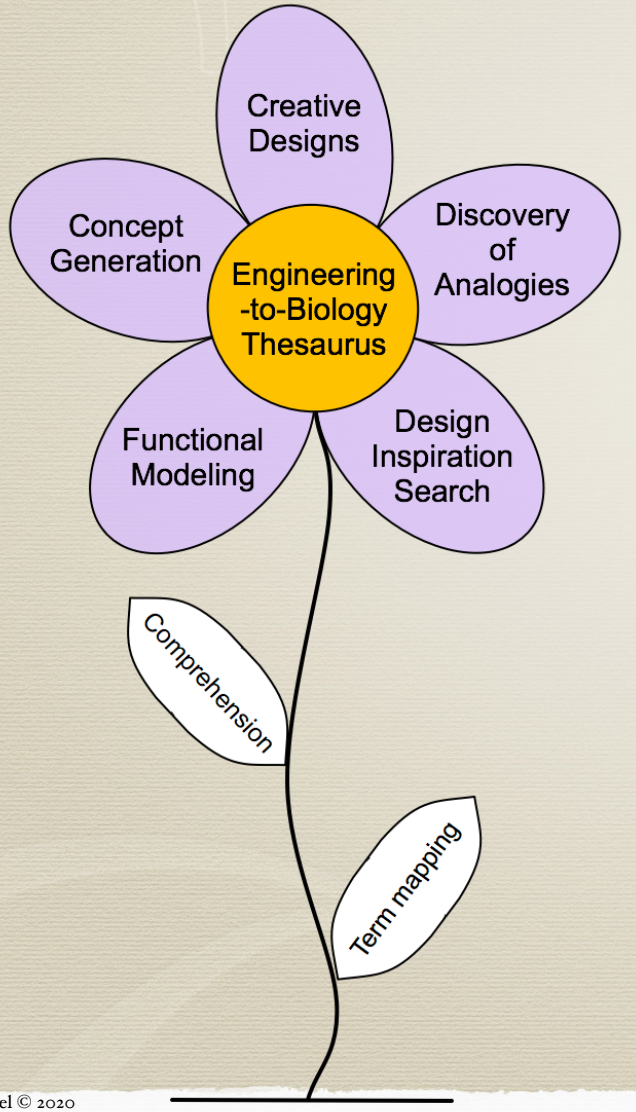
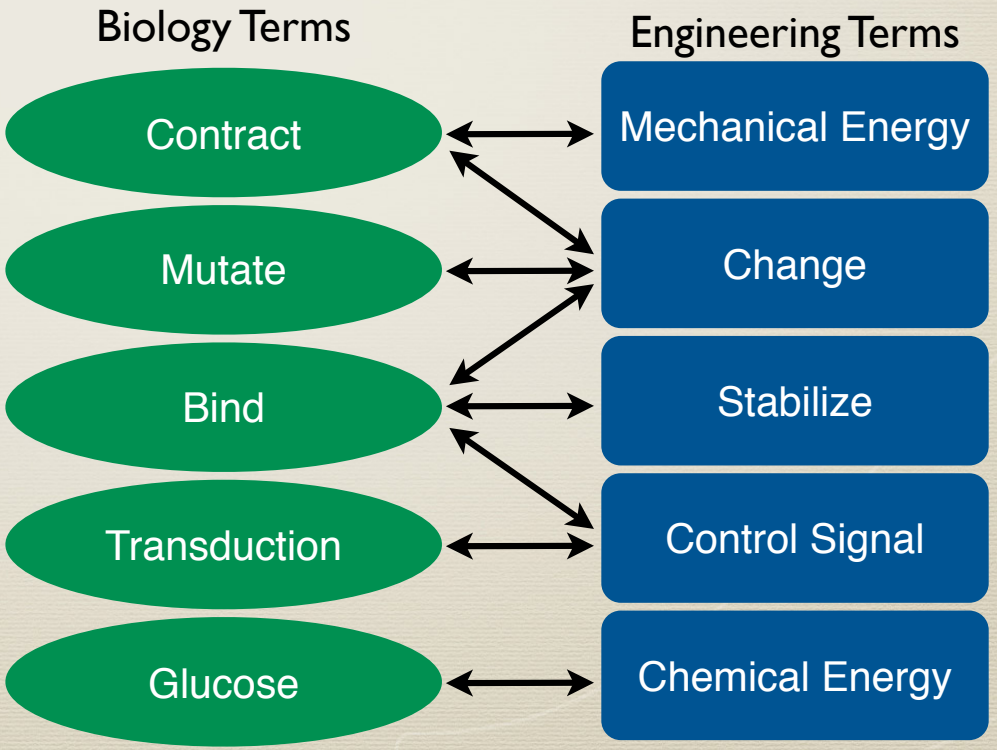
E2B Thesaurus

Translation using an *Engineering-to-Biology Thesaurus* addresses terminology and understanding issues.



