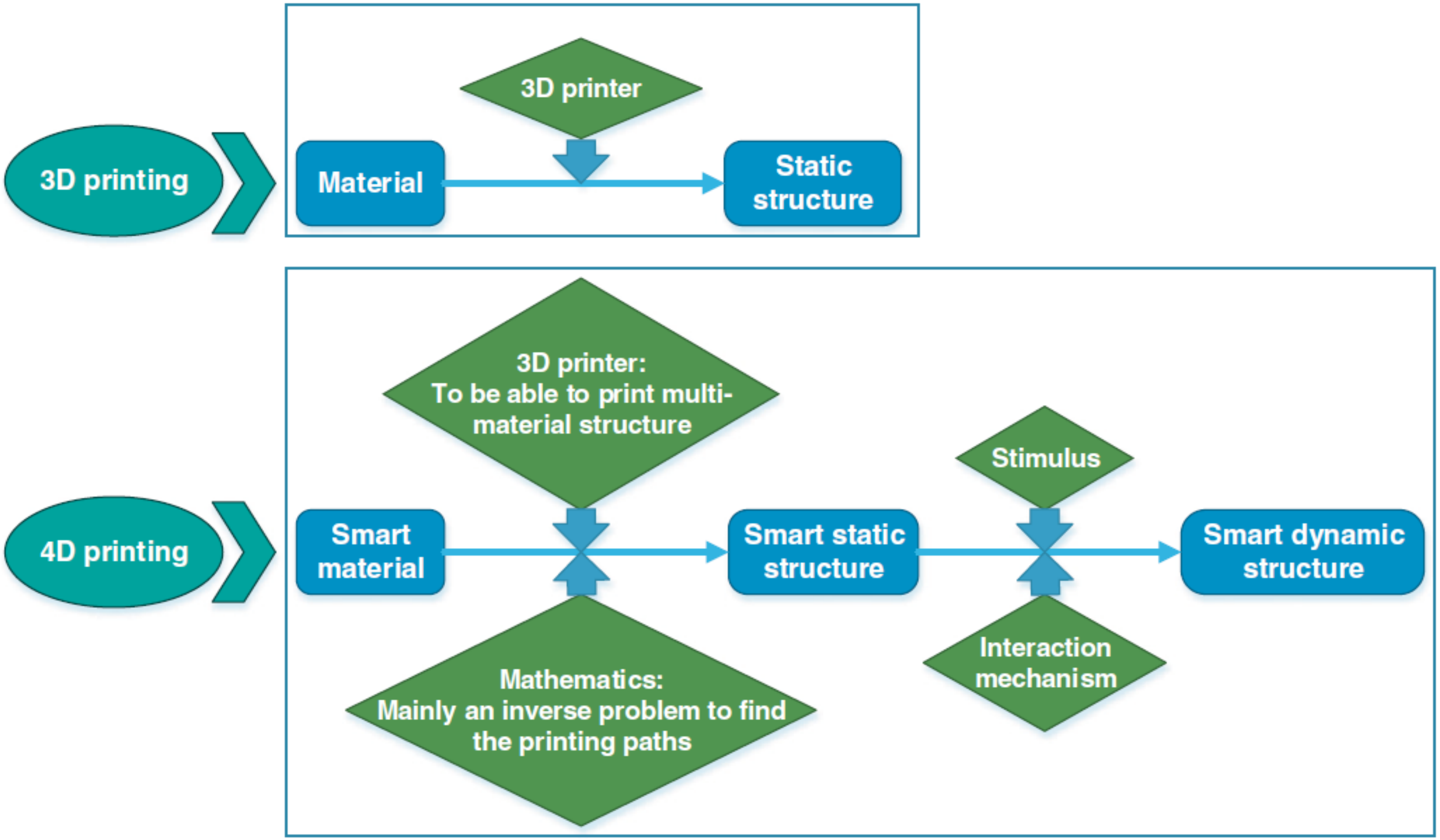


Fig. 2. The differences between 3D printing and 4D printing.

F. Momeni, S. M. M. Hassani. N, X. Liu, J. Ni, A review of 4D printing, Materials and Design 122, 42 (2017)

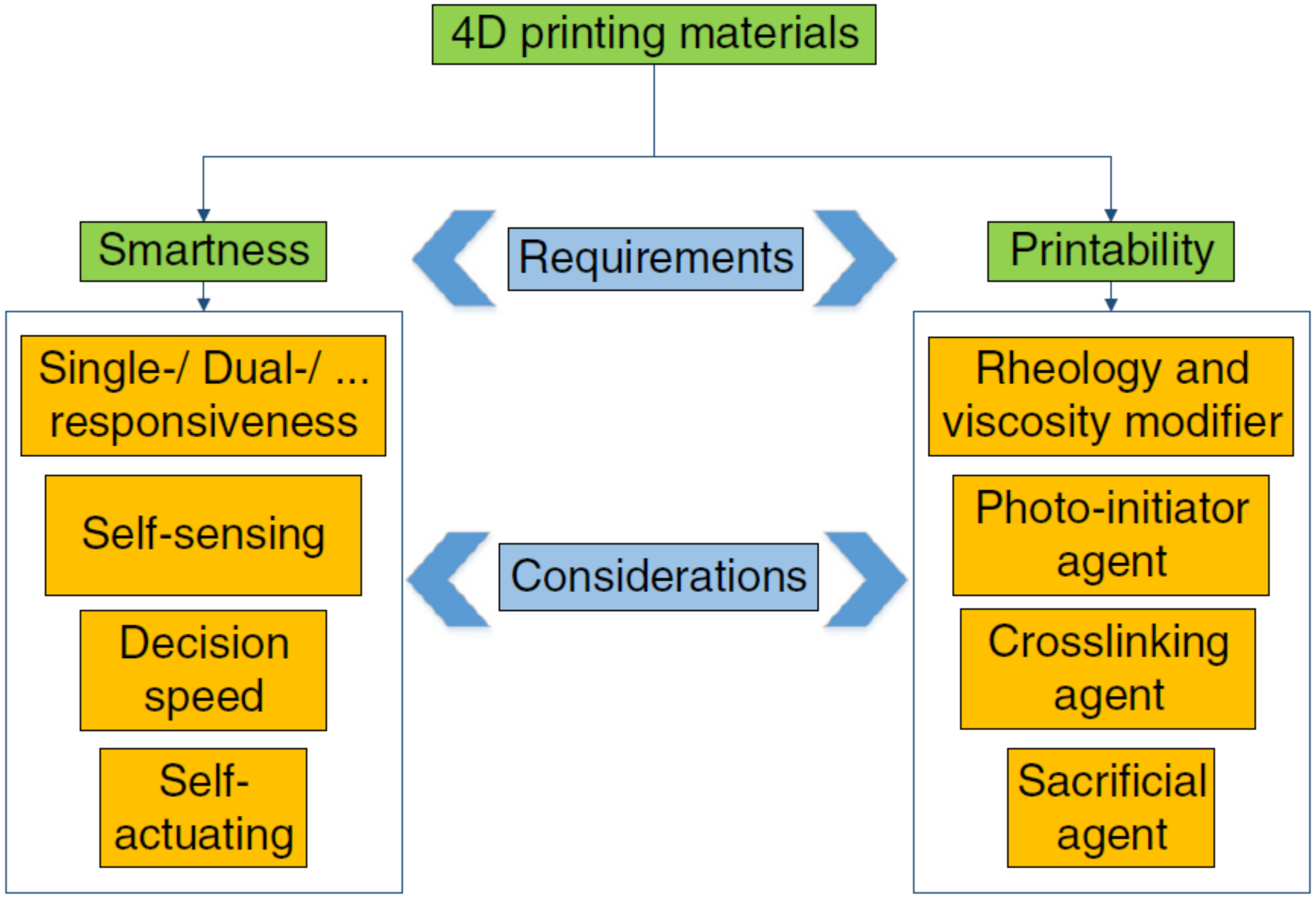


Fig. 50. 4D printing materials.

