

*Simulating Artificial Muscles for  
Controlling a Robotic Arm with Fluctuation*

*Max Braun*

*Osaka University, Yuragi Project, 2007/2008*





ゆらぎ “*Fluctuation*”



ゆらぎ “*Fluctuation*”

*Biology*

*Information science*

*Materials science*

*Robotics*



ゆらぎ “*Fluctuation*”

*Biology*

*Information science*

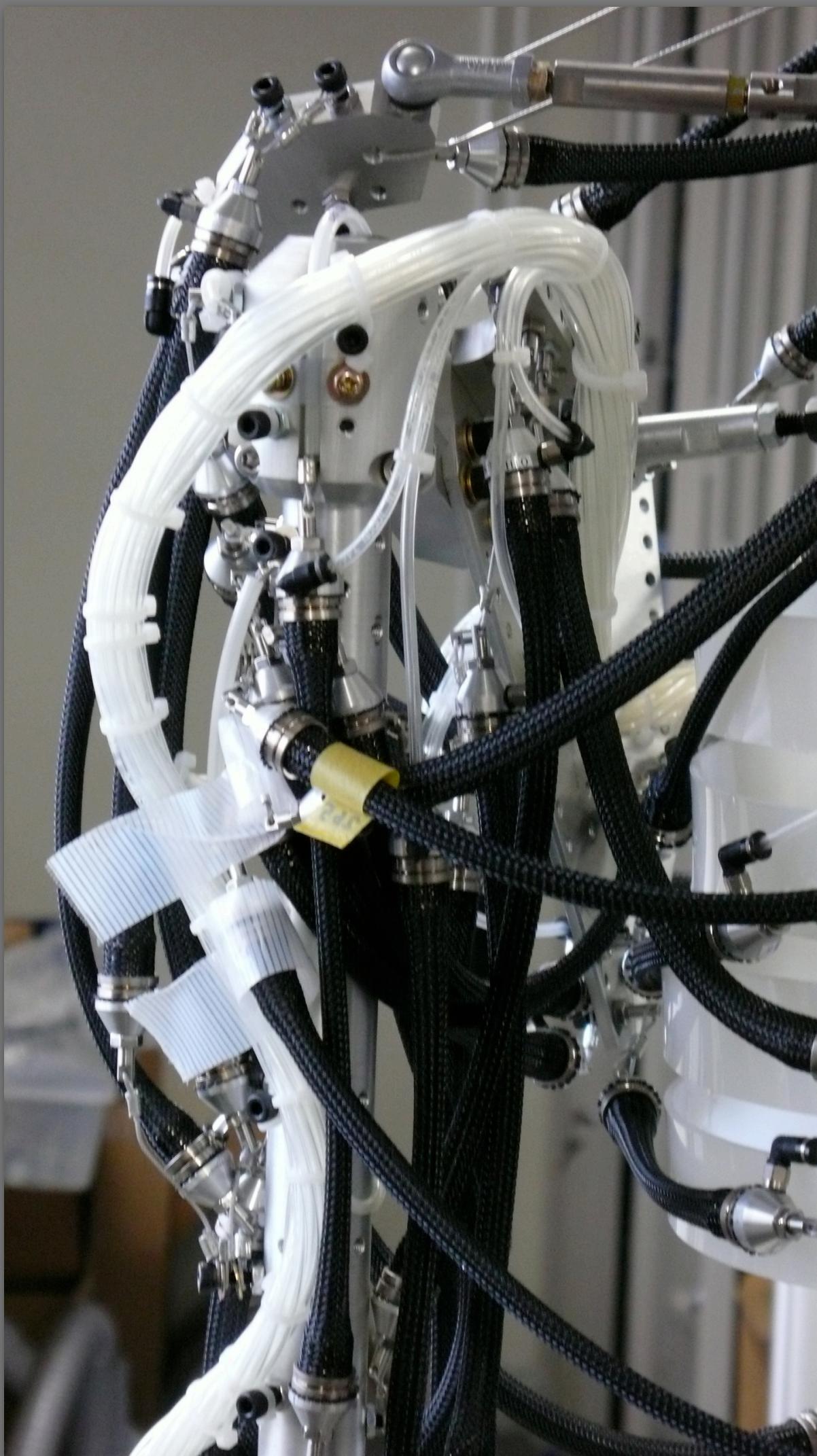
*Materials science*

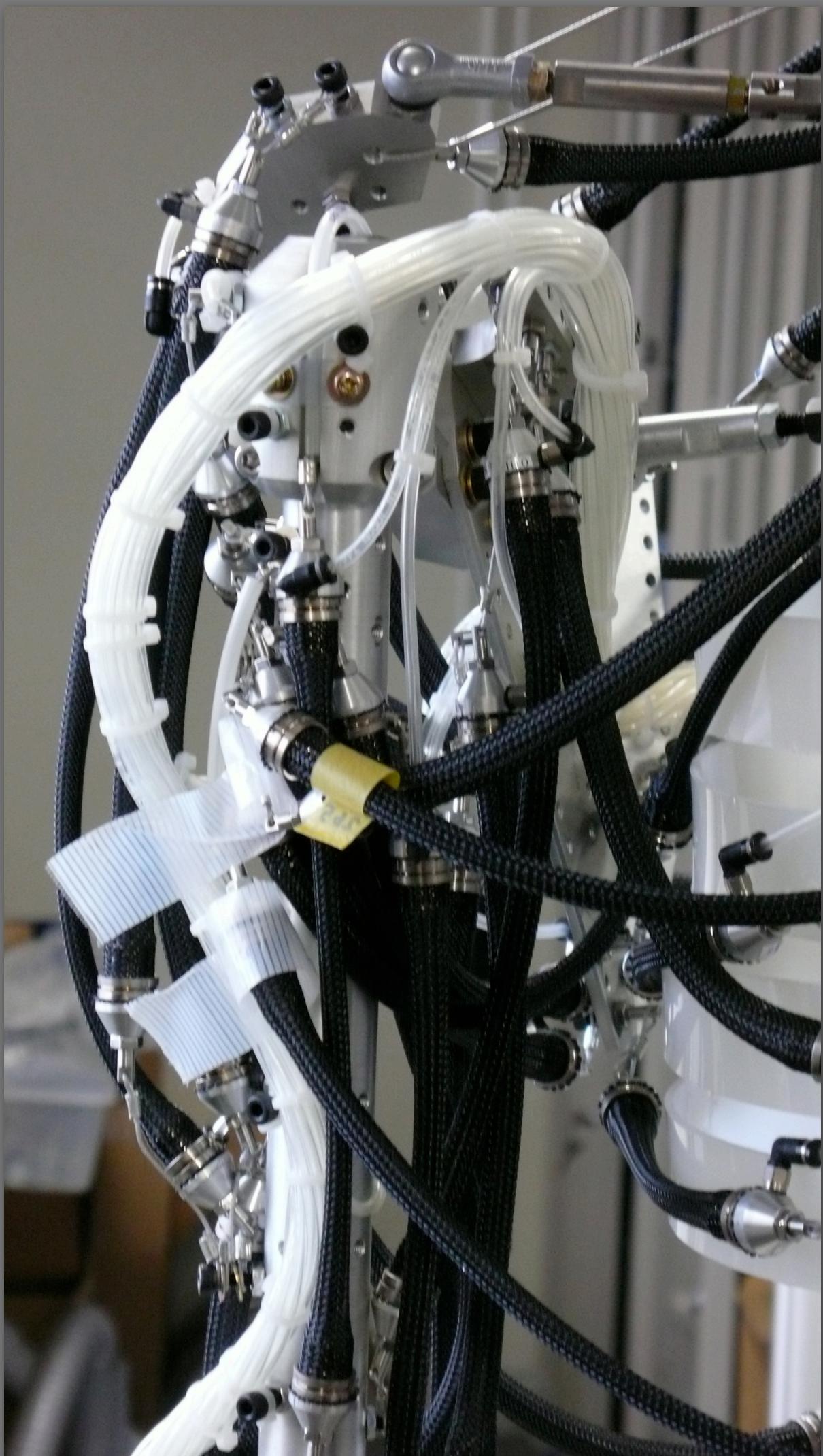
*Robotics*

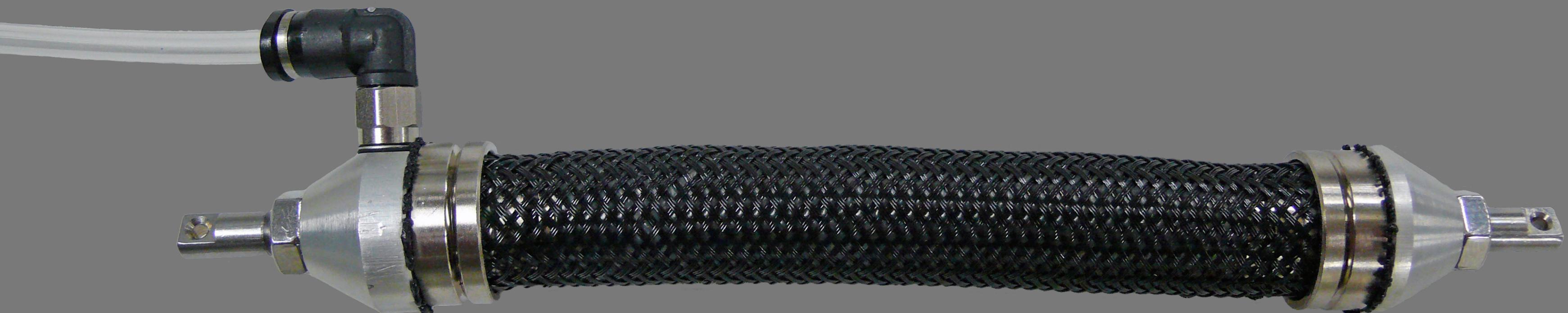
- 1. The robotic arm and its artificial muscles*
- 2. Simulating artificial muscles*
- 3. The simulator software*
- 4. Control algorithm and results*

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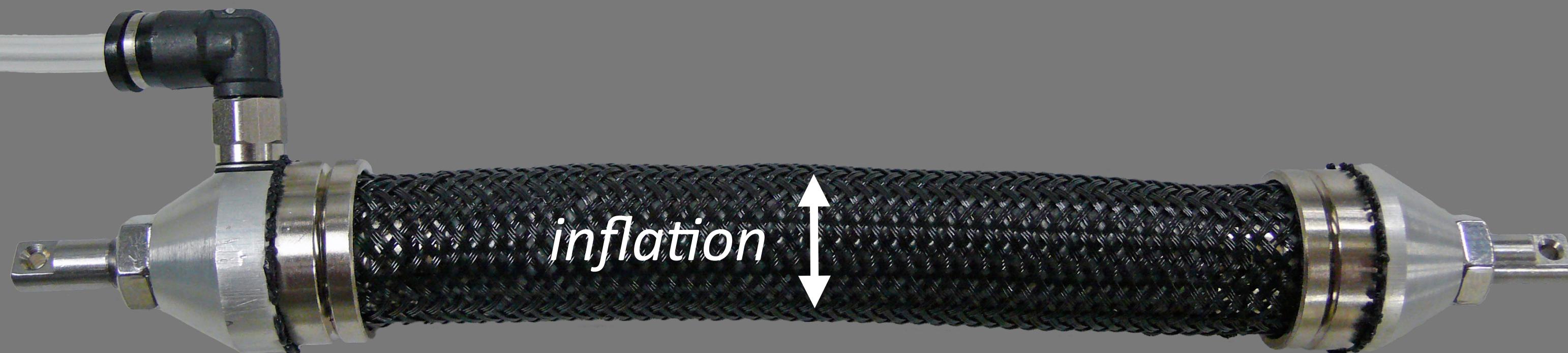