- Maps synonymous biology and engineering terms
- Assists with translating biological information into an engineering context



Flow-based functional models follow a standard lexicon to qualitatively represent a system in terms of its function (i.e., what the system does) as opposed to its form (i.e., what comprises the system).

Functional Basis Modeling Lexicon

Functions

Primary	**Branch**	**Channel**	**Connect**	**Control**	**Convert**	**Provision**	**Signal**	**Support**
Secondary	Separate	Import	Couple	Actuate	Convert	Store	Sense	Stabilize
	Distribute	Export	Mix	Regulate		Supply	Indicate	Secure
		Transfer		Change			Process	Position
		Guide		Stop				

Flows

Primary	**Material**	**Energy**		**Signal**
Secondary	Human	Human	Hydraulic	Status
	Gas	Acoustic	Magnetic	Control
	Liquid	Biological	Mechanical	
	Solid	Chemical	Pneumatic	
	Plasma	Electrical	Radioactive/Nuclear	
	Mixture	Electromagnetic	Thermal	

Hirtz, et al. (2002). "A Functional Basis for Engineering Design: Reconciling and Evolving Previous Efforts." Research in Engineering Design **13**(2): 65-82.

The engineering-to-biology thesaurus is structured similarly to the functional basis.

Functional Basis Structure			Addition
Primary	Secondary		2nd Correspondents	2nd Bio-Correspondents
		Tertiary	3rd Correspondents	3rd Bio-Correspondents
		Tertiary	3rd Correspondents	3rd Bio-Correspondents
	Secondary		2nd Correspondents	2nd Bio-Correspondents
		Tertiary	3rd Correspondents	3rd Bio-Correspondents
Primary	Secondary		2nd Correspondents	2nd Bio-Correspondents
		Tertiary	3rd Correspondents	3rd Bio-Correspondents
		Tertiary	3rd Correspondents	3rd Bio-Correspondents
		Tertiary	3rd Correspondents	3rd Bio-Correspondents
	Secondary		2nd Correspondents	2nd Bio-Correspondents

The engineering-to-biology thesaurus is structured similarly to the functional basis.

Functional Basis Terms			Biological Correspondents
Primary	**Secondary**	**Tertiary**	
Material	Liquid		Acid, water, blood, buffer, plasma
	Solid	Object	Cilia, kidney, heart, bone, plasmid, xylem
		Composite	Enzyme, virus, cytoplasm, prokaryote, symplast
	Mixture	Solid-solid	Adenosine, membrane, ribosome, blastula
		Solid-liquid	Cell, protein, blood, algae, phytochrome
Energy	Chemical		Glucose, glycogen, mitochondria, sugar, ligand
	Mechanical		Depress, pressure, stretch, tension, contraction
Branch	Separate		Bleaching, dialysis, meiosis, detach, abscission
		Divide	Anaphase, cleave, metaphase, division
	Distribute		Circulation, diffusion, exchange, scatter, spread
Connect	Couple		Bond, build, mate, phosphorylate, overlap
Control Magnitude	Regulate		Gate, electrophoresis, respire, sustain, preserve
		Increase	Hyperpolarize, pinocytosis, grow, multiply

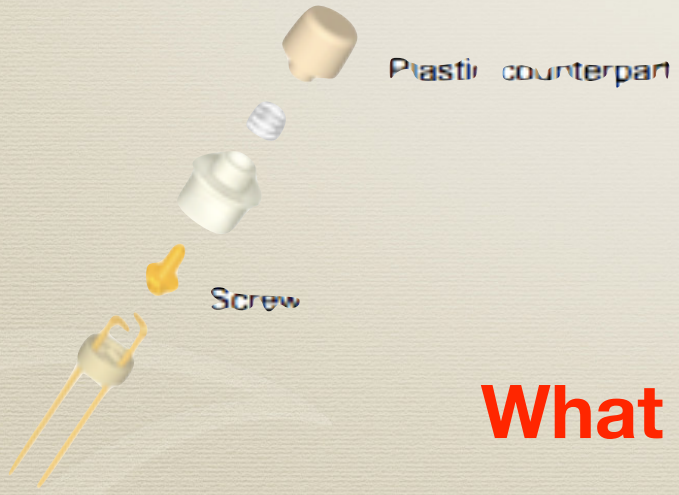
But also structured in the opposite way to allow quick look up of biological terms.