F. Momeni, S. M. M. Hassani. N, X. Liu, J. Ni, A review of 4D printing, Materials and Design 122, 42 (2017)

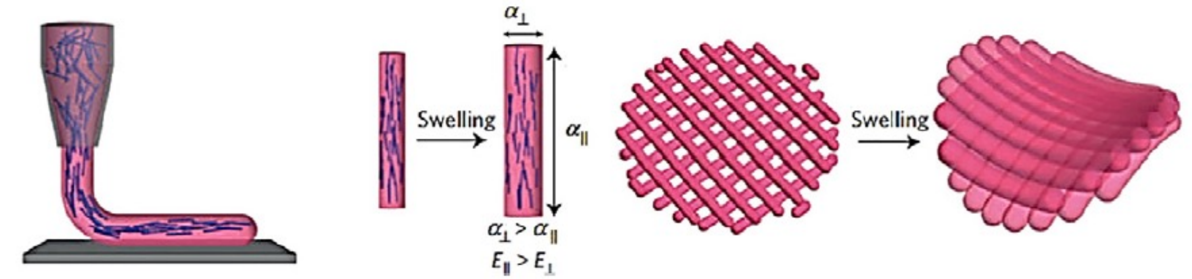


Fig. 65. Longitudinal and transverse swelling strains ($\alpha_\parallel$ and $\alpha_\perp$), (Gladman et al. [10]).

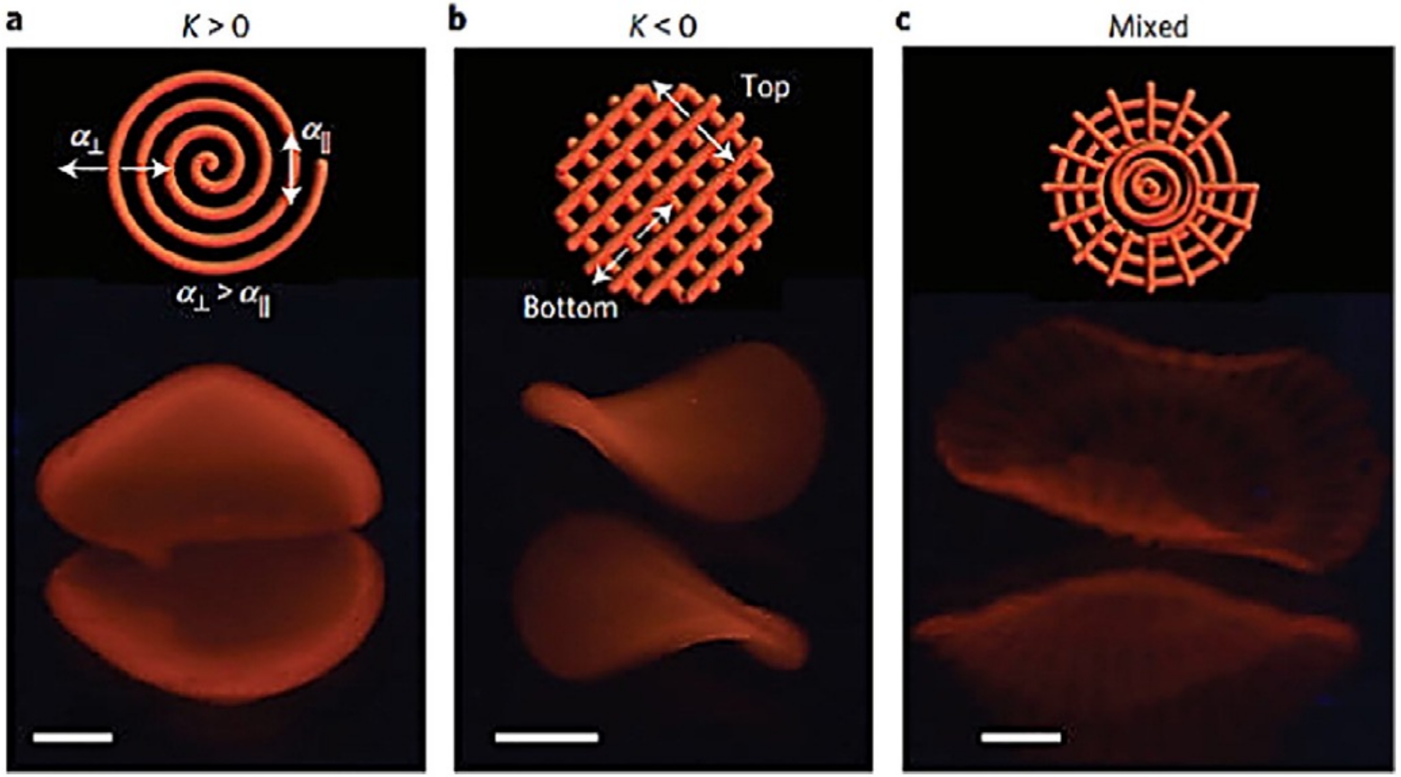


Fig. 66. Print paths and final shapes (a) positive Gaussian curvature (b) negative Gaussian curvature (c) and varying Gaussian curvature (Gladman et al. [10]).

A. S. Gladman, E. A. Matsumoto, R. G. Nuzzo, L. Mahadevan, J. A. Lewis, Biomimetic 4D printing, Nat. Mater. 15, 413 (2016)