*air in*



*air in*



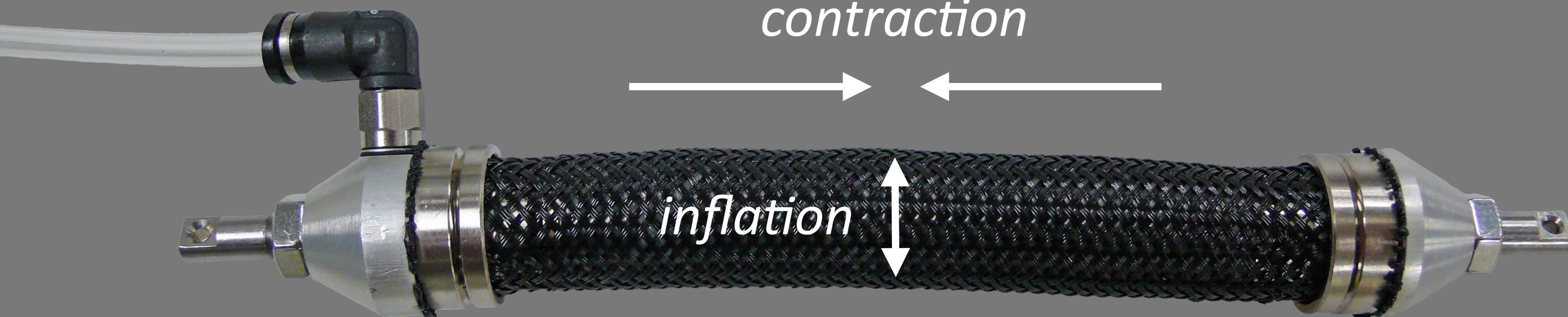
*air in*



*contraction*



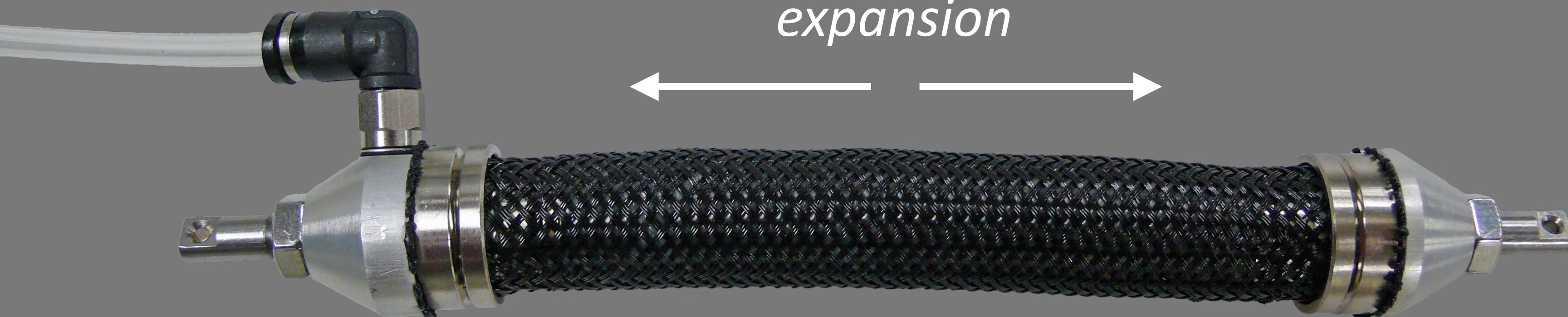
*inflation*



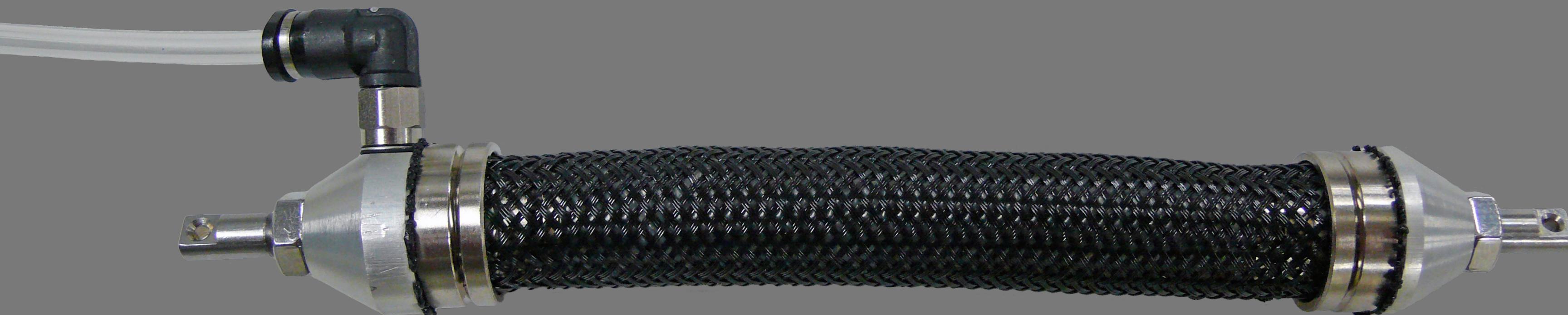
*air out*



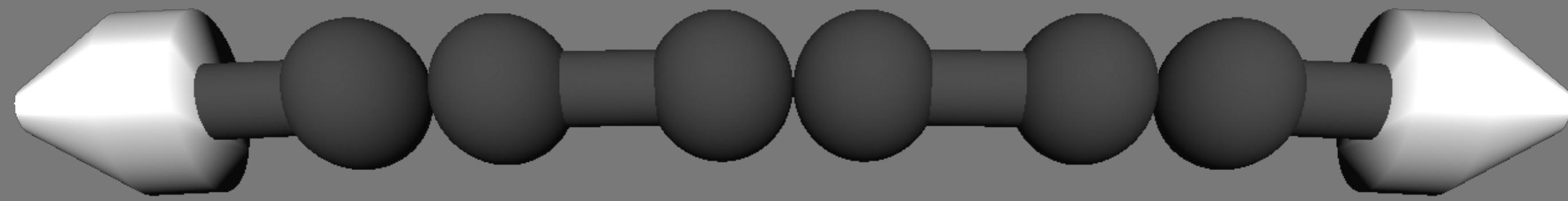
*expansion*



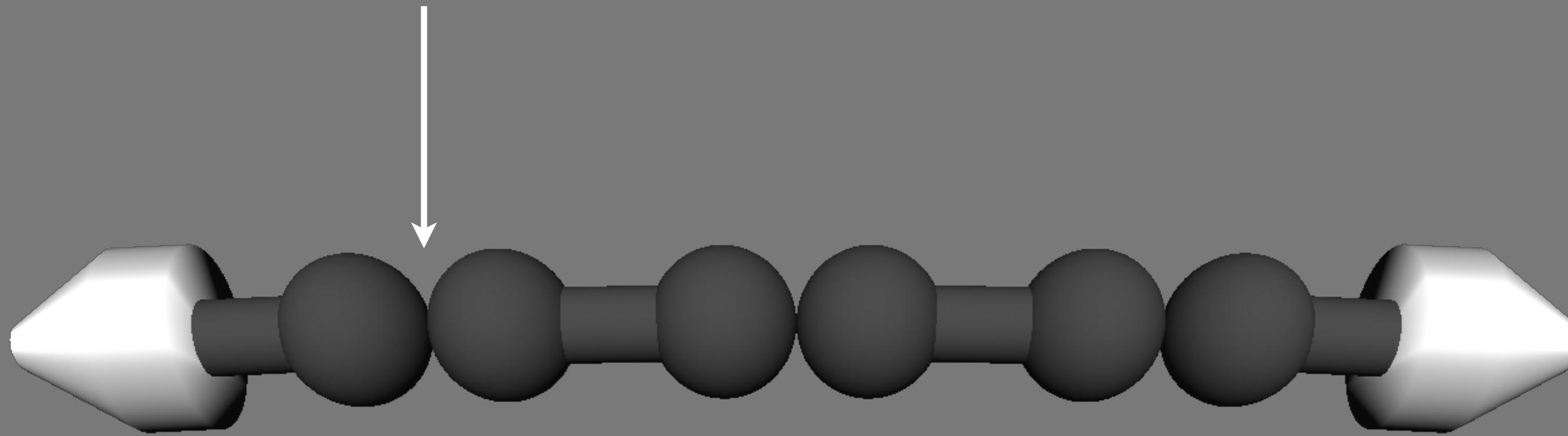
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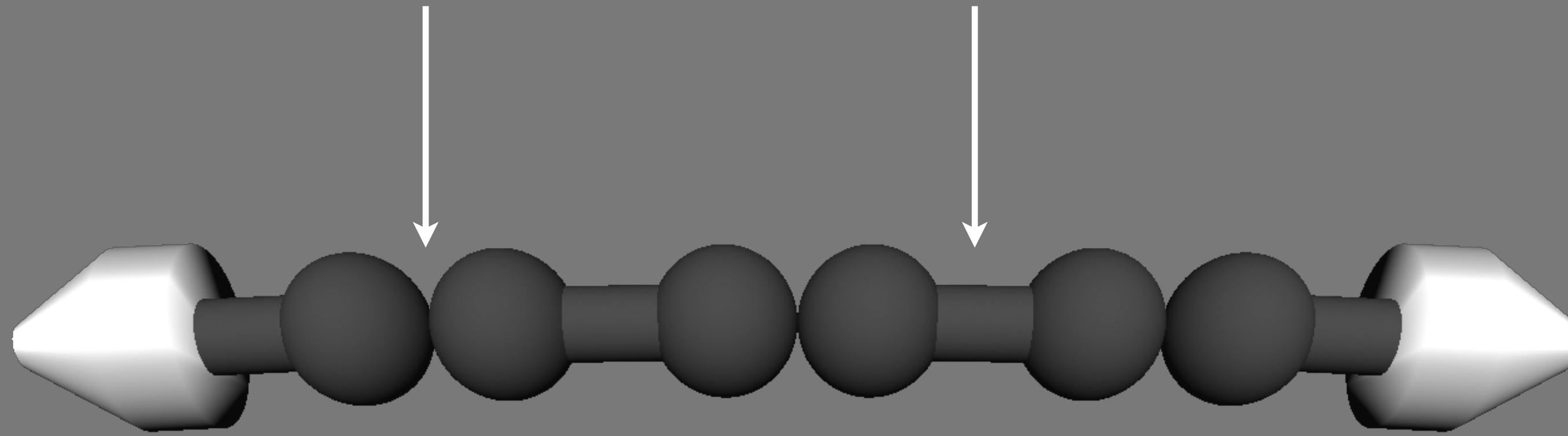