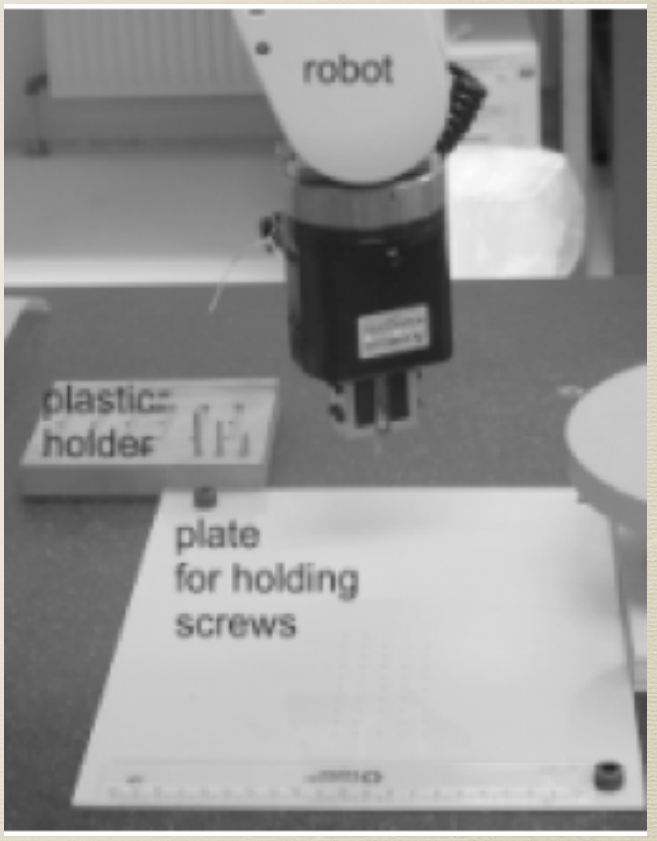
Biological Term (Alphabetical order)	Synonymous Engineering Term (from Functional Basis)
Remain	Regulate
Repel	Export
Replicate	Increase
Repress	Inhibit
Repressor	Solid-Liquid Mixture Material
Respire, respiration	Regulate, Convert
Resting	Status Signal
Retina	Solid-Liquid Mixture Material
Ribosome	Solid-Object Material, Solid-Solid Mixture Material
RNA	Solid-Particulate Material, Solid-Composite Material
Roll	Rotate
Saturated	Status Signal
Scatter	Distribute
Seal	Stop

Example of how one might use the E2B

Re-design a microgripper for an assembly line

- The challenge has been releasing the tiny screws and accurately placing them into the right spot - They are so lightweight and small that van der Waals forces keep them from detaching from the robot's microgripper.





What is the problem here?

Shu, L.H., Hansen, H.N., Gegeckaite, A., Moon, J. and Chan, C. Case Study in Biomimetic Design: Handling and Assembly of Microparts. In Proceedings of ASME IDETC/CIE, 2006.

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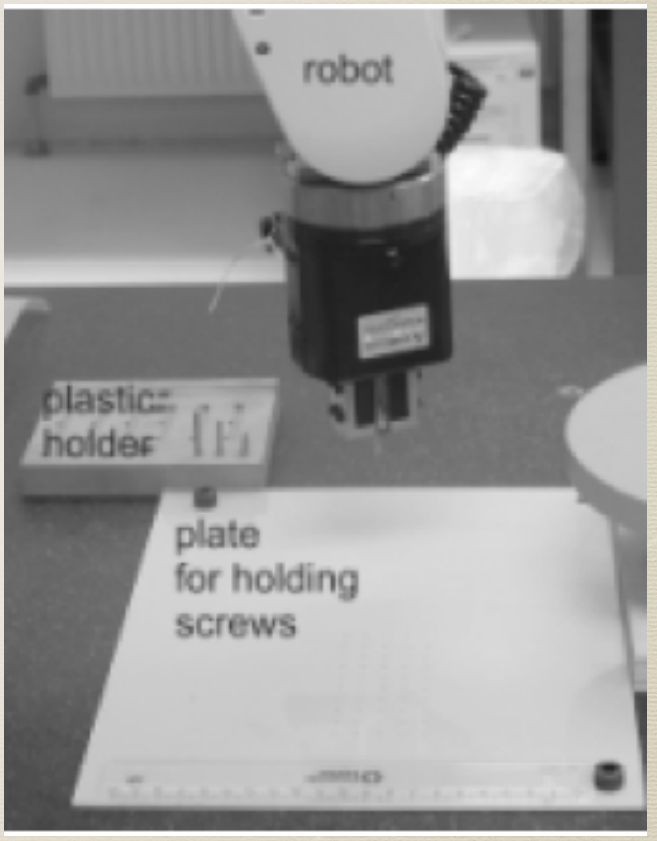