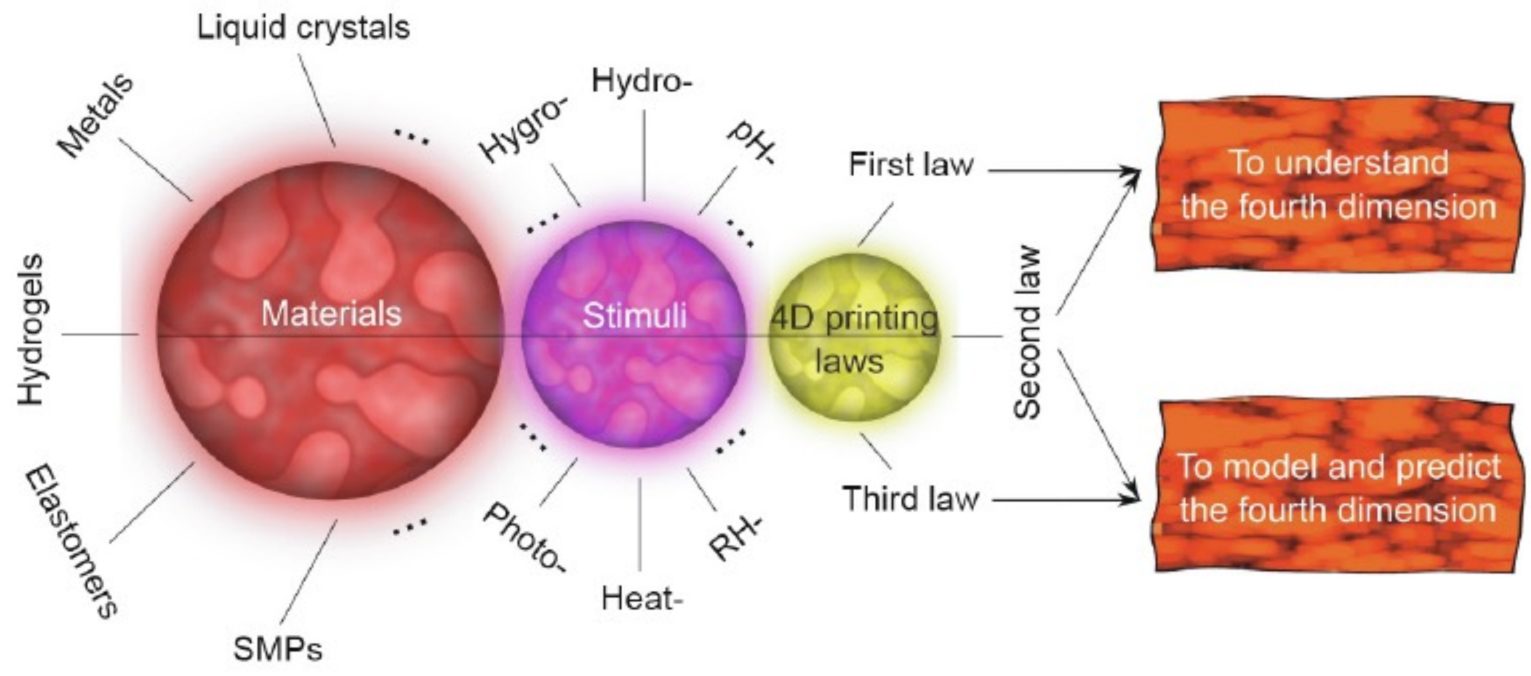
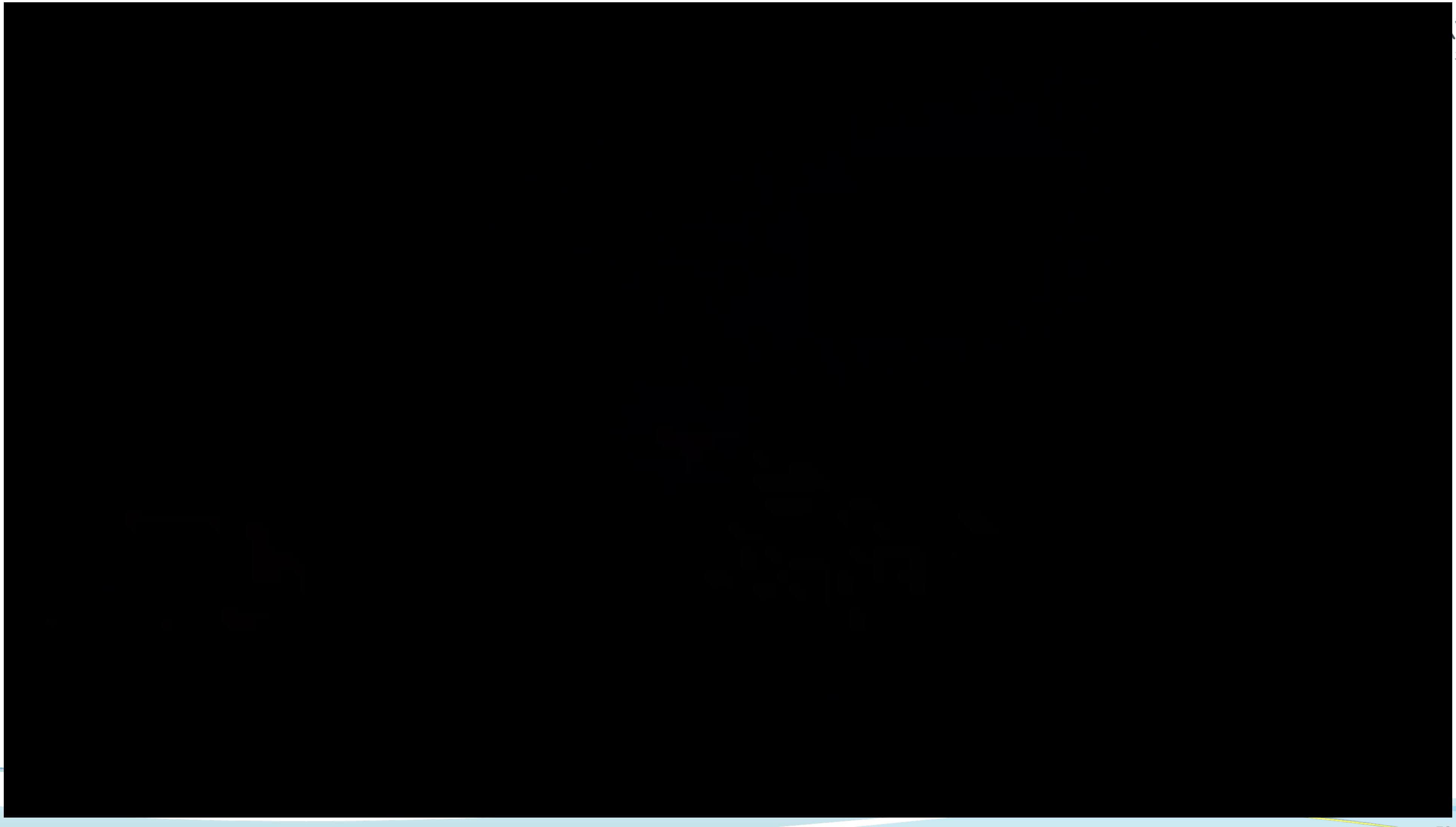


Fig. 1. Toward 4D printing laws. RH: relative humidity.