*hinge joints*

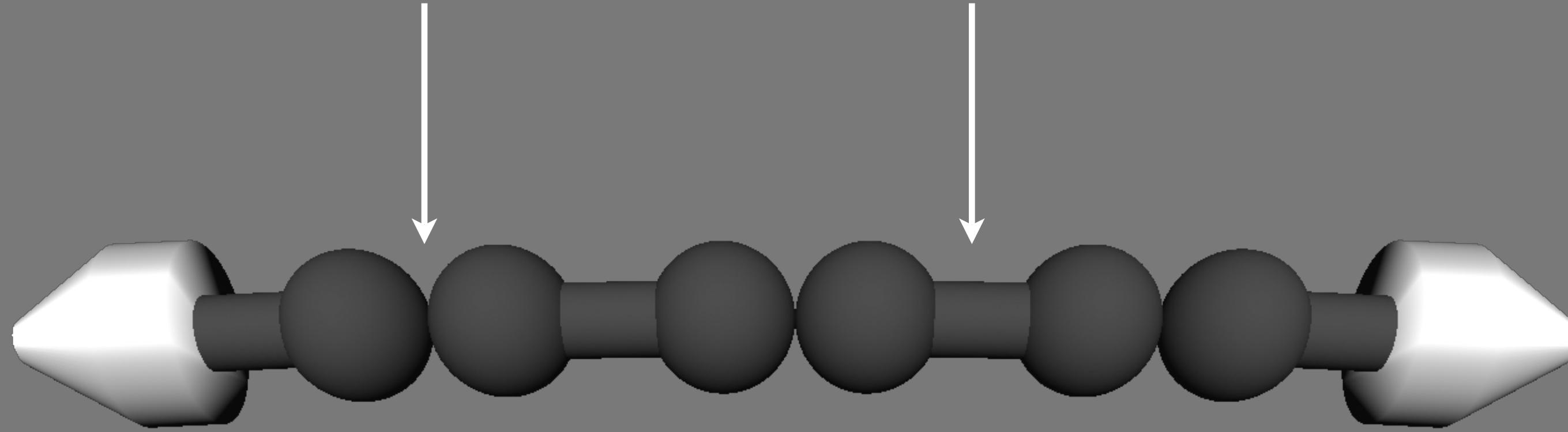


*hinge joints*

*slider joints*

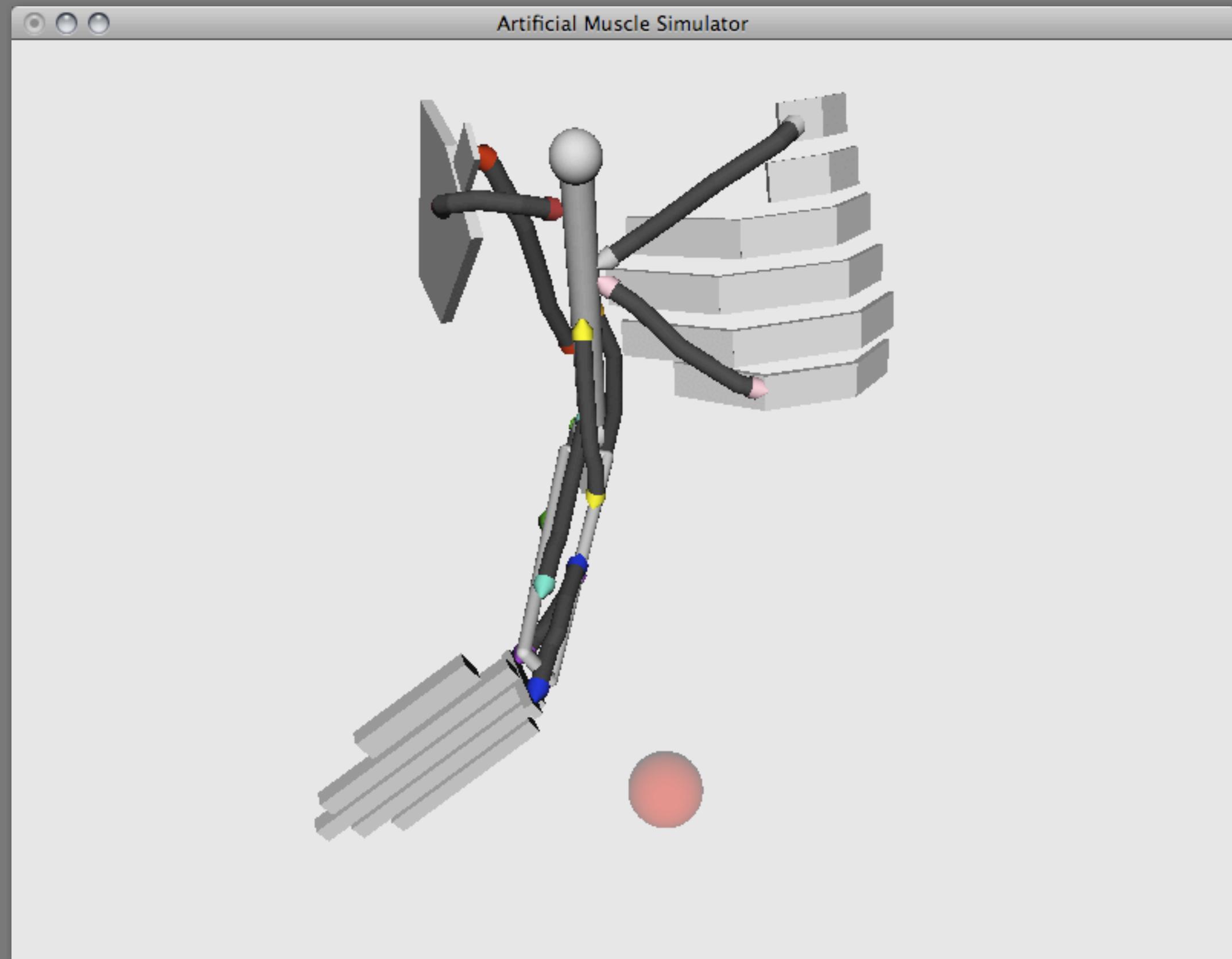


*hinge joints*



*slider joints*

*Open Dynamics Engine (ODE) + OpenGL*



*Demo*

# Refining the model

## Experiment:

- Set ***air pressure*** (8 bit)
- Set ***weight*** (i.e. force, 0–8.7 kg × g)
- Measure ***length*** (e.g. 132–193 mm)

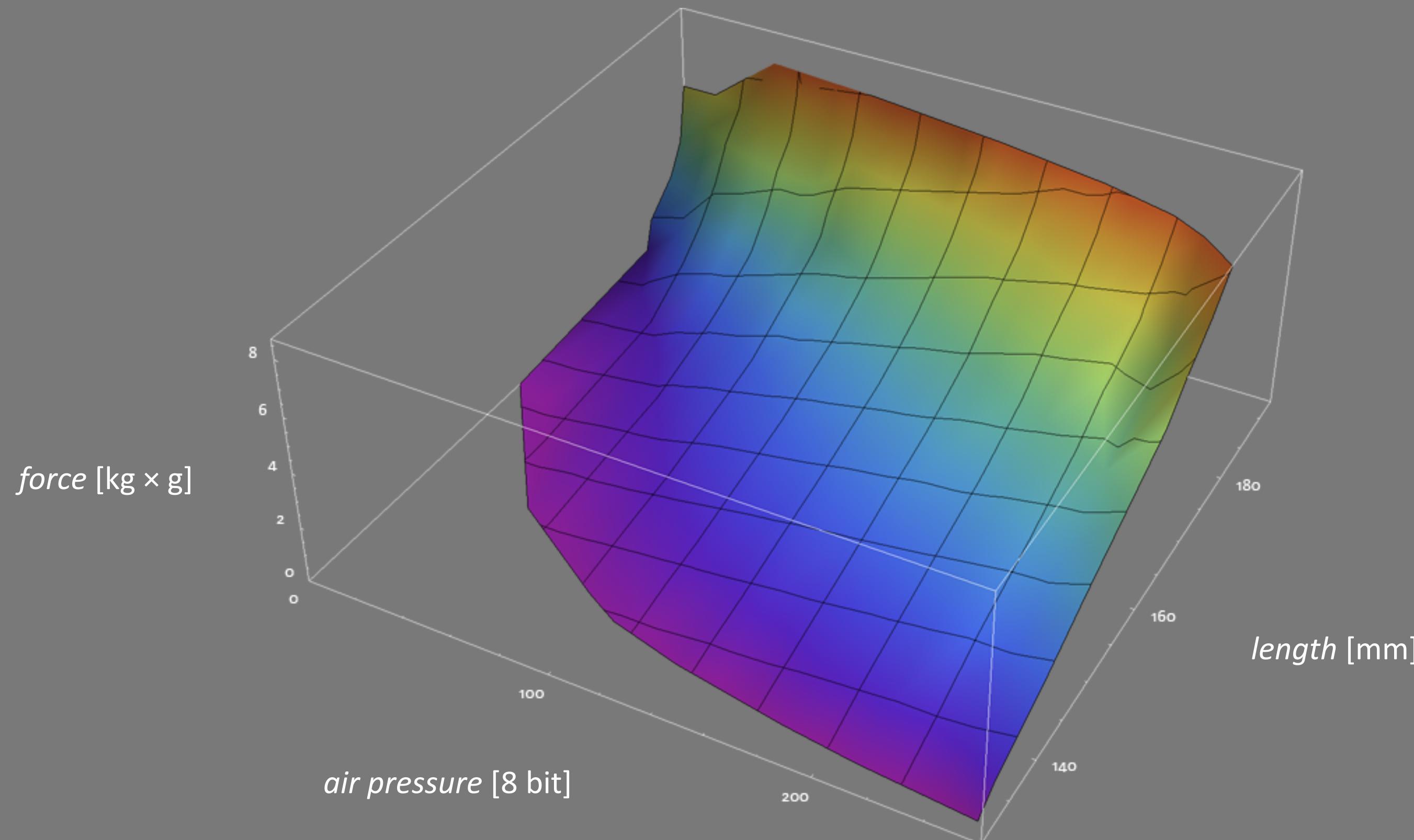
## Simulator:

- Take ***air pressure***
- Measure ***length***
- Exert ***force***



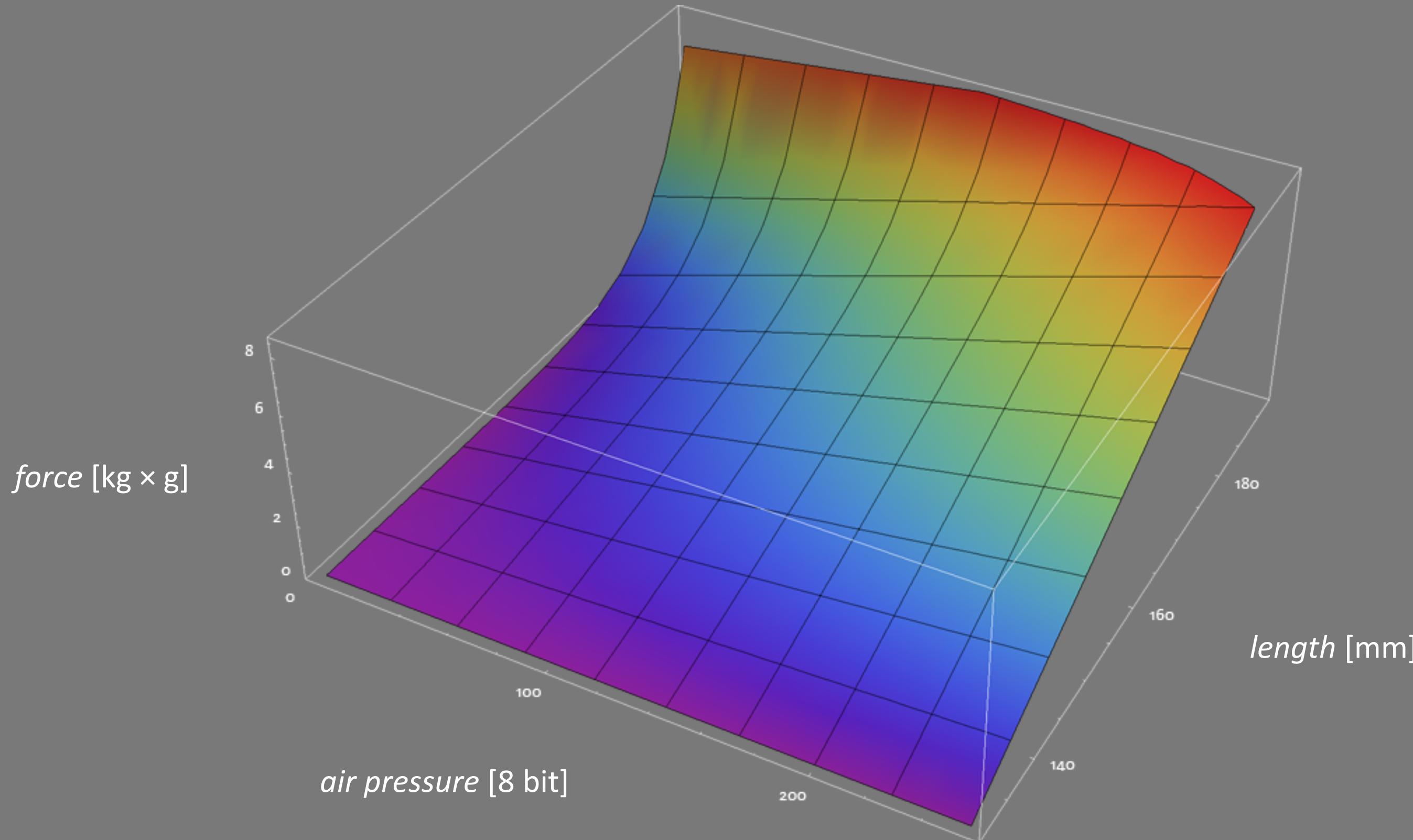
# *Measurement*

From a *set of data points* to a *functional representation*



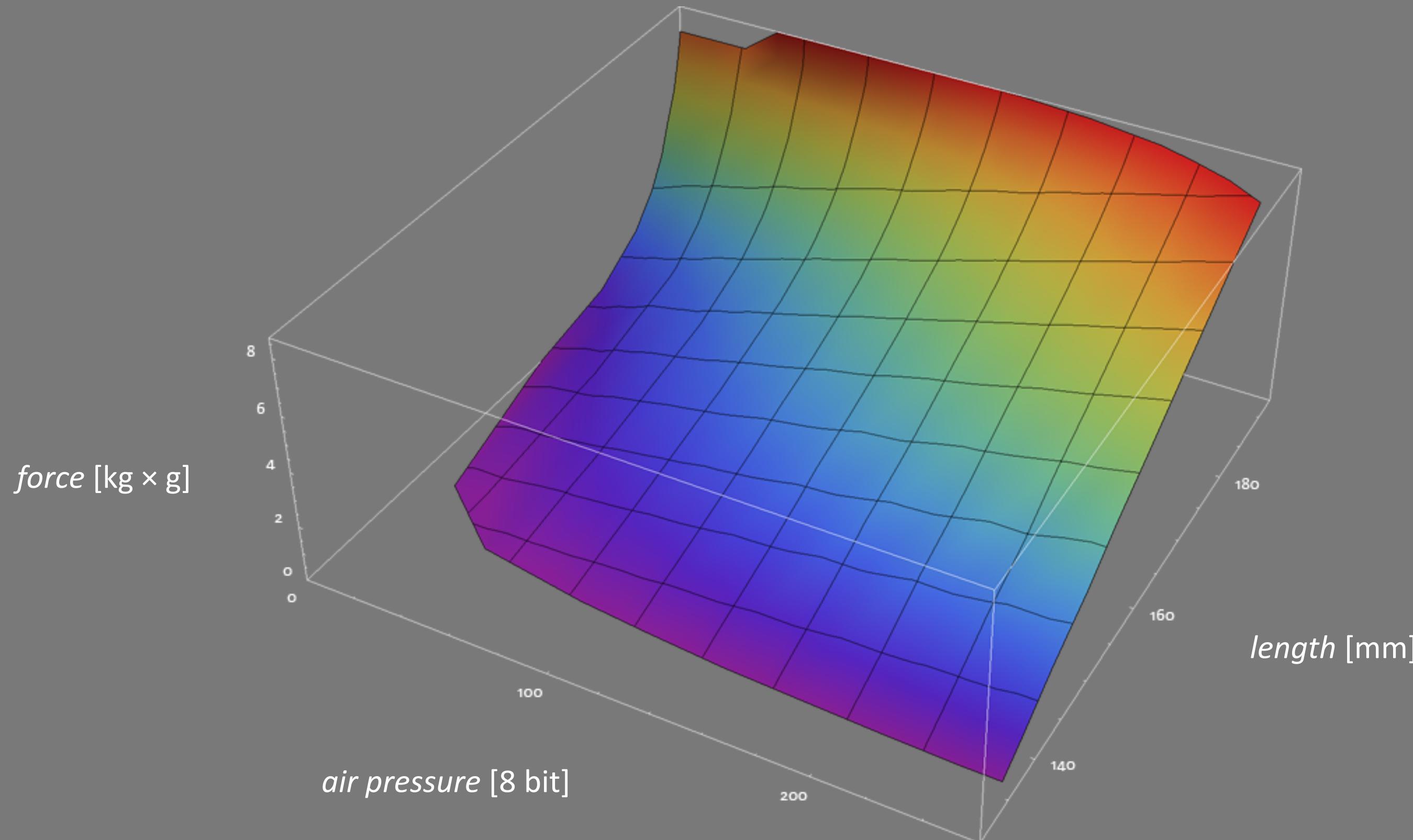
# *Function fit*

$$F(p, l) = c \cdot \left( \frac{p}{p_{\max}} \cdot \frac{l - l_{\min}}{l_{\max} - l_{\min}} + a \cdot \left( 1 - \frac{p}{p_{\max}} \right) \cdot \exp \left( b \cdot \frac{l - l_{\min}}{l_{\max} - l_{\min}} \right) \right)$$



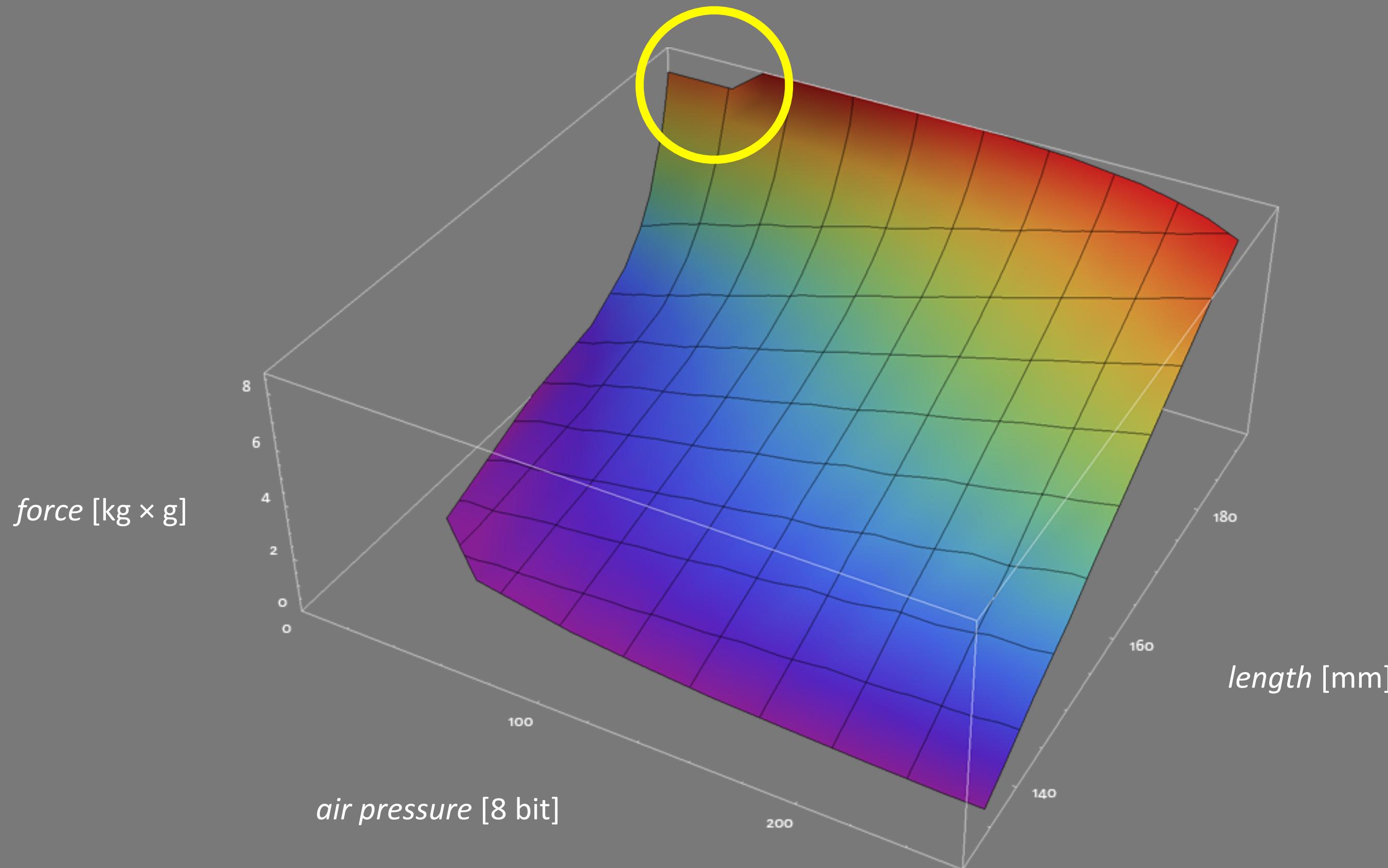
# *Measurement in simulator*

$$\frac{\sum_i (\text{measured}_i - \text{simulated}_i)^2}{\sum_i \text{measured}_i^2} \approx 4.2 \cdot 10^{-4}$$