Separation of screw from robot microgripper

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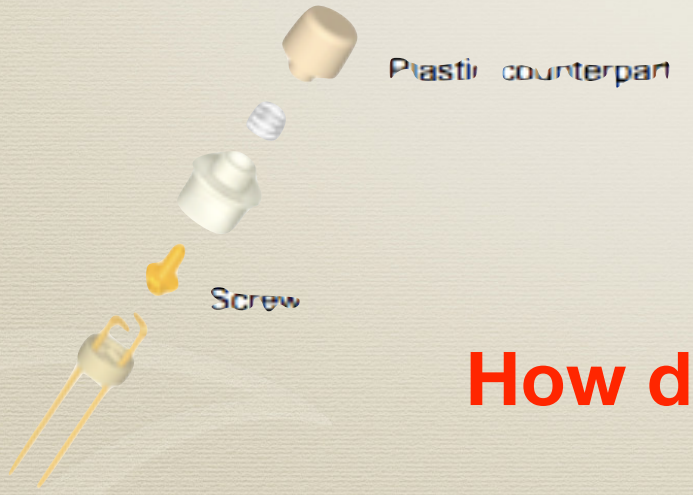
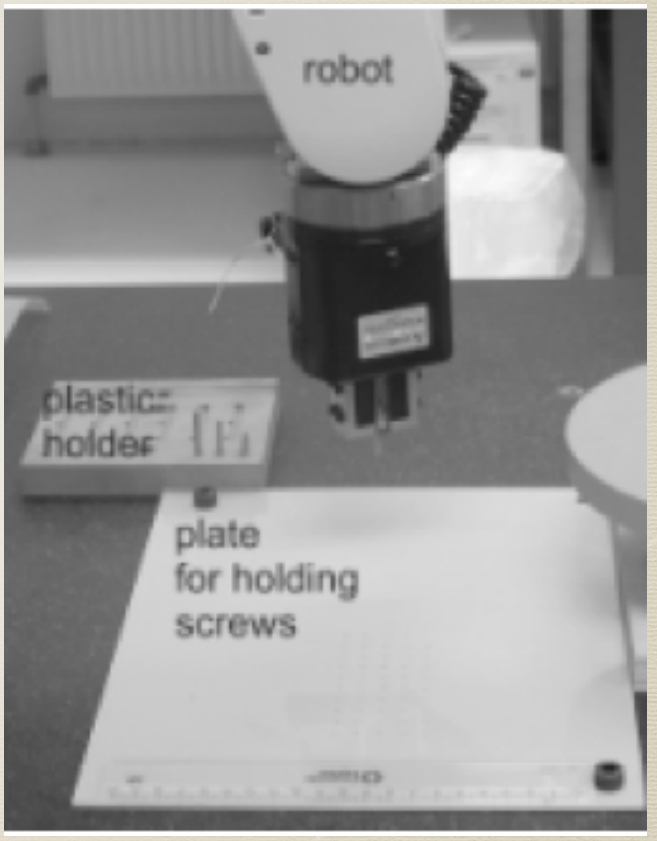




How do natural systems separate?

Shu, L.H., Hansen, H.N., Gegeckaite, A., Moon, J. and Chan, C. Case Study in Biomimetic Design: Handling and Assembly of Microparts. In Proceedings of ASME IDETC/CIE, 2006.

Searching for Inspiration

- Looking to the Engineering-to-Biology Thesaurus for terms that mean *separate* we find:

Table 1: Engineering-to-Biology Thesaurus Function Terms

Functional Basis Terms			Biological Function Correspondent Terms
Class	Secondary	Tertiary	
Branch	Separate		Bleaching, meiosis, abscission, mitosis, segment, *electrophoresis*, dialysis, denature, free, detach, release

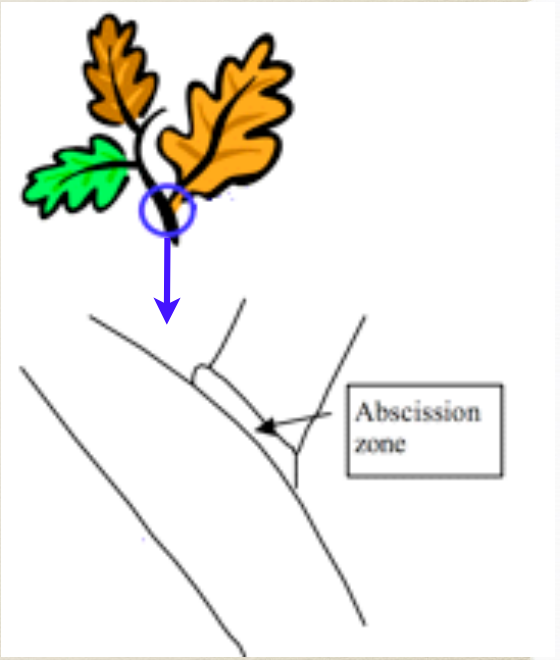
Re-design a microgripper for an assembly line

Biological Term (Alphabetical order)	Synonymous Engineering Term (from Functional Basis)
Abscission	Separate

- Need to read more about Abscission to understand how separation happens
- Use the Engineering-to-Biology Thesaurus to translate the biological information

Translation

- ‘Leaf fall (abscission) is regulated by an interplay of the hormones ethylene and auxin. The effect of auxin on the detachment of old leaves from stems is quite different from root initiation. This process, called abscission, is the cause of autumn leaf fall. Leaves consist of a blade and a petiole that attaches the blade to the stem. Abscission results from the breakdown of a specific part of the petiole, the abscission zone. … The time of abscission of leaves in nature appears to be determined in part by a decrease in the movement of auxin, produced in the blade, through the petiole.’

