Morphogenesis and evolution of Foraminifera in Framsticks

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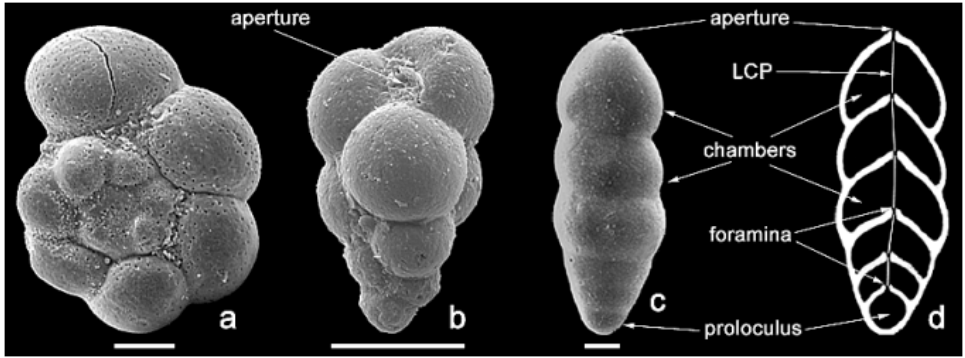
www.framsticks.com

Details of this research are available in [Kom+16]
and at www.framsticks.com/foraminifera.



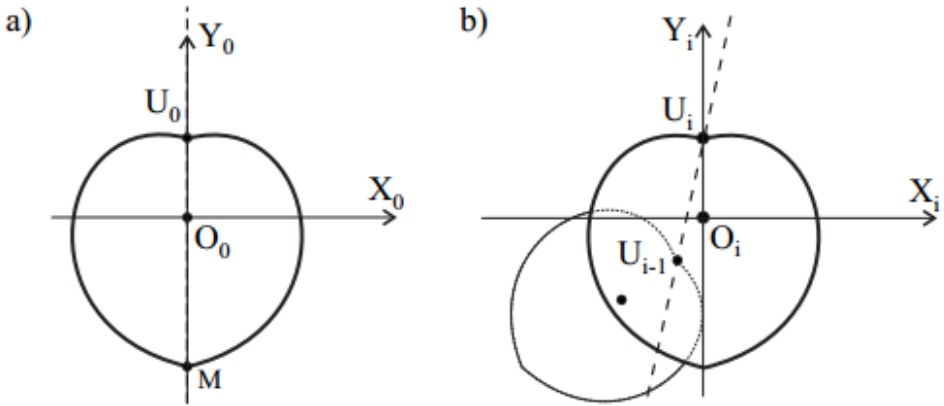
Examples of foraminiferal morphotypes. Scale bar = 50 μm.

Some diagrams shown here come from, and the algorithm is based on [Łab+03].

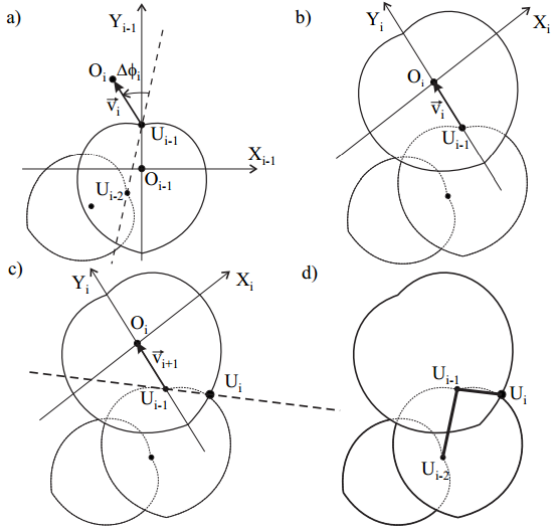
Concepts used in the growth algorithm

- O_i – center of the chamber
- U_i – aperture point
- v_i – growth vector
- reference growth axis

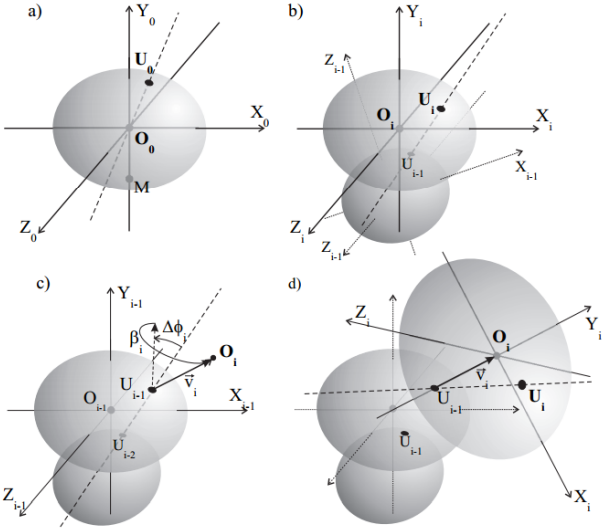
The reference growth axis (2D example)



Creation of a new chamber (2D example)



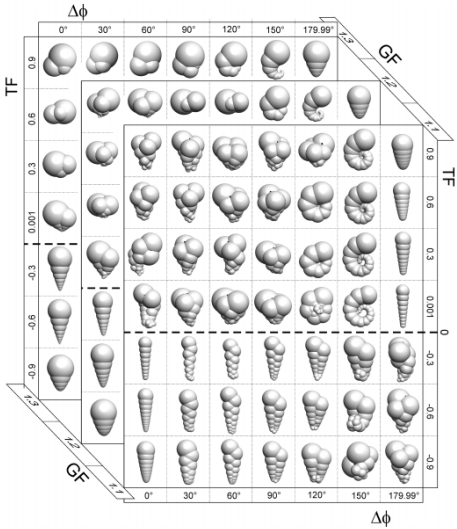
Creation of a new chamber (3D example)