F. Momeni, J. Ni, Laws of 4D Printing, Engineering, 6 1035 (2020)

AWARAKA 3D
3D Co-Creation Consortium



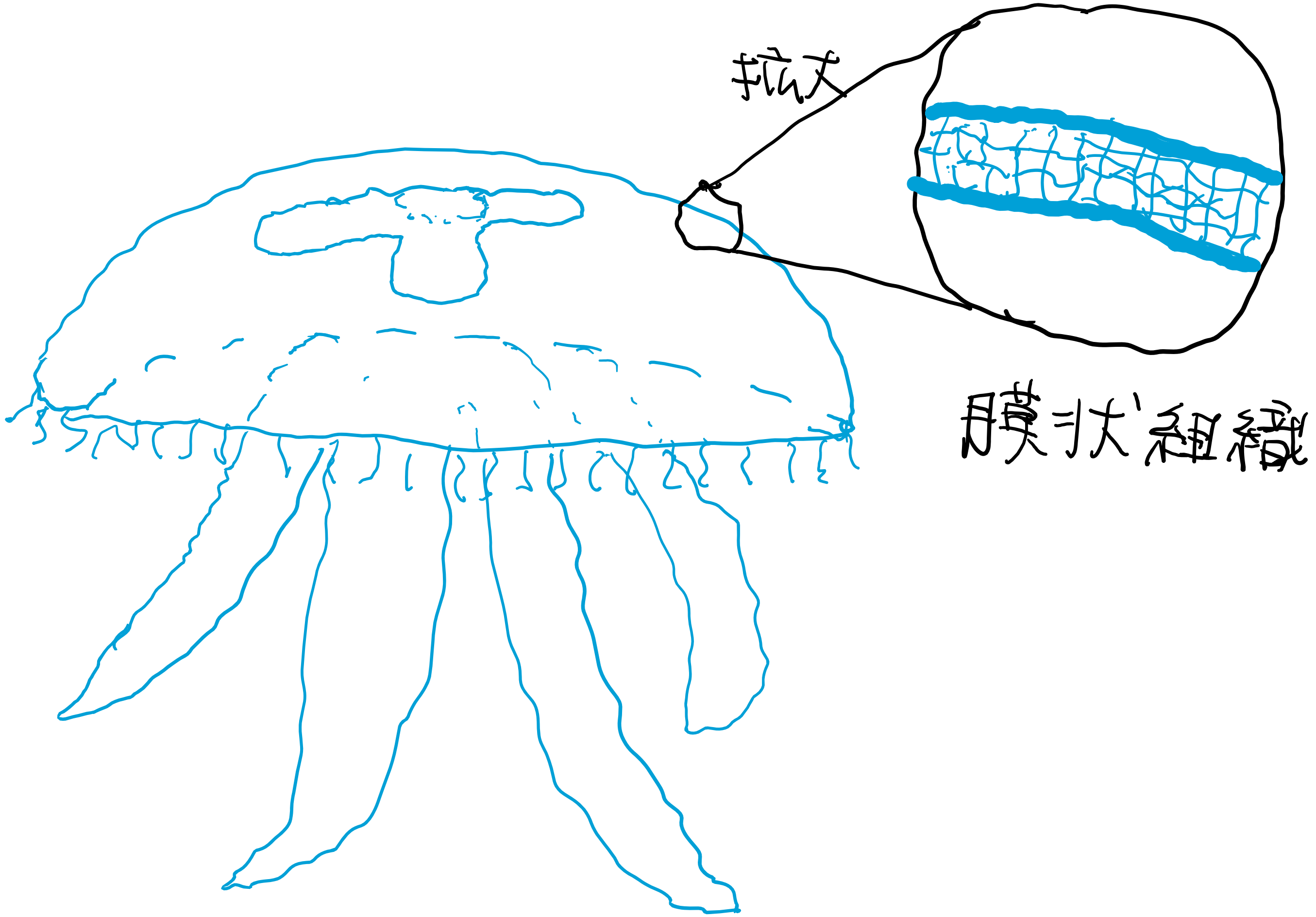


図1 ミズクラゲの傘の膜状構造。水ふうせんのようになっていて大きく変形できる。

Beal, D. N., et al. "Passive propulsion in vortex wakes." Journal of Fluid Mechanics 549 (2006): 385-402.

YAWARAKA 3D
Soft 3D Co-Creation Consortium

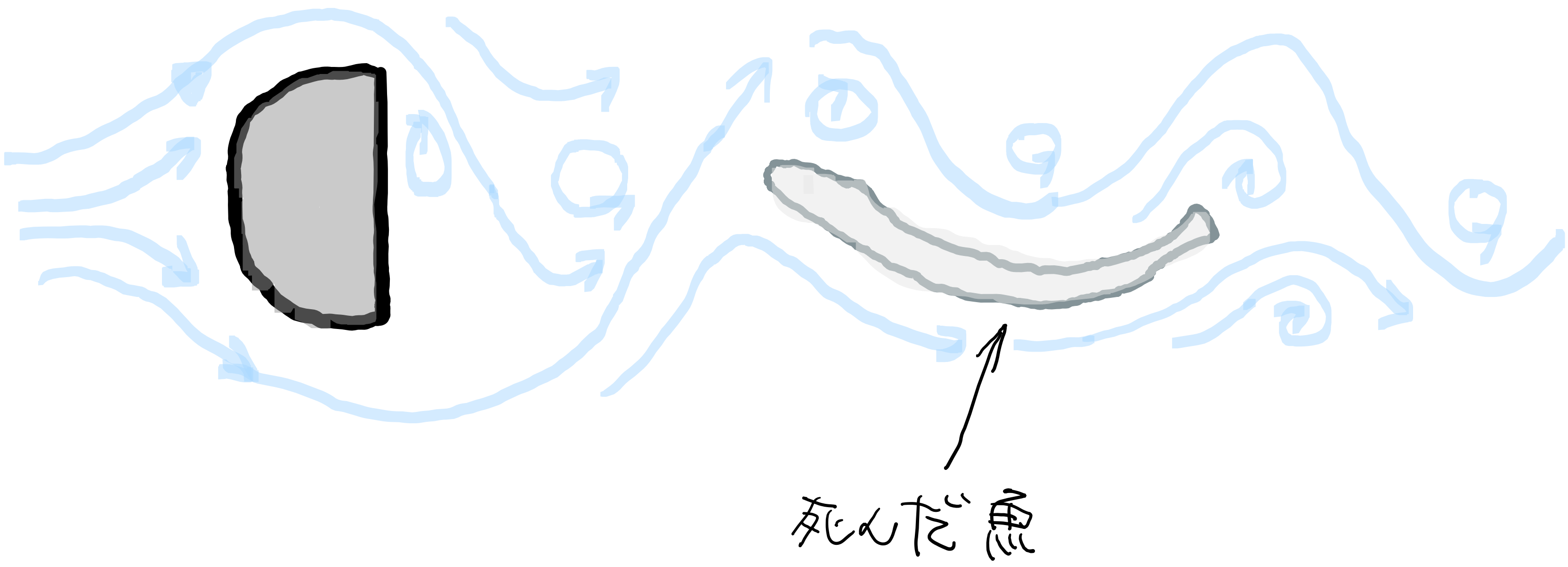


図2　乱流を起こした流れの中に死んだばかりの魚を入れるとまるで生きているかのように振舞う。

KAMO Aquarium in Yamagata (Oct. 2, 2019)

YAWARAKA 3D
Soft 3D Co-Creation Consortium


日本経済新聞
朝刊・夕刊 ストーリー Myニュース 日経会
トップ 速報 経済・金融 政治 ビジネス マーケット テクノロジー 国際 オピニオン スポーツ 社会・