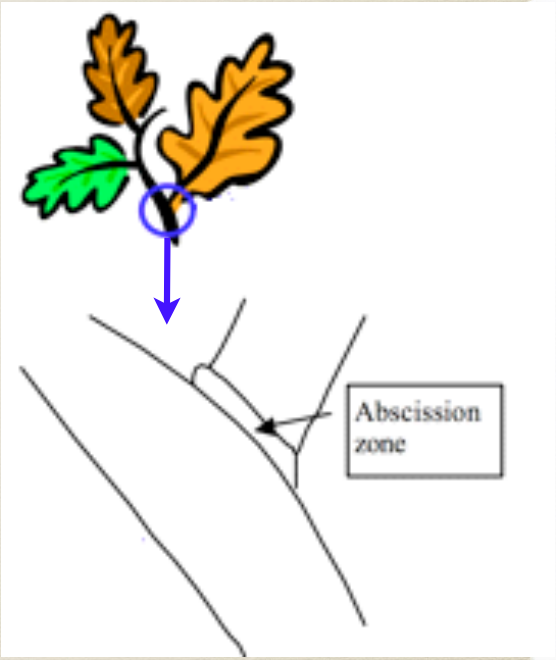


Purves, W.K., Sadava, D., Orians, G.H. and Heller, H.C., 2001, Life, The Science of Biology, 6 ed, Sunderland, MA, Sinauer Associates.

J. H. Shu, Robert B. Stone, Daniel A. McAdams, and James L. Greer. (2007) "Integrating Function-Based and Biomimetic Design for Automatic Concept Generation," International Conference on Engineering Design, v.no. 518.

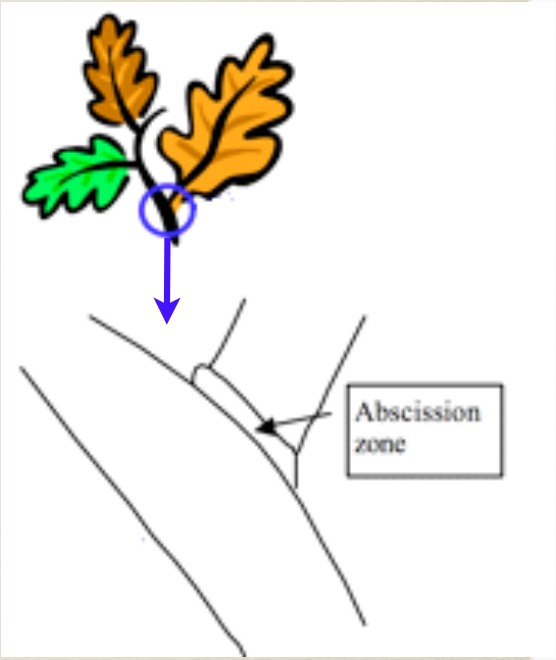
Translation

- Biological term > **Engineering term**
- Abscission > **separation**



Translation

- ‘Leaf fall (**separation**) is regulated by an interplay of the hormones ethylene and auxin. The effect of auxin on the detachment of old leaves from stems is quite different from root initiation. This process, called **separation**, is the cause of autumn leaf fall. Leaves consist of a blade and a petiole that attaches the blade to the stem. **Separation** results from the breakdown of a specific part of the petiole, the **separation** zone. ... The time of **separation** of leaves in nature appears to be determined in part by a decrease in the movement of auxin, produced in the blade, through the petiole.’



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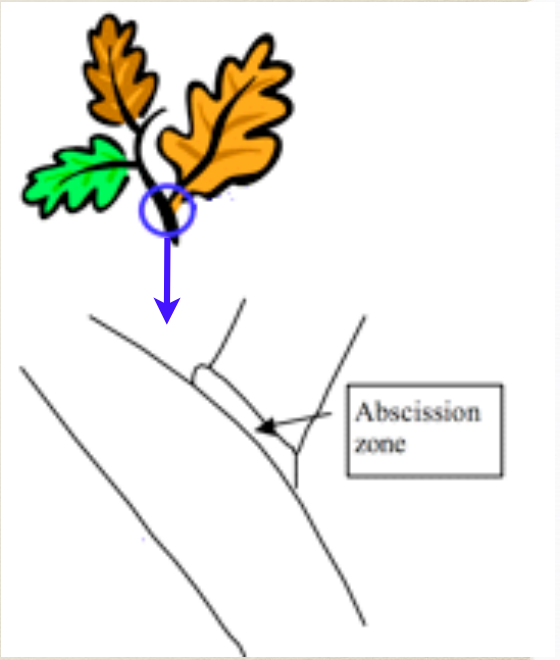
Translation, Round 2

- ‘Leaf fall (**separation**) is regulated by an interplay of the hormones ethylene and auxin. The effect of auxin on the detachment of old leaves from stems is quite different from root initiation. This process, called **separation**, is the cause of autumn leaf fall. Leaves consist of a blade and a petiole that attaches the blade to the stem. **Separation** results from the breakdown of a specific part of the petiole, the **separation** zone. … The time of **separation** of leaves in nature appears to be determined in part by a decrease in the movement of auxin, produced in the blade, through the petiole.’