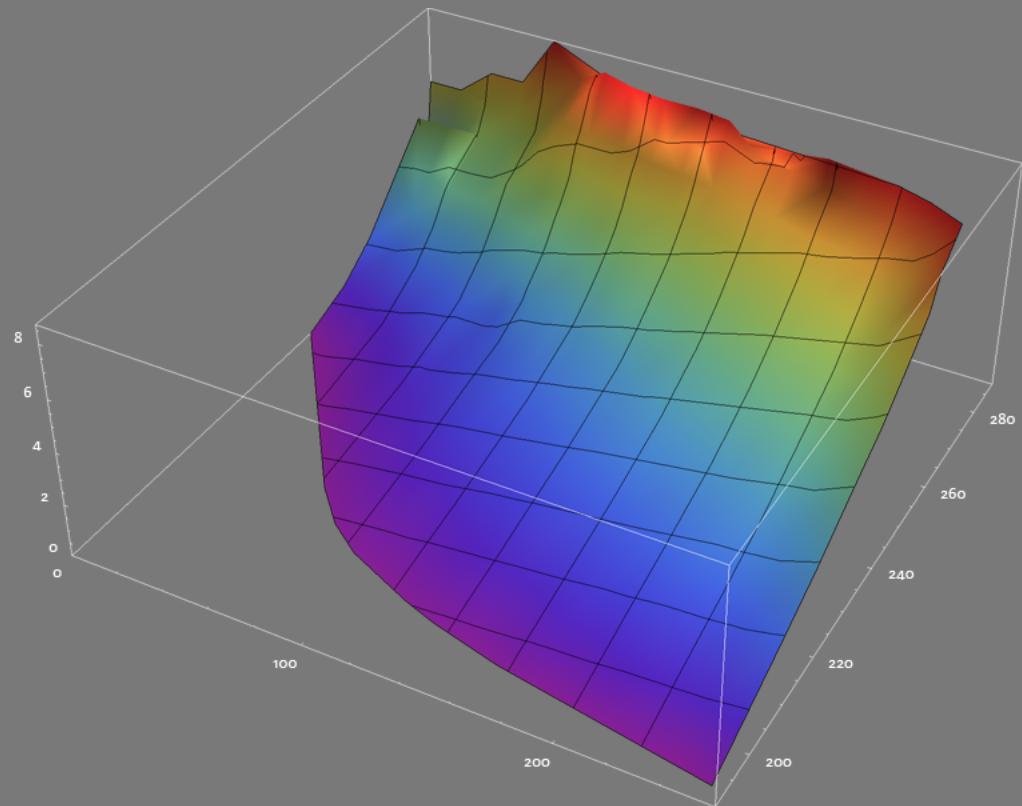


# *Measurement in simulator*

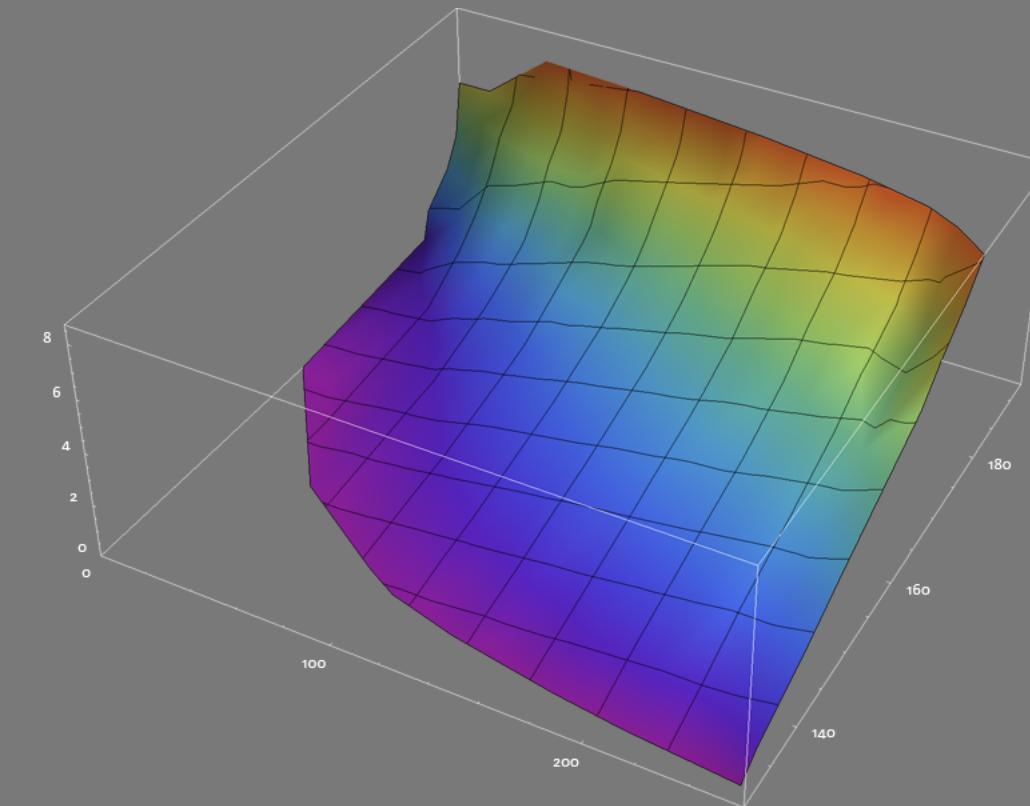
$$\frac{\sum_i (\text{measured}_i - \text{simulated}_i)^2}{\sum_i \text{measured}_i^2} \approx 4.2 \cdot 10^{-4}$$



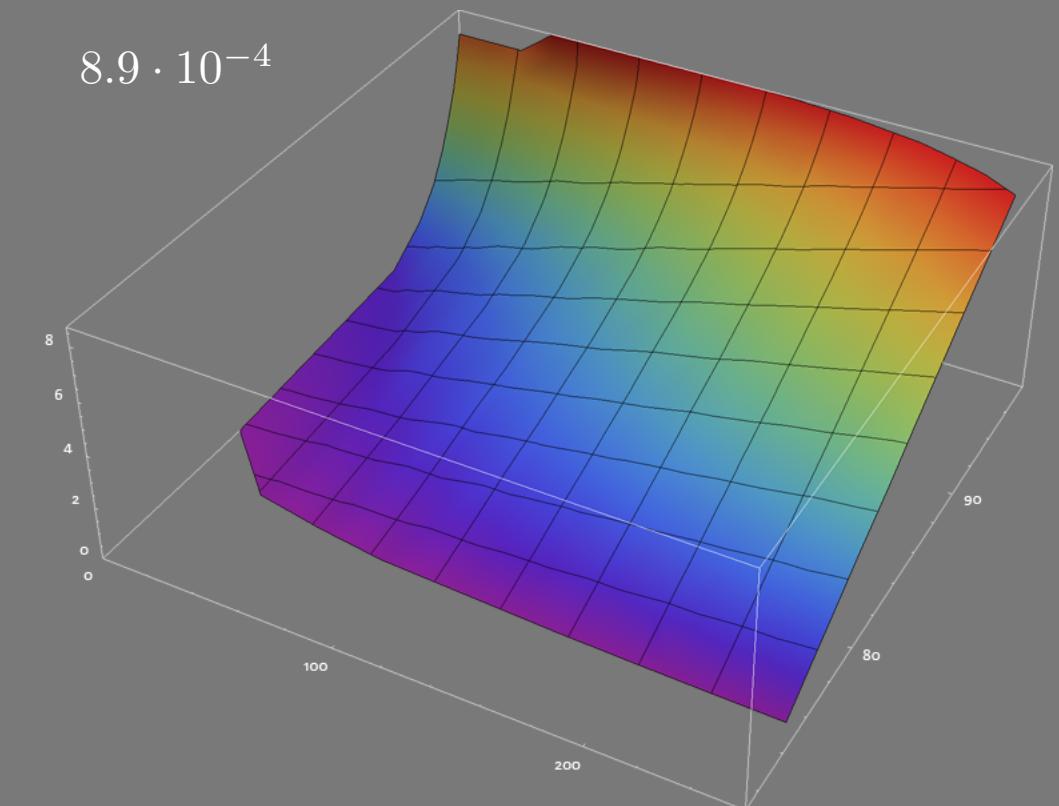
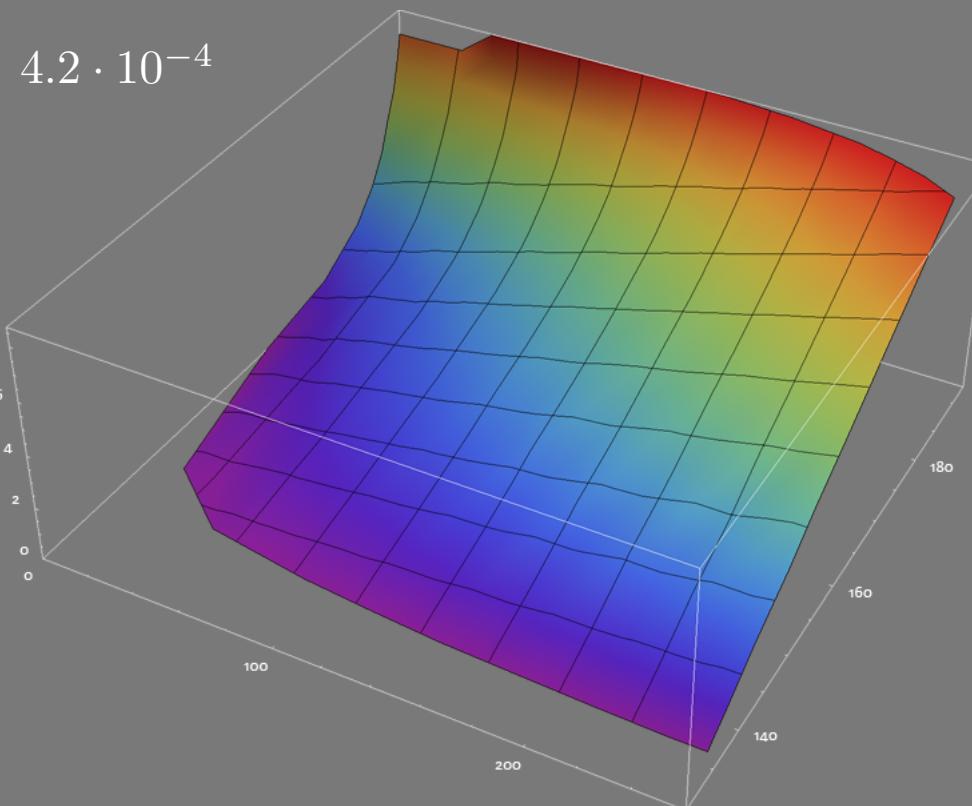
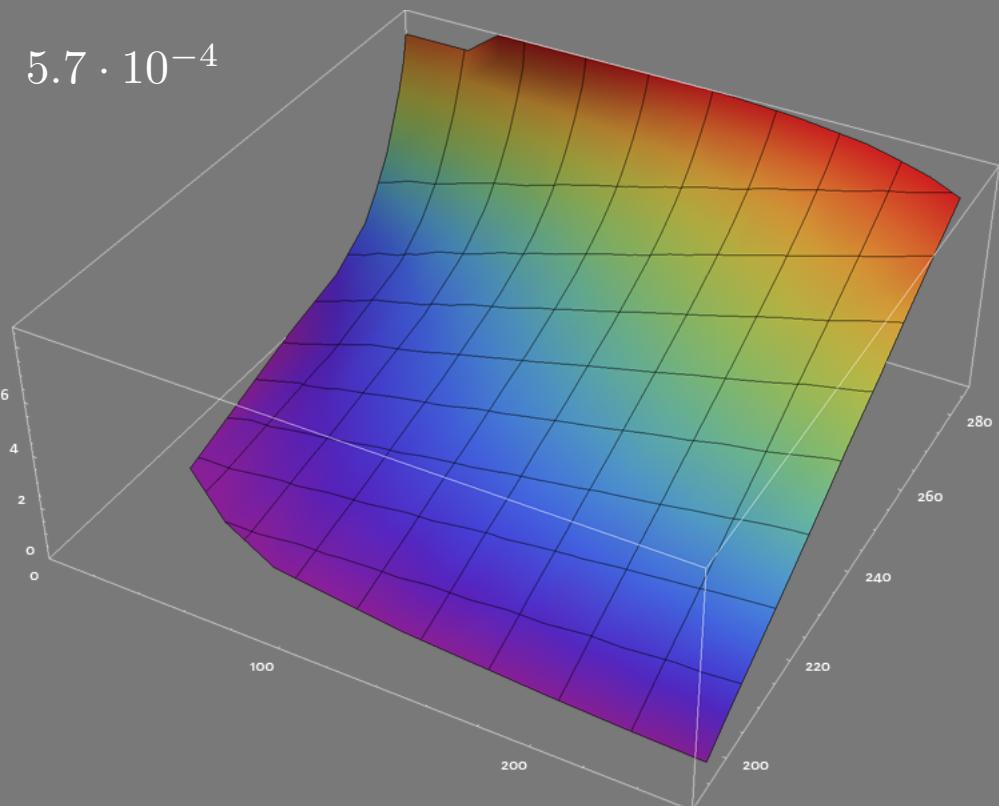
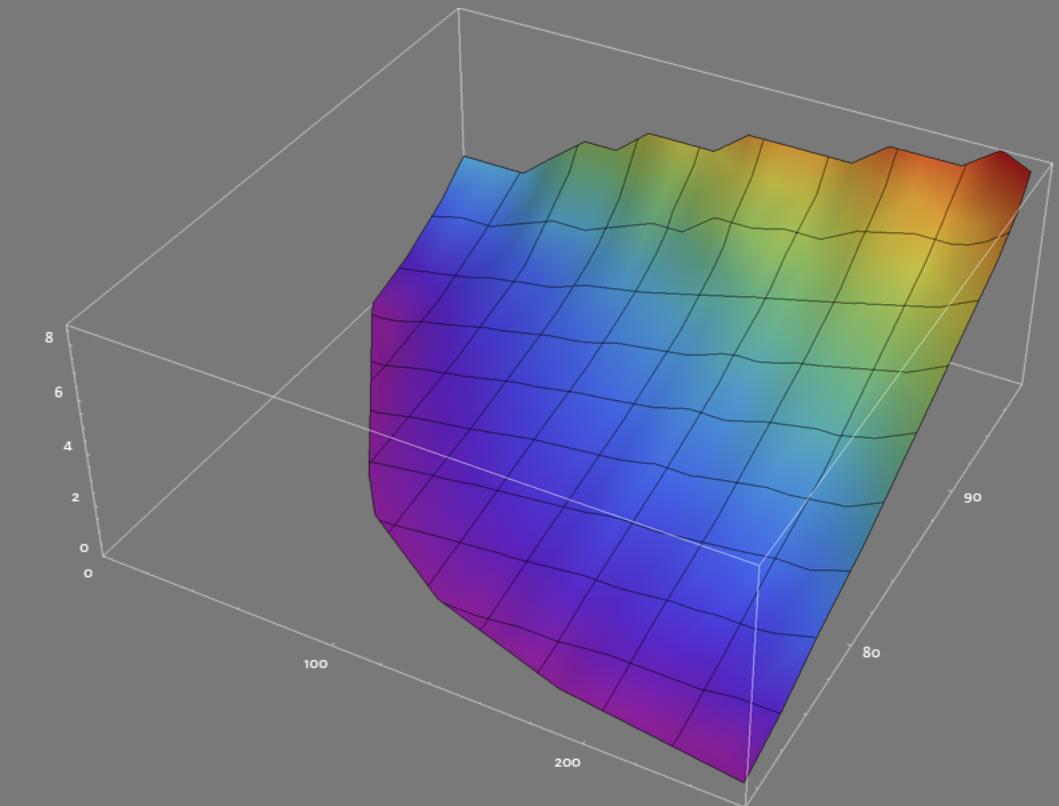
*long muscle*