有料会員限定 記事 今月の閲覧本数： 10 本中 2 本

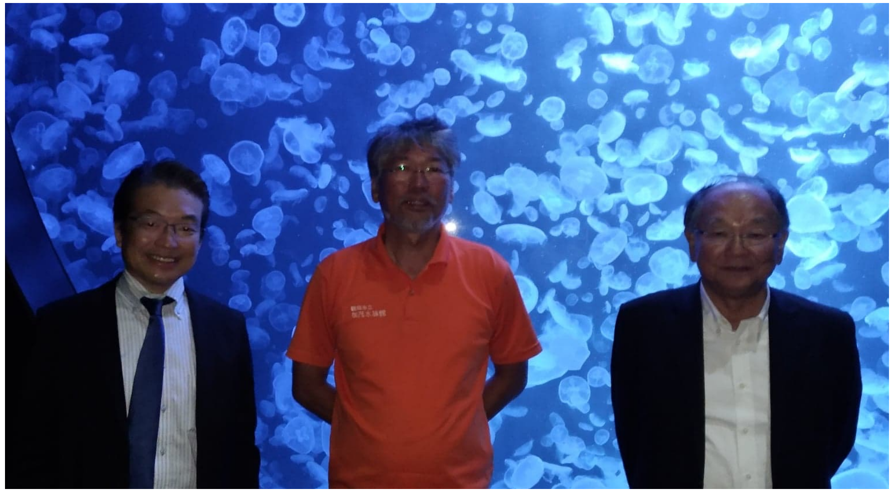
NDソフト、山形大学の技術で医療関連機器

2019/11/21 18:09|日本経済新聞　電子版

保存 共有 印刷 その他

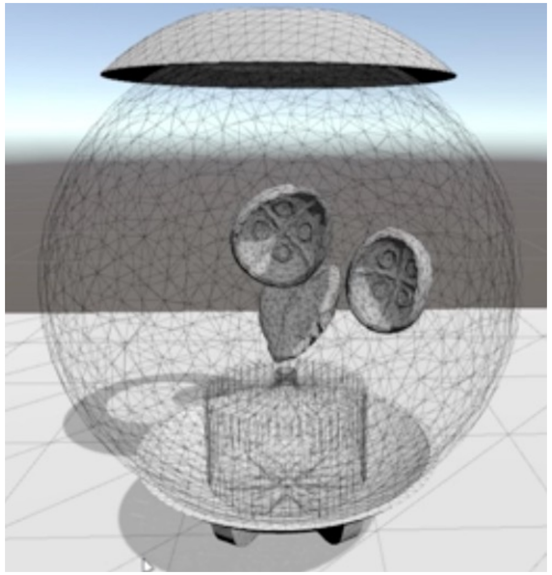
医療・介護ソフト大手のエヌ・デーソフトウェア（NDソフト、山形県南陽市）は山形大学の技術を使った医療関連機器を販売する。癒やしを与える人工クラゲ鑑賞装置や脈拍などを感知するセンサーなど4製品。今後は通信機器メーカーと在宅医療向けの遠隔診療装置なども開発する。介護現場の人手不足は深刻で、省力化につながる製品を中心にソフトからモノへ事業領域を広げる。

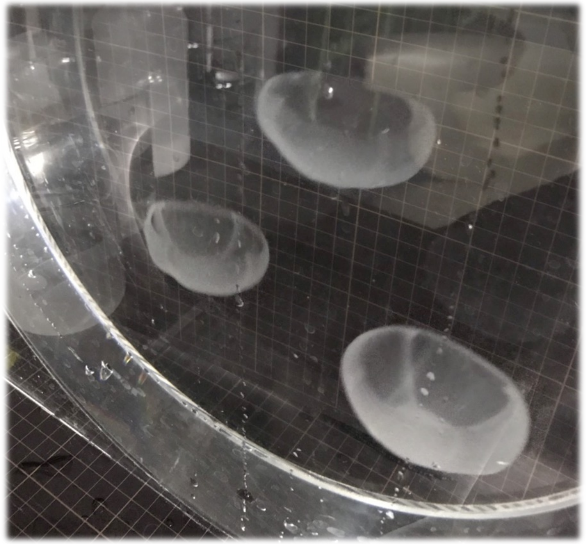
山形大の古川英光研究室と共同開発した「クラゲロボットシステム」は癒やしを与えるとして人気が出ているクラゲの動きを人工的に再現した。古川教授は柔らかいゲル状の物質を応用した研究で知られる。NDソフトが同システムを鑑賞装置として介護施設などに販売していく。