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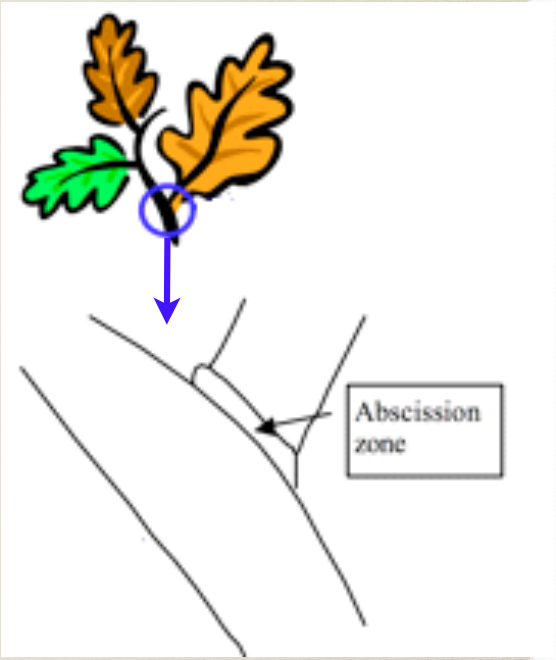
J. H. Shu, Robert B. Stone, Daniel A. McAdams, and James L. Greer. (2007) "Integrating Function-Based and Biomimetic Design for Automatic Concept Generation," International Conference on Engineering Design, v.no. 518.

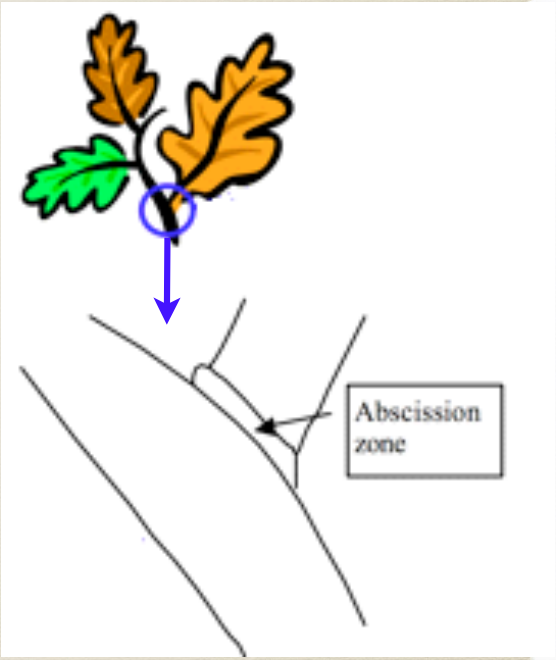
Translation, Round 2

- Biological term > **Engineering term**
- Auxin > **liquid-liquid mixture material**
- Hormones > **liquid-liquid mixture materials**



Translation

- ‘Leaf fall (**separation**) is regulated by an interplay of the **liquid-liquid mixture materials**. The effect of **liquid-liquid mixture material** on the **separate** of old leaves from stems is quite different from root initiation. This process, called **separation**, is the cause of autumn leaf fall. Leaves consist of a blade and a petiole that attaches the blade to the stem. **Separation** results from the breakdown of a specific part of the petiole, the **separation** zone. ... The time of **separation** of leaves in nature appears to be determined in part by a decrease in the movement of **liquid-liquid mixture material**, produced in the blade, through the petiole.’



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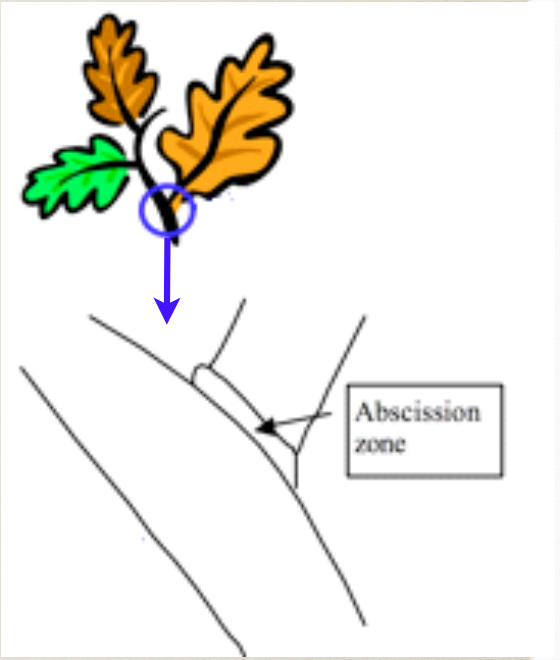
J. H. Shu, Robert B. Stone, Daniel A. McAdams, and James L. Greer. (2007) "Integrating Function-Based and Biomimetic Design for Automatic Concept Generation," International Conference on Engineering Design, v.no. 518.