*medium muscle*

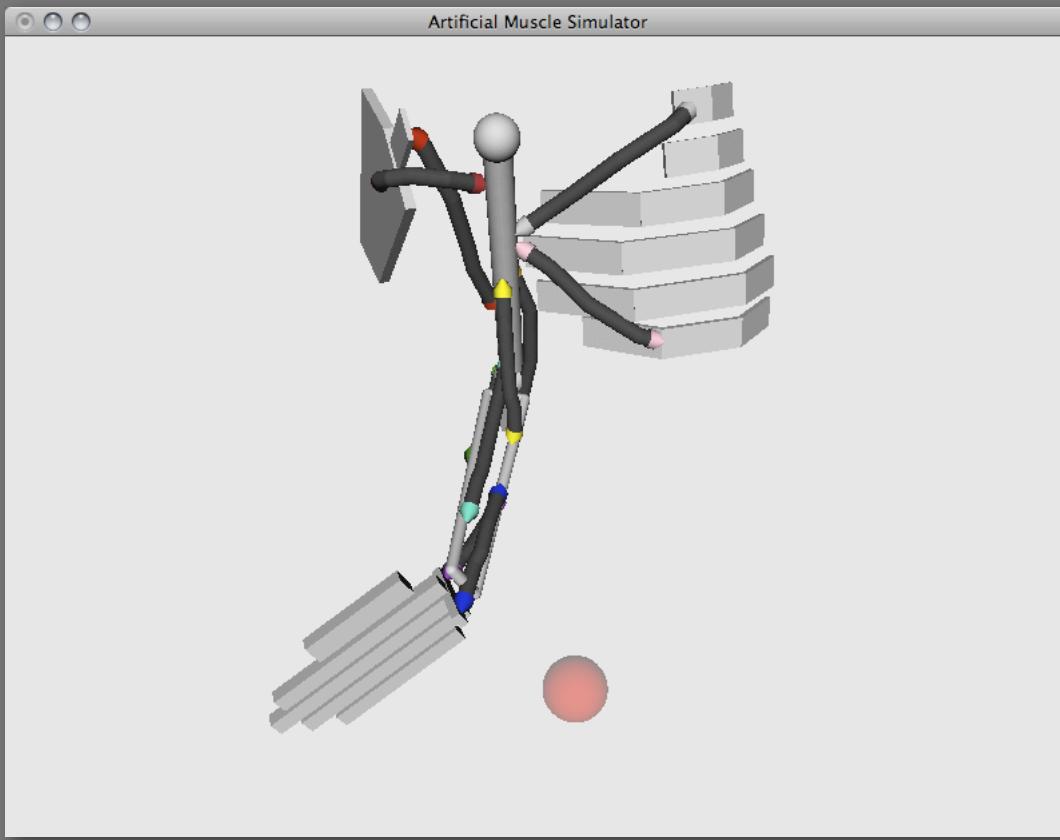


*short muscle*



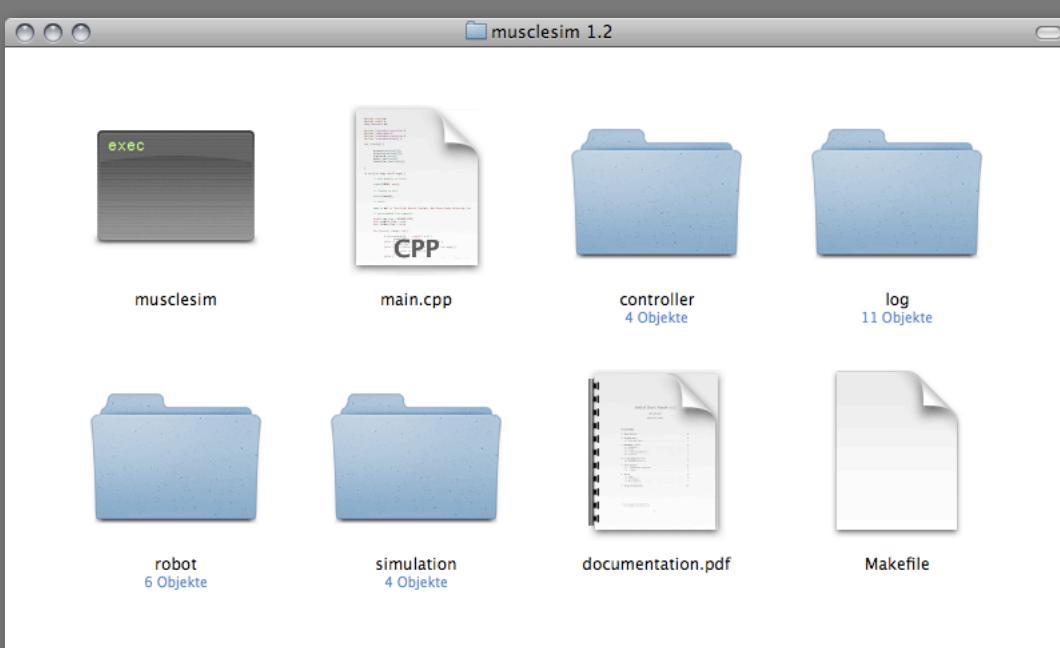
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# *Software engineering*



*User tasks:*

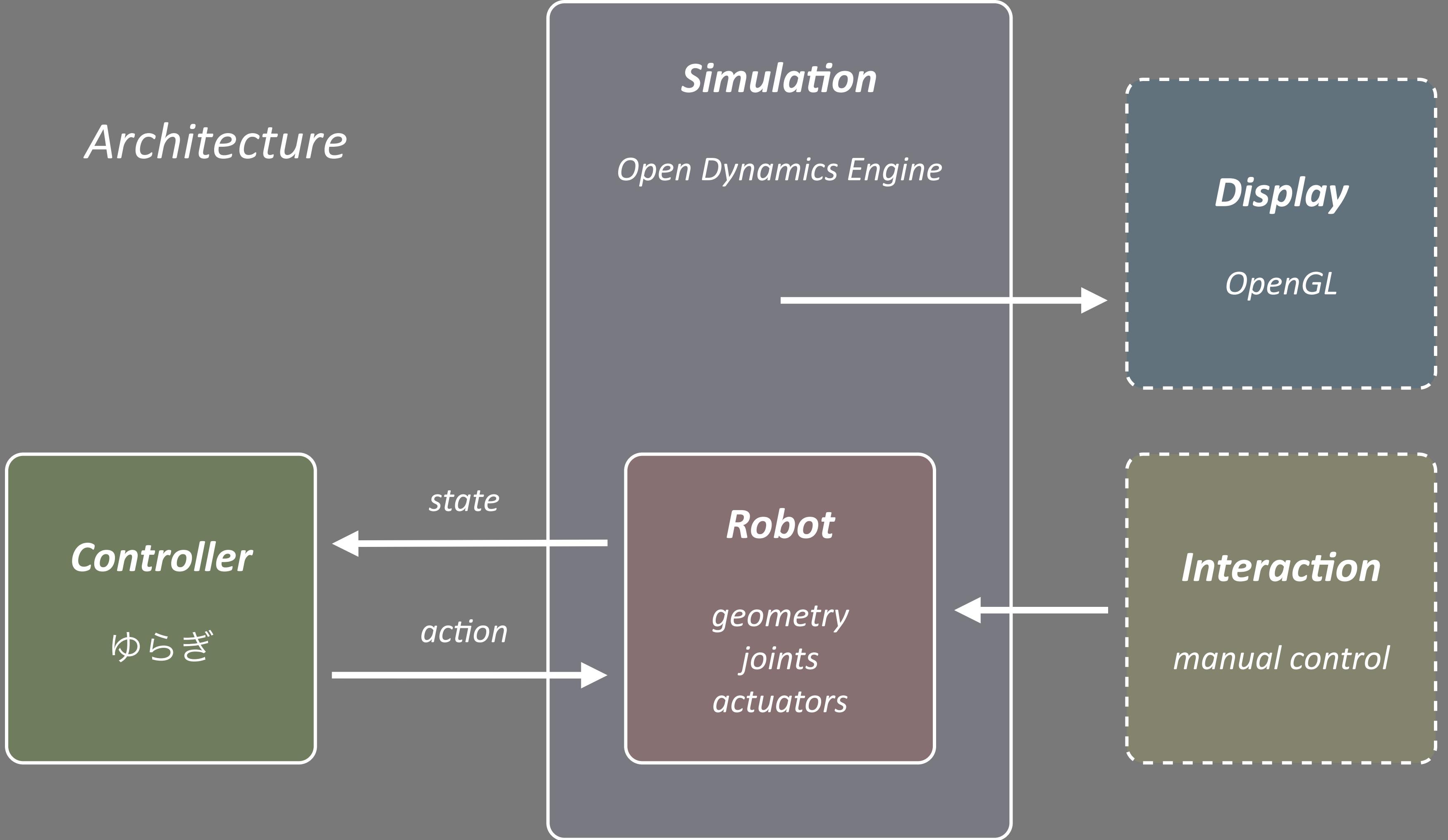
1. *Build* a robot
  - Create geometry
  - Connect with joints
  - Place actuators
2. *Control* the robot dynamically



*Realization:*

- Abstraction of *ODE* and *OpenGL*
- Written in *C++* (also interface)

# *Architecture*



# *Documentation*



\*nac.treasures.eng.osaka-u.ac.jp

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# *Attractor selection model*

$$\dot{\mathbf{x}} = a \cdot \nabla P(\mathbf{x}) + \eta$$

# *Attractor selection model*

*state change*  $\longrightarrow \dot{\mathbf{x}} = a \cdot \nabla P(\mathbf{x}) + \eta$

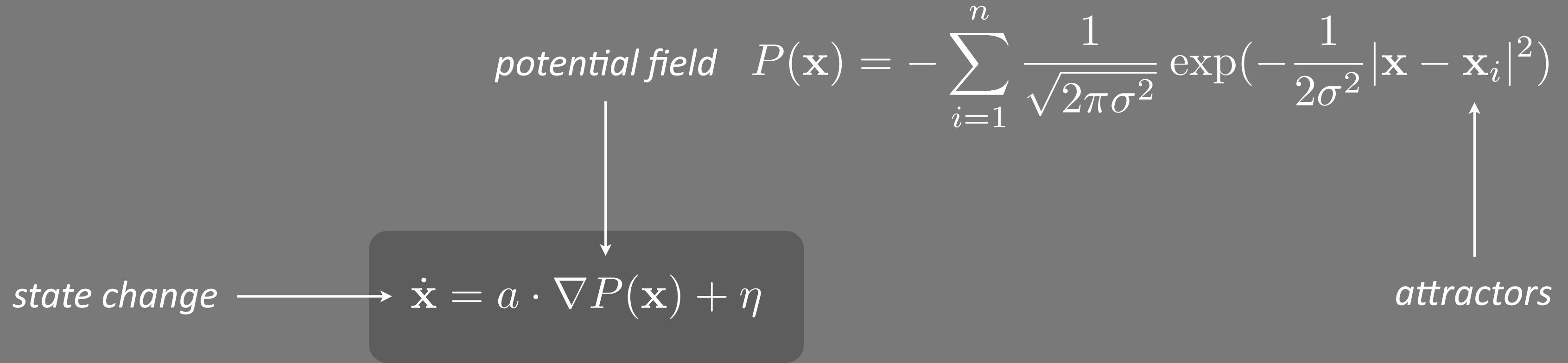
## *Attractor selection model*

*potential field*     $P(\mathbf{x}) = - \sum_{i=1}^n \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{1}{2\sigma^2} |\mathbf{x} - \mathbf{x}_i|^2\right)$