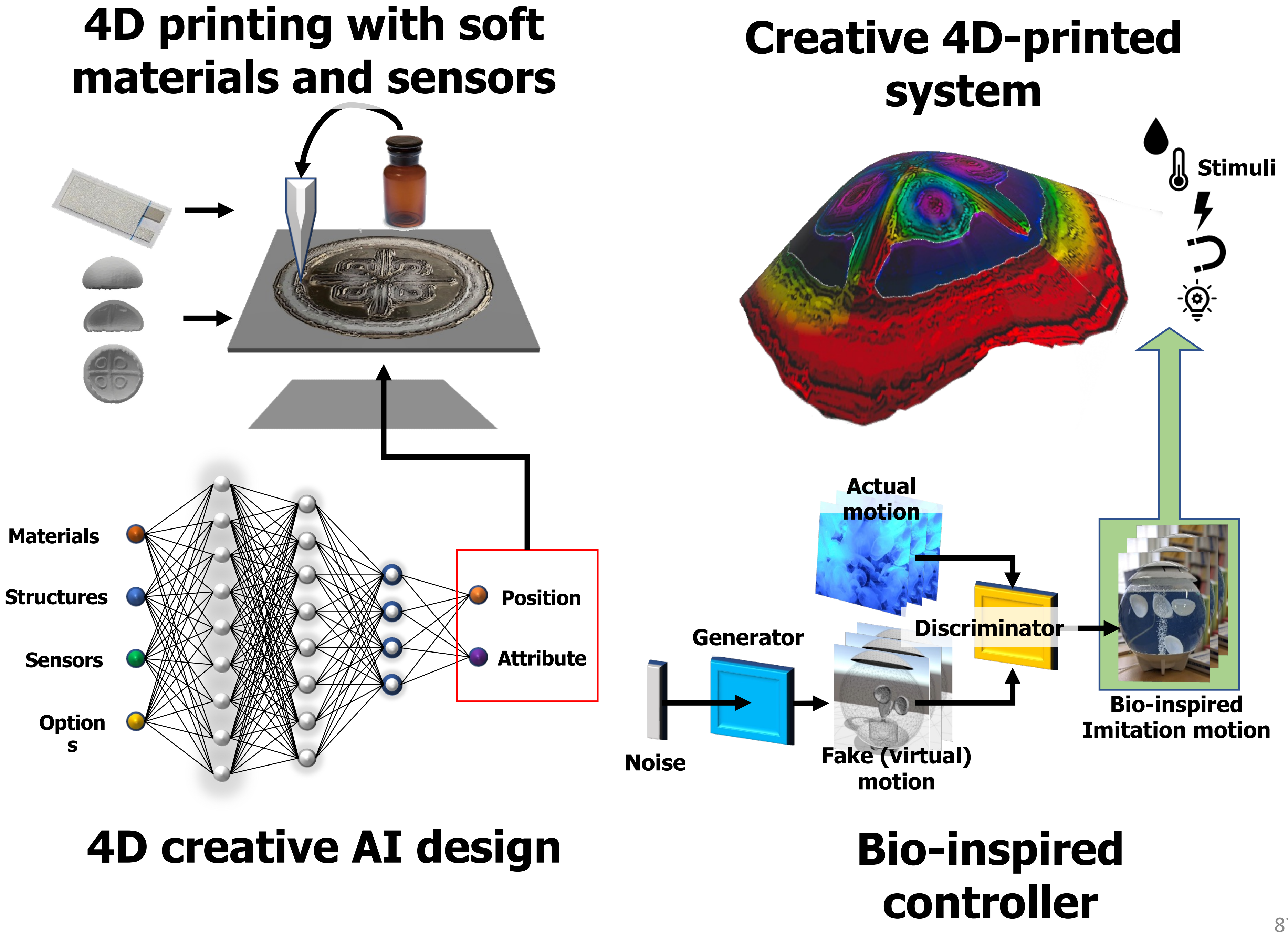


Being Sold in April, 2020

Digital Design and Analysis of Jelly Fish Gel Robot



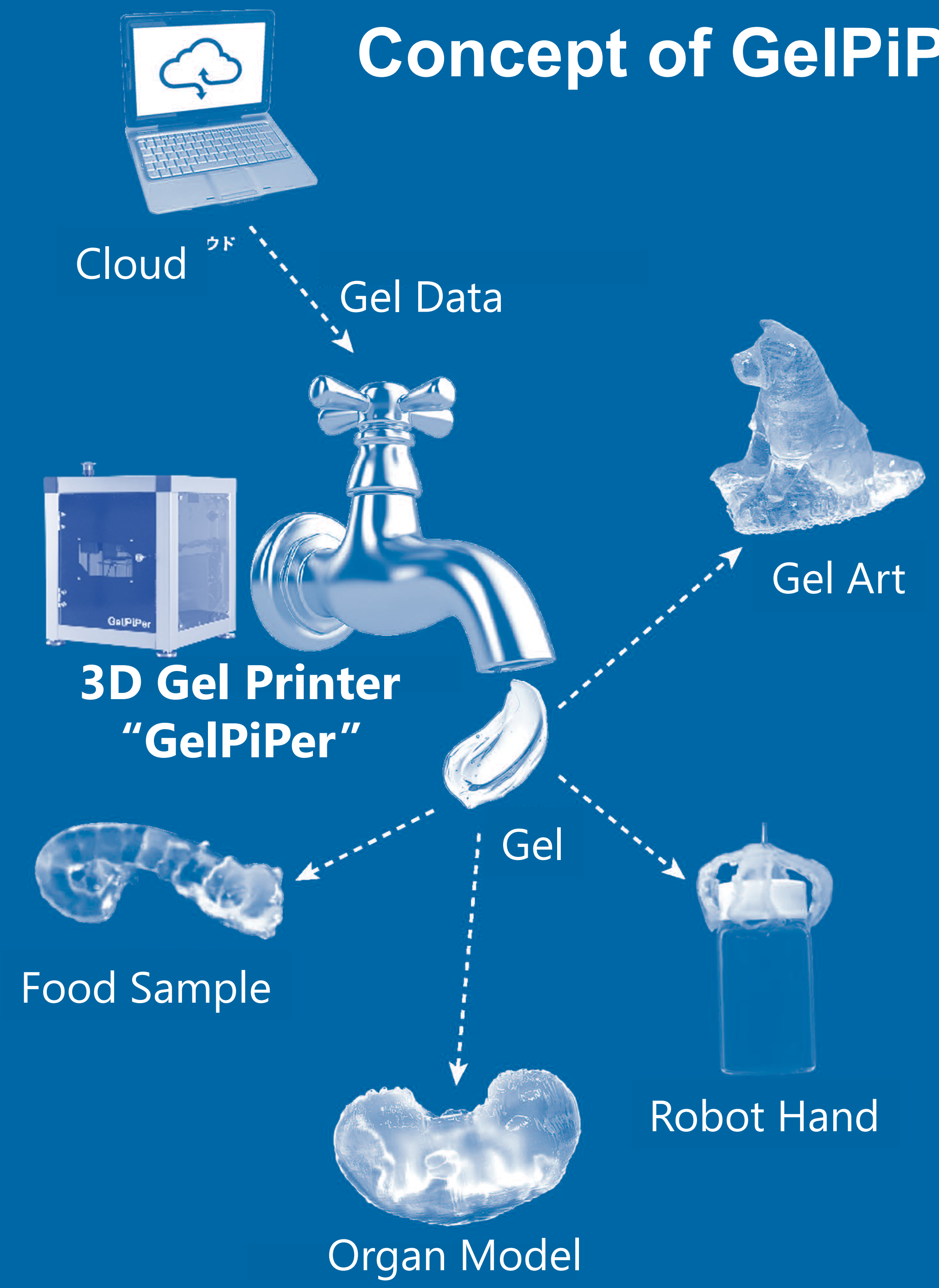



4D printing with soft materials and sensors
Creative 4D-printed system
Stimuli
Materials
Structures
Sensors
Option
s
Position
Attribute
Actual
motion
Generator
Discriminator
Noise
Fake (virtual)
motion
Bio-inspired
Imitation motion
4D creative AI design
Bio-inspired
controller

Gel Fullerene

YAWARAKA 3D
Soft 3D Co Creation Consortium

Concept of GelPiPer



YAMAGATA, JAPAN

END OF TALK

End of Talk

Soft matter Robotics

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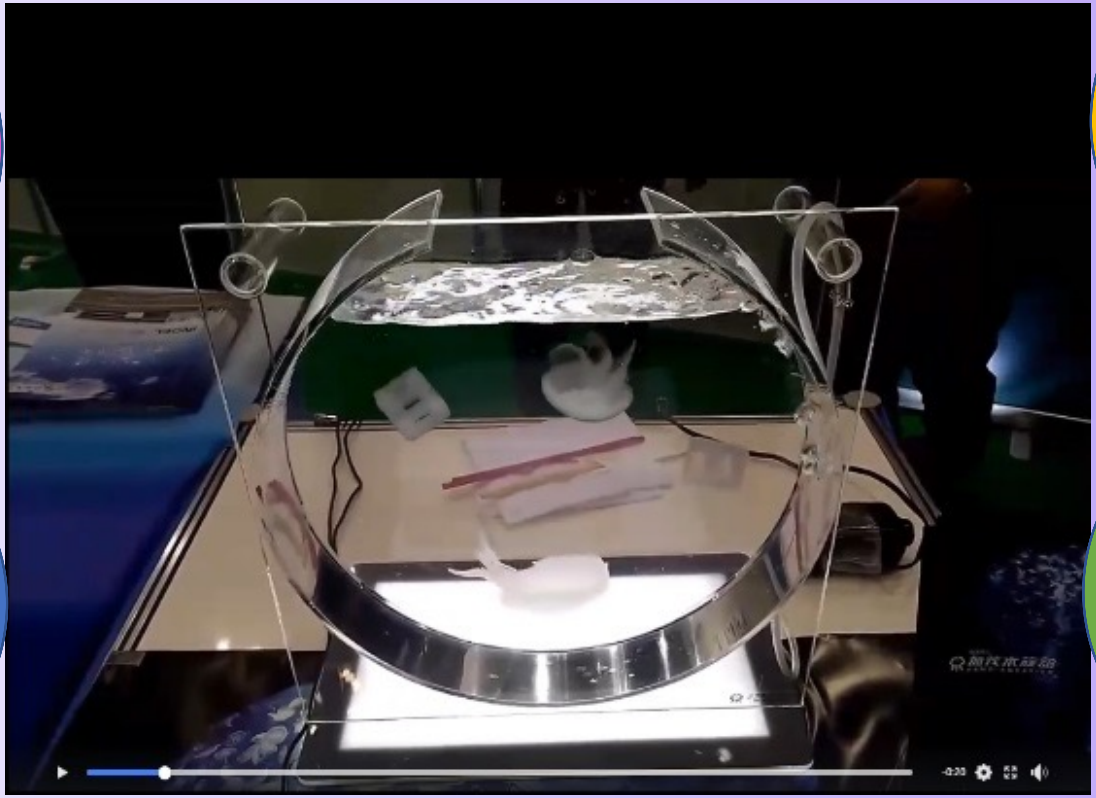
Guard
(IoT)