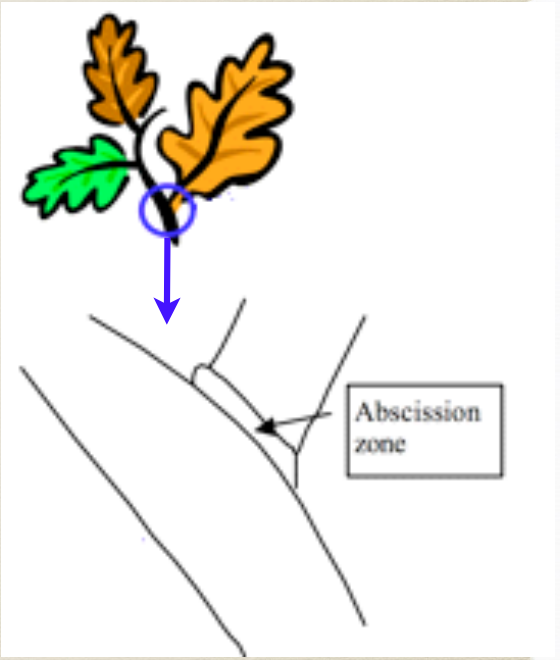
What can we learn?

- When a liquid material stops flowing between the plant and the leaves, a separation zone occurs and the leaf separates from the plant.



Re-design a microgripper for an assembly line

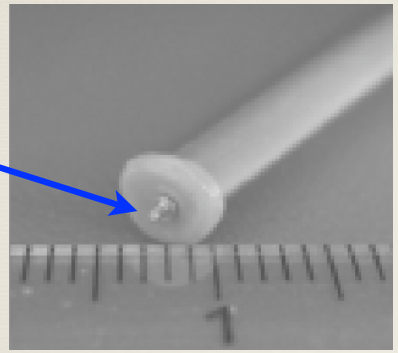
- **Functional requirement:** Separation of screw from robot microgripper
  - Abscission ⇔ Separate
- What is different between abscission and engineered systems?



The separation is sacrificial. The leaf does not re-attach, but a new one can grow.

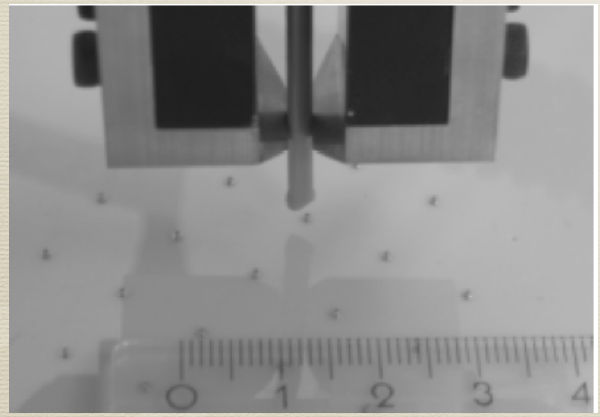
Re-design a microgripper for an assembly line