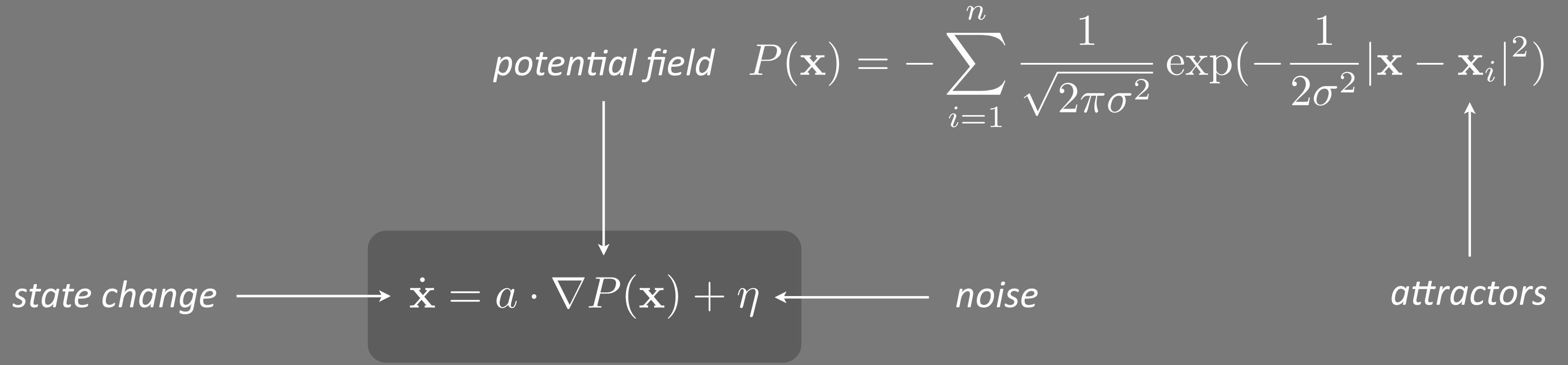


*state change*  $\longrightarrow \dot{\mathbf{x}} = a \cdot \nabla P(\mathbf{x}) + \eta$