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Shopp
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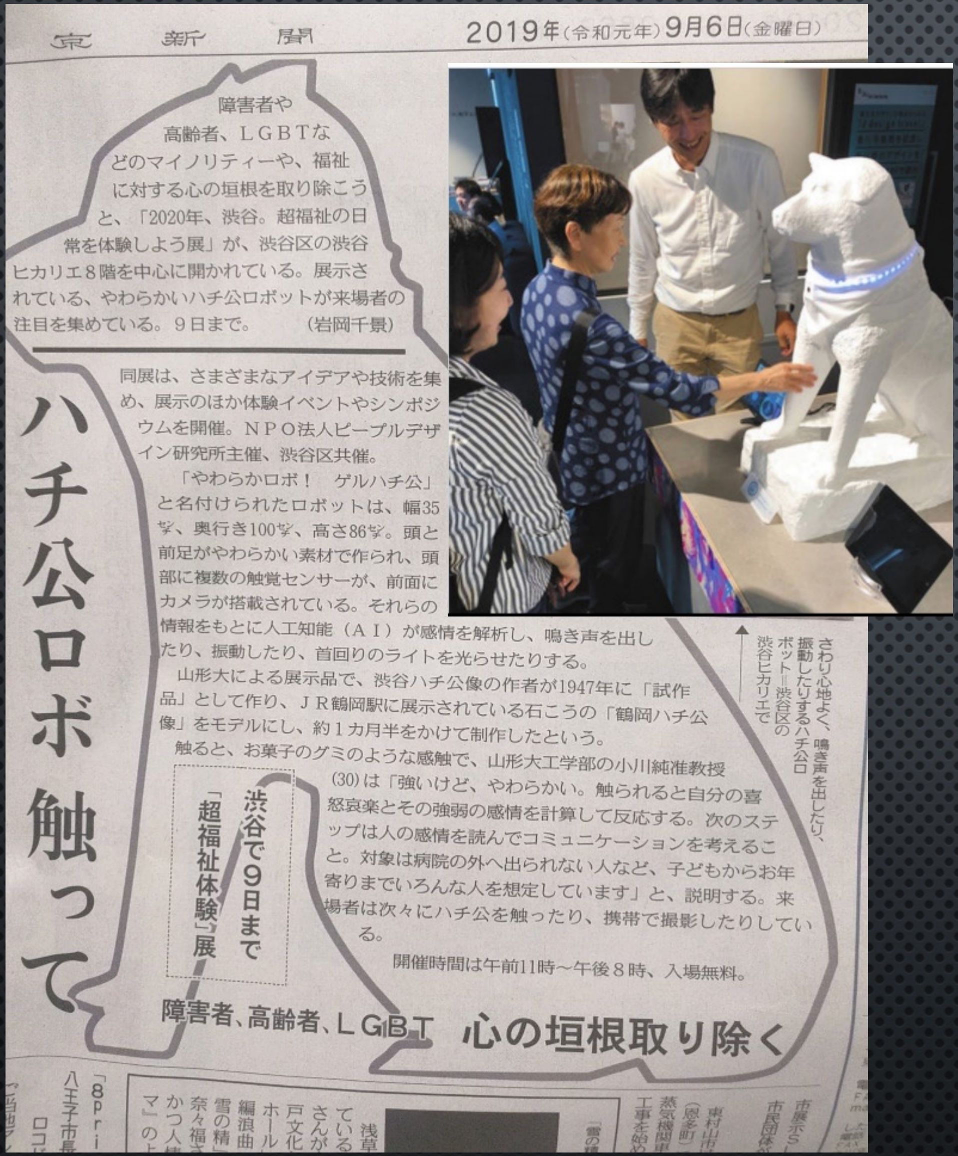
山形大学
Yamagata University



京新聞　2019年（令和元年）9月6日（金曜日）

障害者や高齢者、LGBTなどのマイノリティーや、福祉に対する心の垣根を取り除こうと、「2020年、渋谷。超福祉の日常を体験しよう展」が、渋谷区の渋谷ヒカリエ8階を中心に開かれている。展示されている、やわらかいハチ公ロボットが来場者の注目を集めている。9日まで。（岩岡千景）

ハチ公ロボ触って

渋谷で9日まで 「超福祉体験」展

同展は、さまざまなアイデアや技術を集め、展示のほか体験イベントやシンポジウムを開催。NPO法人ピープルデザイン研究所主催、渋谷区共催。

「やわらかロボ！　ゲルハチ公」と名付けられたロボットは、幅35㌢、奥行き100㌢、高さ86㌢。頭と前足がやわらかい素材で作られ、頭部に複数の触覚センサーが、前面にカメラが搭載されている。それらの情報をもとに人工知能（AI）が感情を解析し、鳴き声を出したり、振動したり、首回りのライトを光らせたりする。

山形大による展示品で、渋谷ハチ公像の作者が1947年に「試作品」として作り、JR鶴岡駅に展示されている石こうの「鶴岡ハチ公像」をモデルにし、約1カ月半をかけて制作したという。

触ると、お菓子のグミのような感触で、山形大工学部の小川純准教授(30)は「強いけど、やわらかい。触られると自分の喜怒哀楽とその強弱の感情を計算して反応する。次のステップは人の感情を読んでコミュニケーションを考えること。対象は病院の外へ出られない人など、子どもからお年寄りまでいろんな人を想定しています」と、説明する。来場者は次々にハチ公を触ったり、携帯で撮影したりしている。