Sacrificial part

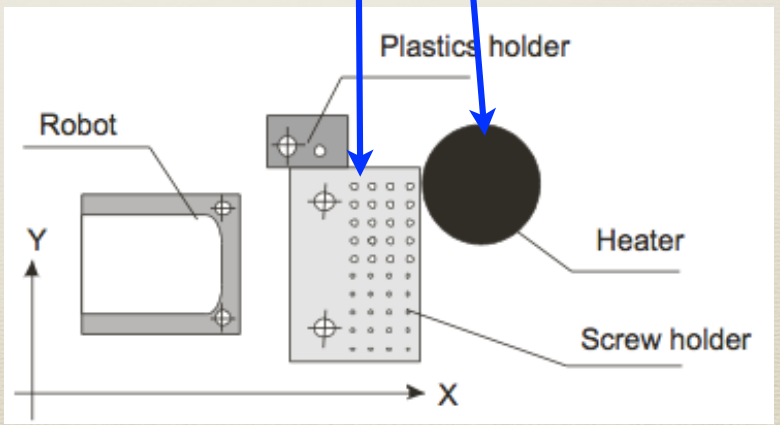


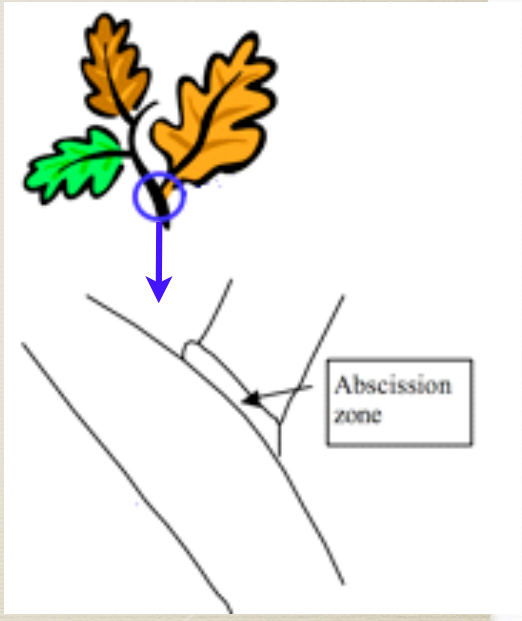
Polypropylene rod with screw

Microgripper holding polypropylene rod



The rod is touched to the hot plate and then to the screw to form an "abscission zone"





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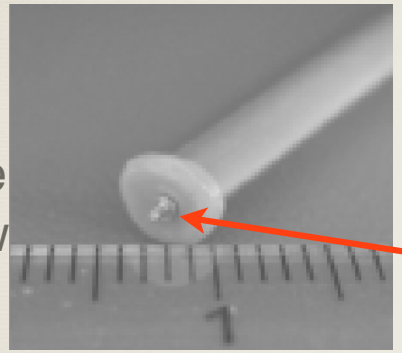
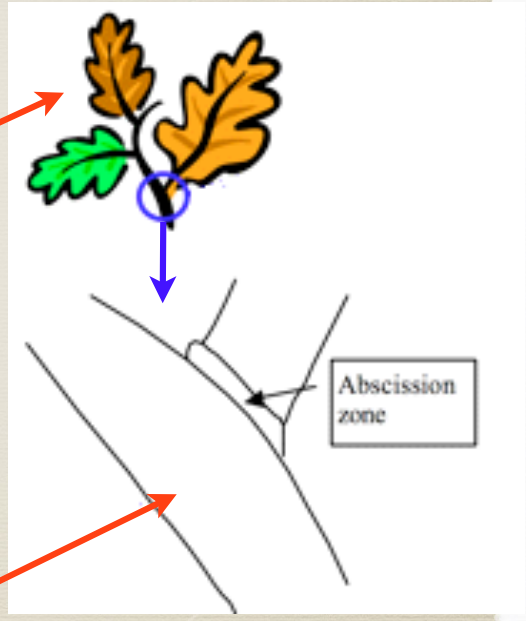
Re-design a microgripper for an assembly line

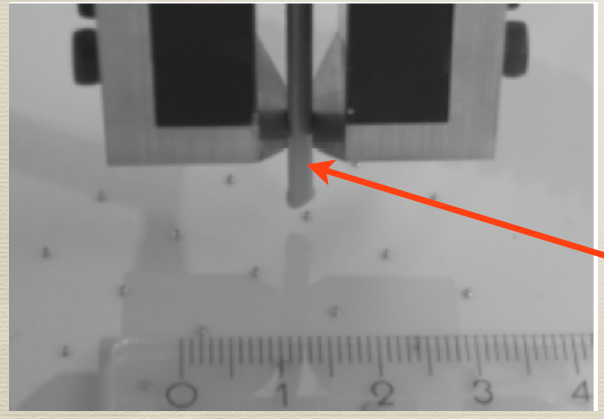
Polypropylene rod with screw



The screw is analogous to the leaf



Microgripper holding polypropylene rod



The polypropylene rod is analogous to the plant

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E2B Thesaurus Summary

* Formatted as a look up table
* Italicized words indicate that it they have multiple meanings
* Useful for...
  * translating biological terms into engineering ones for comprehension
  * establishing analogies through terminology
  * defining biology keywords for an inspiration search

References

* Nagel, J.K.S. (2014) "A Thesaurus for Bioinspired Engineering Design." Chapter 4 in Biologically Inspired Design: Computational Methods and Tools, A. Goel, D.A. McAdams, R.B. Stone (eds.), Springer, ISBN: 1447152476.

* Nagel, J.K.S., Nagel, R., and Eggermont, M. (2013) "Teaching Biomimicry with an Engineering-to-Biology Thesaurus," Proceedings of ASME IDETC/CIE 2013, DEC-12068, Portland, OR. *Nominated for best paper award.

* Nagel, J.K.S., Stone, R.B., McAdams, D.A. (2010) "An Engineering-to-Biology Thesaurus for Engineering Design." ASME IDETC/CIE 2010 DTM-28233, Montreal, Quebec, Canada.

* Stroble, J.K., Stone, R.B., McAdams, D.A., Watkins, S.E. (2009) "An Engineering-to-Biology Thesaurus to Promote Collaboration, Creativity and Discovery." Proceedings of the CIRP Design Conference 2009, pp. 335-368, Cranfield, Bedfordshire, England.