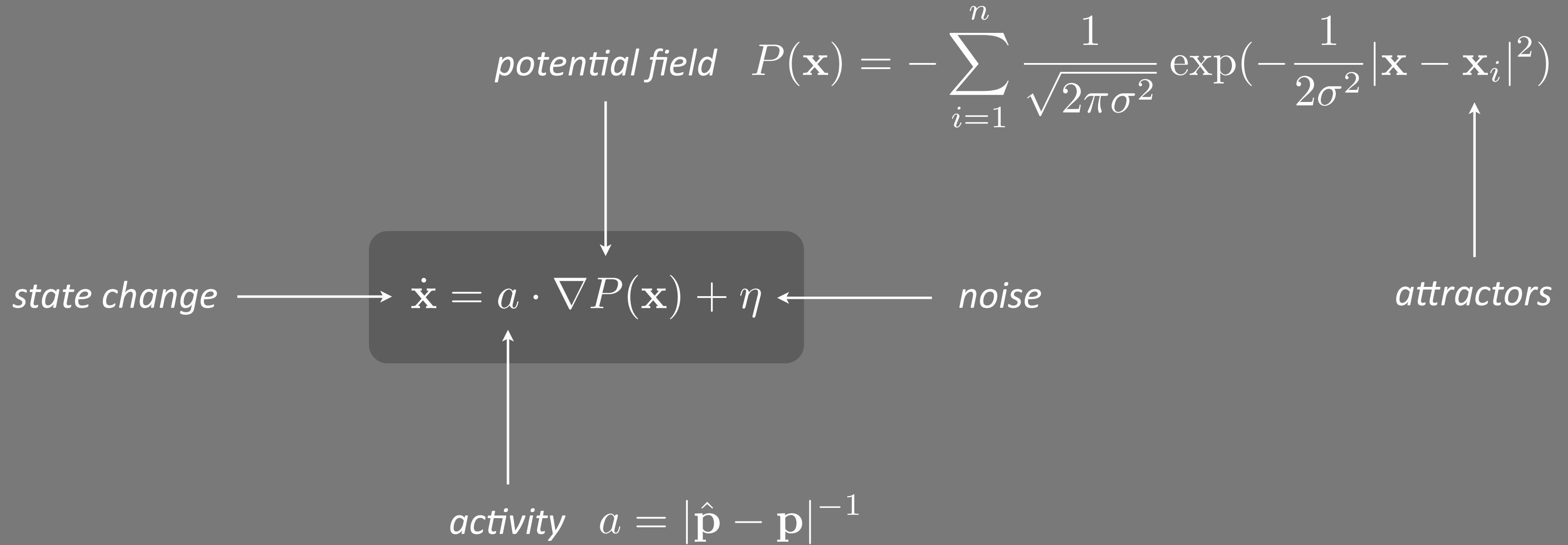
# *Attractor selection model*



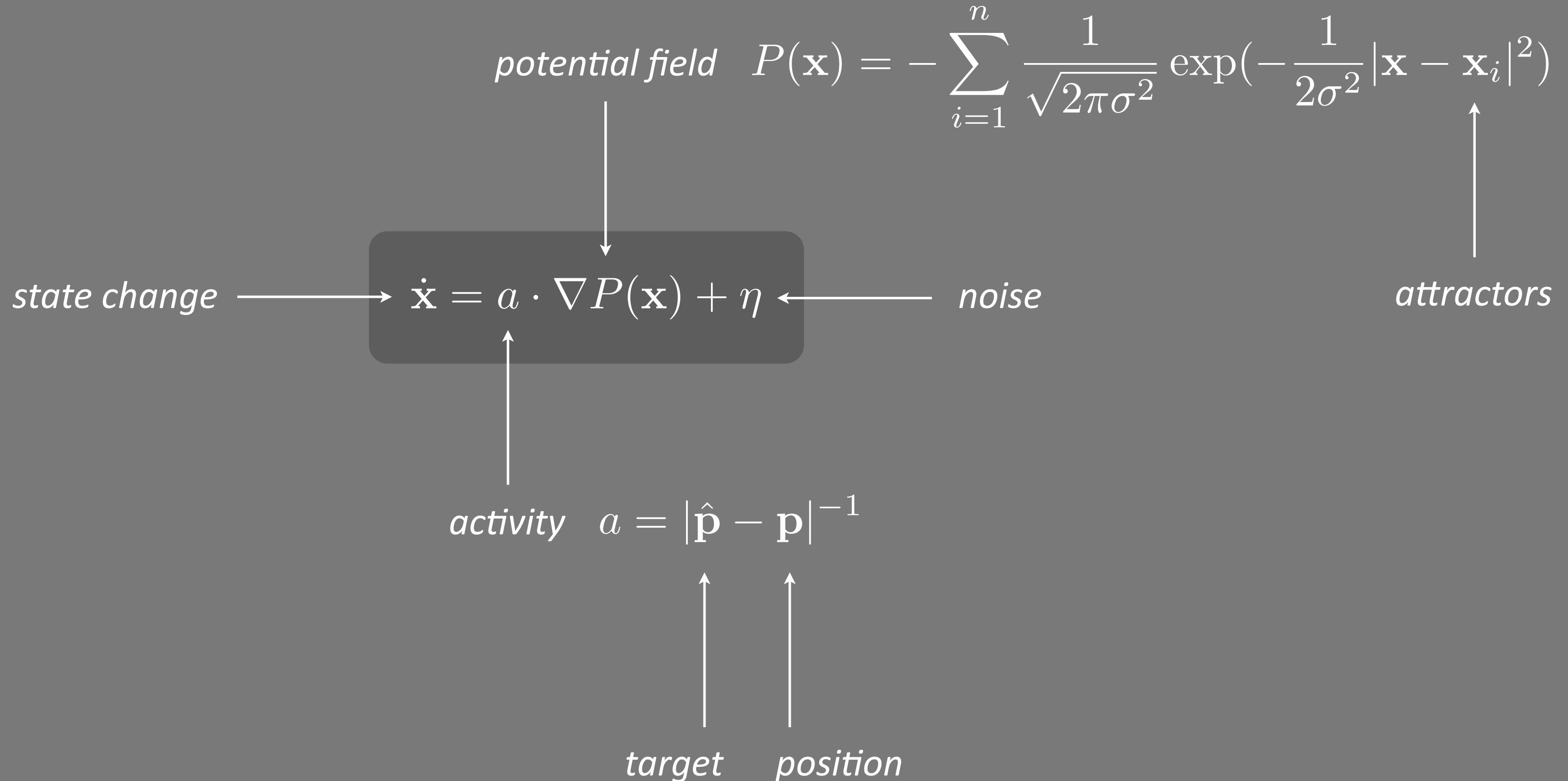
# Attractor selection model

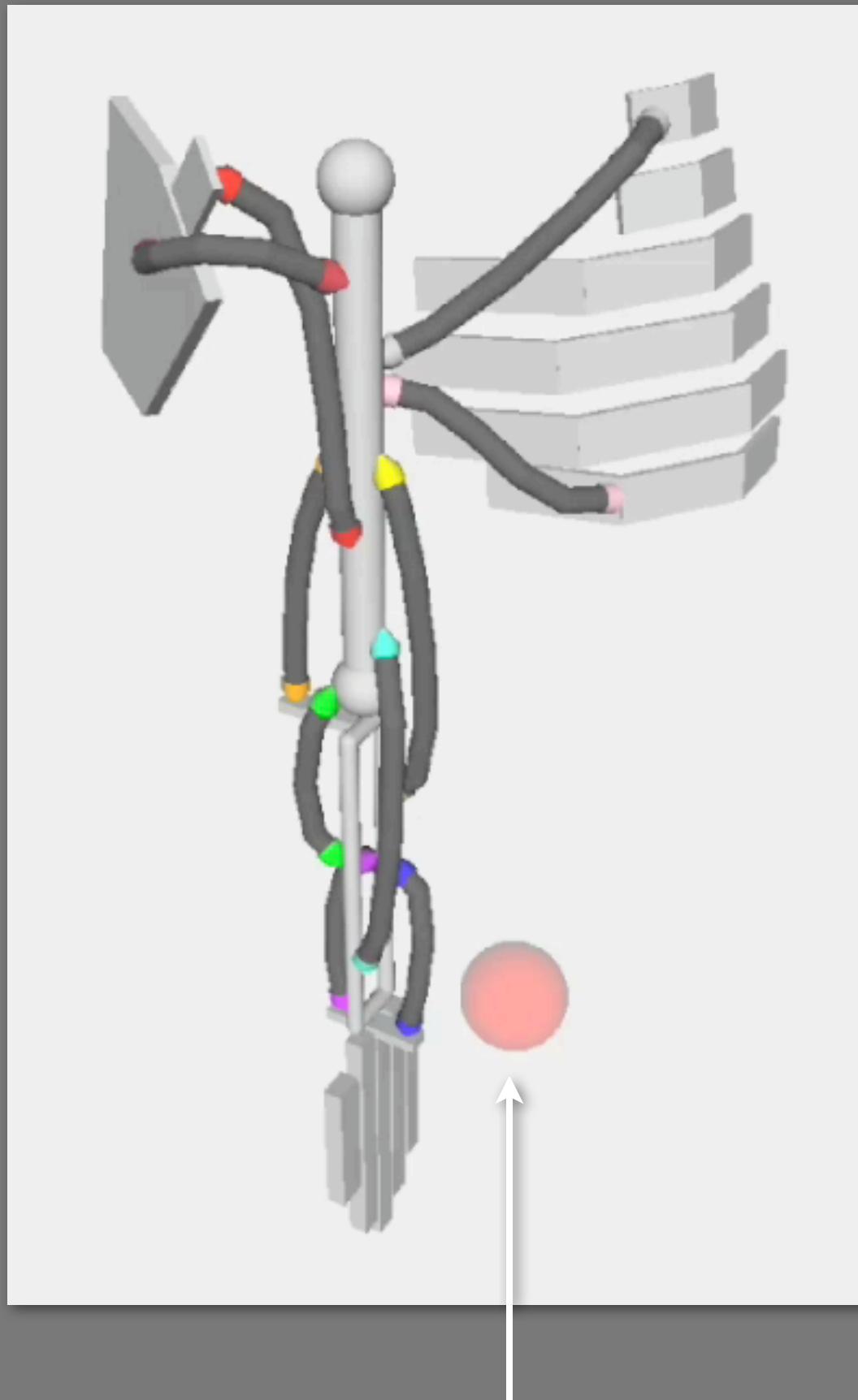


# Attractor selection model

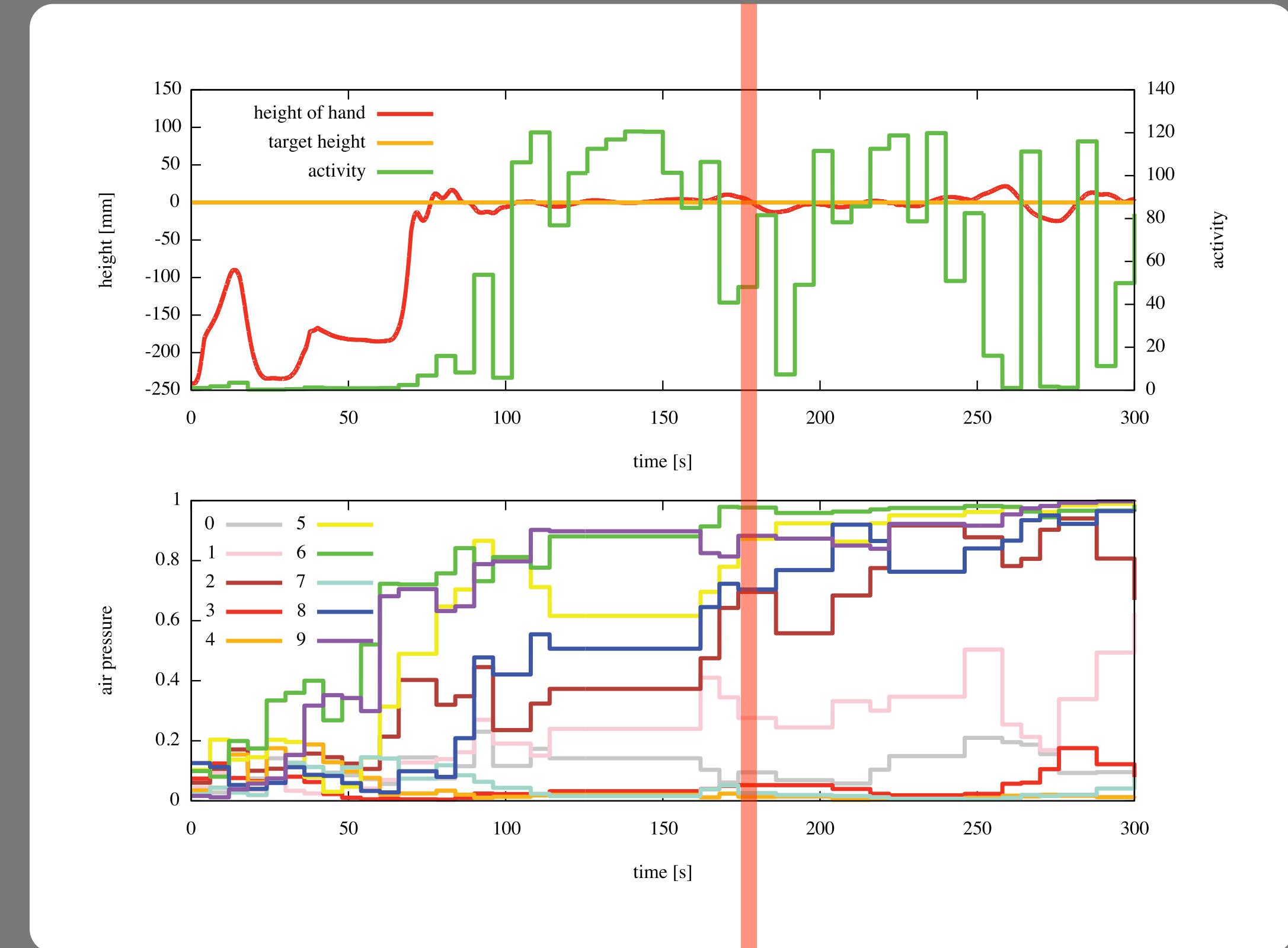


# Attractor selection model





*target*



CONFIDENTIAL. Limited circulation. For review only.

**Control of human-like robotic arm based on biological fluctuation**

Yutaka Nakamura, Ipppei Fukuyori, Max Braun, Yoshio Matsumoto, and Hiroshi Ishiguro

**Abstract**— Animals whose bodies have complex structure can work flexible, but controlling a complex system by existing control method is difficult. In this paper, we propose a simple and flexible control mechanism inspired by biological fluctuation. We propose a model of human-like robotic arm and apply our proposed method to the control of the robot. Experimental results show that our proposed method can be applied to the control of a robot with complex structure.

**I. INTRODUCTION**

Various robot systems are working in our society, and are indispensable for our lives in these days. However, there are some works of robots which are not designed for us. In the future, robots are expected to support our daily lives [4], [8], however there is no robots which can work in the real, unstructured environments. In order for the robots to work in our daily lives, they are required to have robustness against various disturbance, flexibility for unknown environment, and ability for performing practical tasks. In order to realize such functions, robots should have large degrees of freedom, and achieve complex motions. Humans and animals have complex mechanical structures, and many robot systems inspired by their structures have been developed[2], [1].

However, some of proposed methods have been studied. The representatives of them are classical control theory which utilizes transfer function, and optimal control theory such as  $H_\infty$  control. However, the more the complexity of the target system becomes, the harder the modeling of the system becomes. Learning method such as reinforcement learning can also be used, but the number of trials increases exponentially when the complexity of the system increases[3], [11], [10], [9]. This paper focuses on the problems in which the system is hard to model due to its complexity and fluctuation of the environment, and proposes a simple and robust control method inspired by biological systems. The biological system is known to have a power to adapt to new unknown and noisy environment. The mechanism of such flexible adaptation is investigated especially in molecular biology, and the importance of the biological fluctuation is made clear[12]. The fluctuation in molecular science is actually a noise due to the heat fluctuation, which is unavoidable and unpredictable. In conventional control for robot systems, such noise should be removed to the maximum extent. However, it is now believed that biological systems do not remove the noise but rather make use of it in order to adapt to the environment. Recent biological studies reveals that animals utilize (or exploit) biological fluctuation to achieve such flexibility. In this paper, we propose a simple and flexible control mechanism inspired by biological fluctuation. We propose a model of human-like robotic arm and apply our proposed method to the control of the robot. Experimental results show that our proposed method can be applied to the control of a robot with complex structure.

**II. BIOLOGICAL FLUCTUATION**

Bacteria can handle environmental changes. For example, even if some important nutrient dominantly decreases, bacteria can handle such crisis by alteration of gene expression. Kashiwagi et al. built a model of this adaptation mechanism based on a biological fluctuation, and explained the behavior of the bacteria. In this model, the gene expression is controlled by a dynamical system with some attractors, and this model is called “attractor selection model”[5].

**1) Attractor selection model:** The attractor selection model can be represented by Langevin equation as:

$$\tau_x \dot{x} = f(x) \times A + \epsilon, \quad (1)$$

where  $x$  and  $f(x)$  are the state and the dynamics of the attractor selection model, and  $\tau_x$  and  $\epsilon$  are the time constant and the noise, respectively. This formulation (1) is not the only way to implement the attractor selection model, but it is convenient to explain the behavior of the attractor selection model.

The variable, called “activity” which indicate the fitness of the state  $x$  to the environment, and controls the behavior of the attractor selection model. That is,  $f(x) \times A$  becomes dominant in (1) when the activity is large, and the state transition approaches deterministic. On the other hand, the noise  $\epsilon$  becomes dominant in (1) when the activity is small, and the state transition becomes more probabilistic. Because  $f(x)$  is designed to have some attractors, the state of the system is entrained into one attractor when the activity is

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# IROS 2008 submission

**Y. Nakamura, I. Fukuyori, M. Braun,  
Y. Matsumoto, H. Ishiguro:  
*Control of human-like robotic arm  
based on biological fluctuation.***

**Yuragi: Ausnutzung von Fluktuation am Beispiel eines komplexen Roboterarms**

Max Braun, Yoshio Matsumoto, Hiroshi Ishiguro

„Yuragi“ ist das japanische Wort für Fluktuation. Im gleichnamigen interdisziplinären Projekt an der Universität Osaka werden natürliche biologische Prozesse, die Fluktuation ausnutzen, nachgeahmt und für technische Anwendungen nutzbar gemacht. Aus dem Teilbereich Robotik wird hier exemplarisch ein junges Projekt vorgestellt, in dem ein einfaches, biologisch inspiriertes Modell zur Steuerung eines komplexen Roboterarms genutzt wird.

**1 Prinzip und Projekt**

In den meisten technischen Anwendungen ist zufälliges Rauschen ein Störfaktor, den man mit großem Aufwand zu unterdrücken versucht. Bei normalen Temperaturverhältnissen sorgt die Brown'sche Bewegung immer eine unvorhersehbare und unregelmäßige Fluktuation. Der Effekt ist auf der makroskopischen und mikroskopischen Ebene und beeinflusst damit viele biologische Prozesse.

Yamada et al. [1] konnten zeigen, dass sich Mutterzellen der Fluktuation zur zielgerichteten Fortbewegung bedienen und Kashiwagi et al. [2] beschreiben die Genexpressions in Bakterien zur Anpassung an unbekannte Umweltumstände als Ausnutzung von Fluktuationen.

Dieses biologische Prinzip inspirierte ein interdisziplinäres Projekt an der Universität Osaka mit dem Namen „Yuragi“ dem japanischen Wort für Fluktuation. In den vier Teilbereichen Biologie, Materialwissenschaft, Informationstechnik und Robotik wird versucht, Kontrolle über das allgemeine Phänomen Fluktuation zu gewinnen und es als Lösung für verschiedenste Probleme anzuwenden.

Im Teilbereich Roboter bestimmt sich ein Großteil der Projekte mit dem Thema Roboter unterschiedlicher Art. Im Bereich des Mensch-Roboter-Interaktion wird unter anderem mit Mitsubishi Haushaltsroboter „Wakamaru“ [3] gearbeitet. Für ihn werden Algorithmen zur Aufgabenverteilung und Wegfindung entwickelt, die biologische Prozesse nachahmen. Die Anwendung ist die soziale Interaktion mit dem Nutzer, die biologisch möglichst natürliche Bewegungen zu erzeugen.

Im Folgenden wird eine konkrete Anwendung des Yuragi-Prinzips am Beispiel eines biologisch orientierten Amboeben vorgestellt. Anhand einer physikalischen Simulation des Roboters wird anschließend die Qualität der verwendeten Methode untersucht.

**2 Roboterarm**

Der Roboter in Abb. 1 ist eine Nachbildung der Knochen und Muskeln in einem menschlichen Arm und Brustkorb. Er hat daher viele Freiheitsgrade und die pneumatischen künstlichen Muskeln sind wegen ihrer Elastizität schwer zu handhaben. Sie zeigen

**3 Attractor Selection Model**

Die mathematische Grundlage für Yuragi bildet hier das Attractor Selection Model, umgestaltet für die Steuerung der Wechsel von generischen Programmen in Bakterien. Die fluktuante Bewegung findet im  $\mathbb{R}^n$  statt, wobei  $n$  im einfachsten Fall die Anzahl der Freiheitsgrade ist. In diesem Raum sind Attraktoren

gefördert vom japanischen Ministerium für Bildung, Kultur, Sport, Wissenschaft und Technologie

# Zeitschrift Künstliche Intelligenz submission

**M. Braun, Y. Matsumoto, H. Ishiguro:  
*Yuragi: Ausnutzung von Fluktuation am Beispiel eines komplexen Roboterarms.***



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