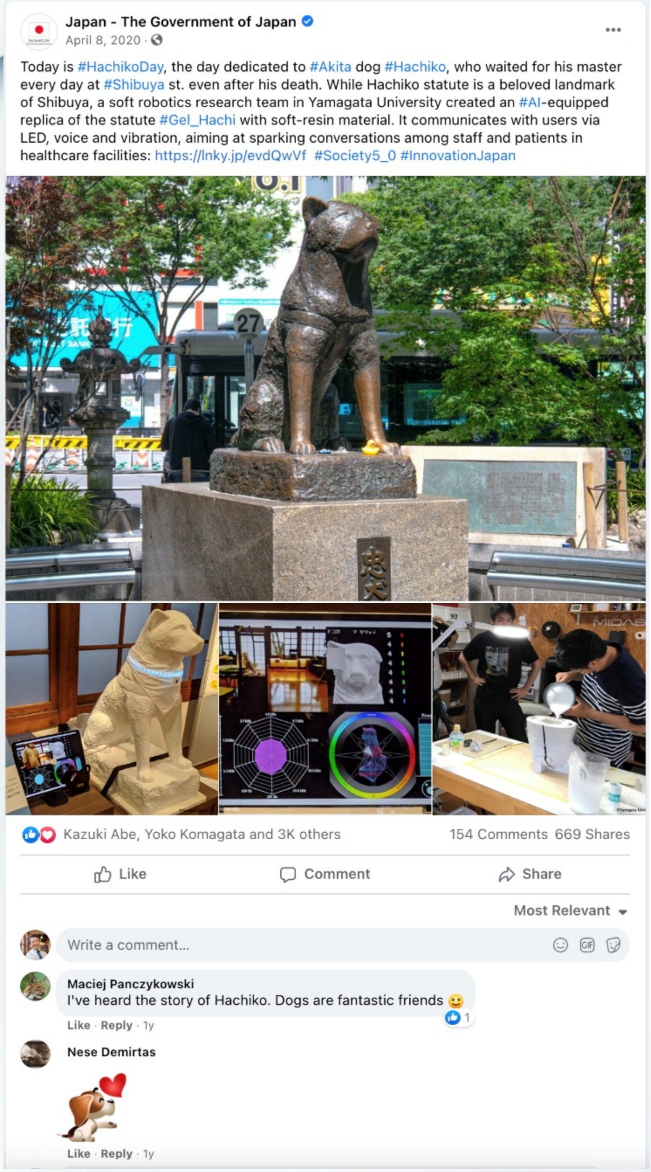
開催時間は午前11時～午後8時、入場無料。

さわり心地よく、鳴き声を出したり、振動したりするハチ公ロボット＝渋谷区の渋谷ヒカリエで

障害者、高齢者、LGBT　心の垣根取り除く

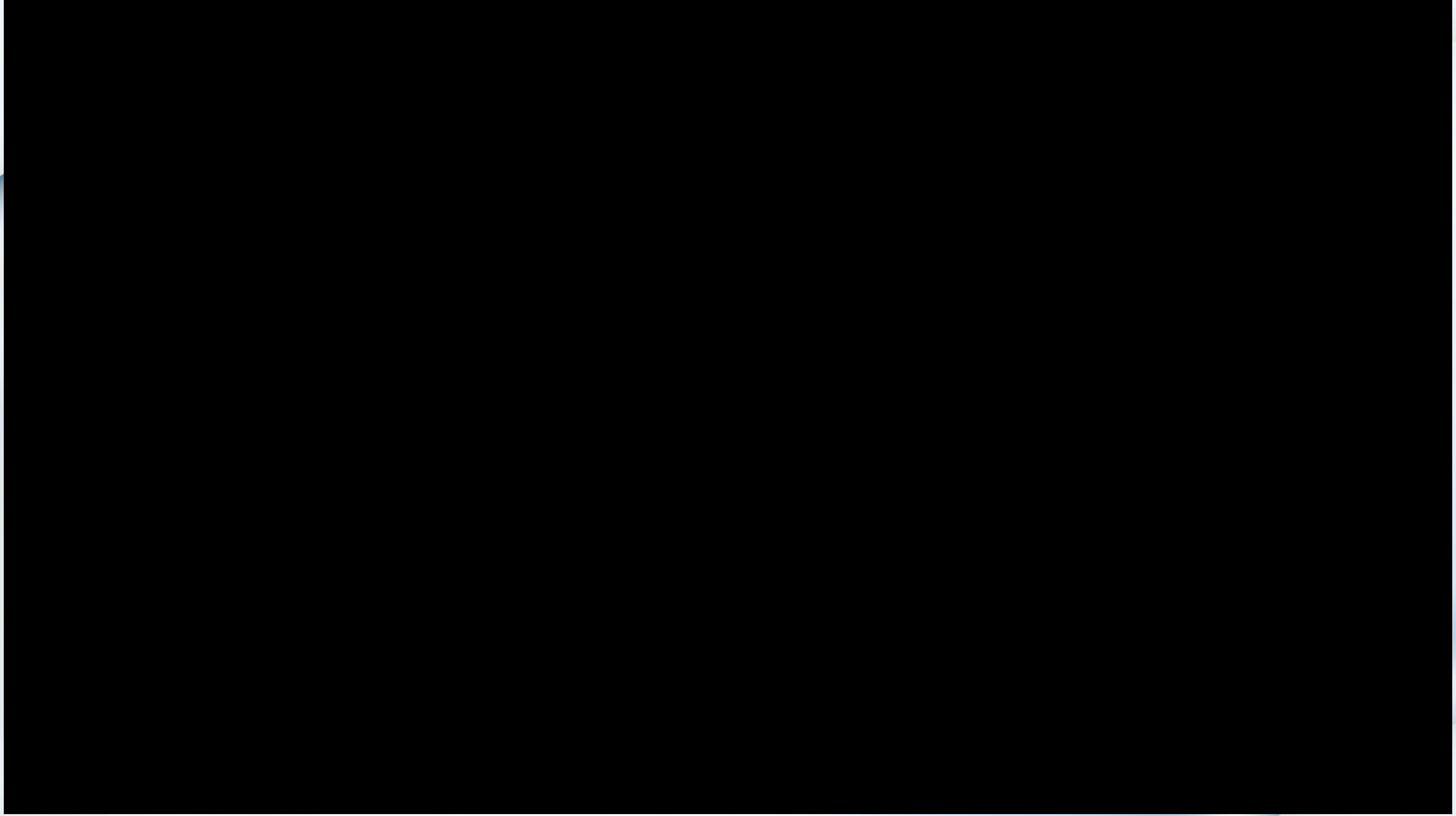
やわらかロボ！ ゲルハチ公

SOFTMATTER ROBOT "GEL HACHI"



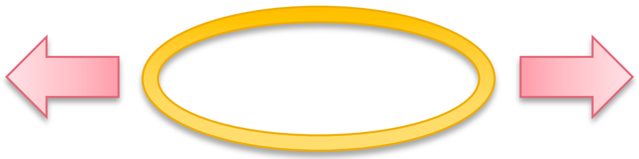
https://www.facebook.com/JapanGov/posts/2914525455271234

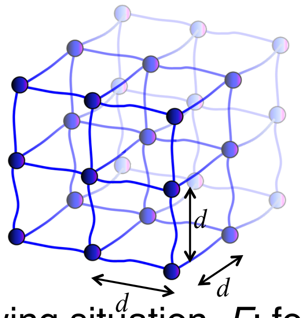
https://twitter.com/JapanGov/status/1247846764012384262



Soft-matter Robot "Gel HACHI”
Shibuya Ward, Tokyo
November 3-9, 2019.

Quiz for the report of this lecture





1) Estimate the Young's modulus E (Pa) of a rubber band in the following situation. F: force, 100gf ≈ 1N. A: area, 1mm^2 = 1 x 10^{-6}m^2. (1Pa = 1N/m^2.) Strain: ε=3.

2) Estimate the chain density per unit volume ν in the rubber hand of 1),at 300K, where we the rubber band behaves as an ideal rubber. Additionally, estimate the volume of a chain in the rubber band.

3) Estimate the molecular weight M_w of the chain in the rubber band of 1), when the density of the rubber is 0.6 g/cm^3 .

4) Estimate the polymerization degree N of the rubber band of 1) made from isoprene, where the molecular weight of isoprene (C_5H_8) ≈ 70 g/mol.

5) Estimate the radius of the chain R_{Gauss} in the rubber band of 1) swollen in toluene based on the ideal chain (Gauss chain) model, where the segment size a=0.3nm.

6) Estimate the Flory radius of the chain R_{Flory} in the rubber band of 1) swollen in toluene based on the real chain model, where the segment size a=0.3nm.

7) Finally, please write down your impressions of this class. It can be in Japanese. （最後にこの授業の感想を書いてください。日本語でも良いです。）