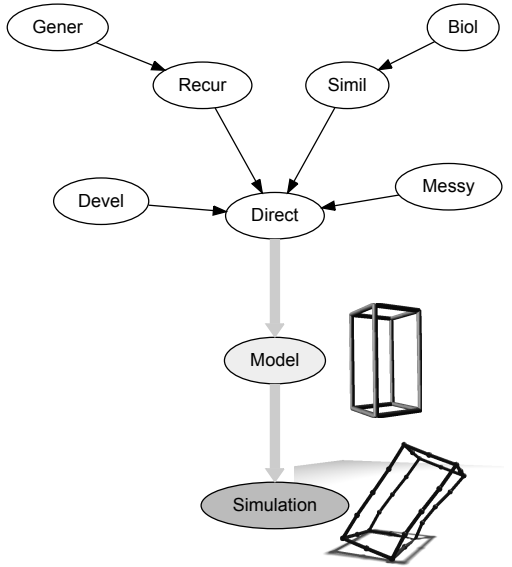
Growth simulation parameters

- k_x, k_y, k_z – chamber scaling rates
  (can be assumed equal: growth factor $GF = k_x = k_y = k_z$)
- TF – translation factor, $TF \in [-1, 1]$
- $\Delta\phi$ – deviation angle, $\Delta\phi \in [-180°, 180°]$
- β – rotation angle, $\beta \in [-180°, 180°]$

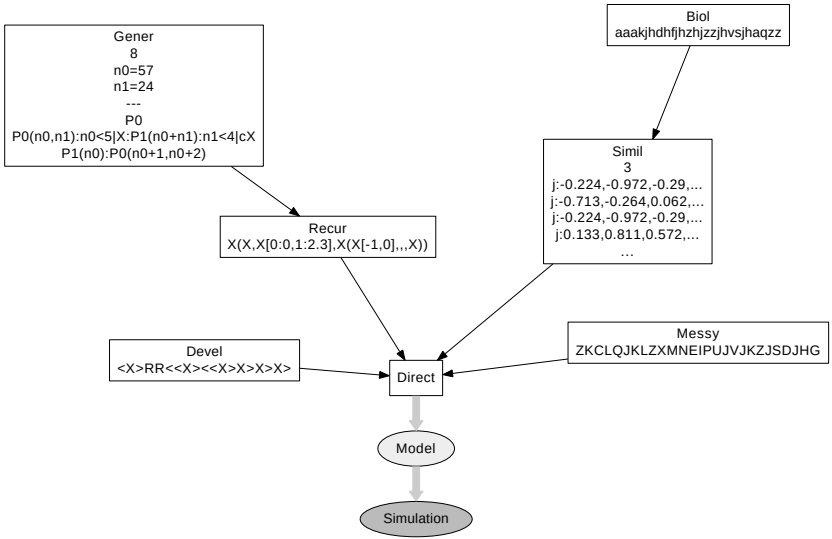
Morphospace resulting from the model



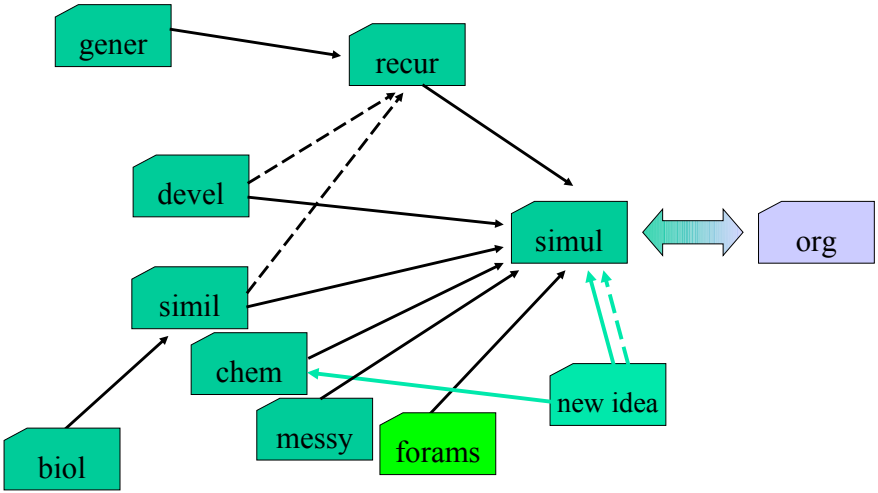
The hierarchy of genetic encodings in Framsticks



Specialized genetic operators for each genetic encoding



Adding foraminiferal genetics to Framsticks



Foraminiferal genotype in Framsticks

"n"	"number of chambers"	d	1	15	6
"sx"	"scale x"	f	1.0	1.1	1.05
"sy"	"scale y"	f	1.0	1.1	1.05
"sz"	"scale z"	f	1.0	1.1	1.05
"tr"	"translation factor"	f	−1	1	0
"a1"	"angle 1"	f	−3.14	3.14	0
"a2"	"angle 2"	f	−3.14	3.14	0

Foraminiferal genotype in Framsticks (C++)


```
// This file is a part of the Framsticks GDK.

ParamEntry fF_growth_params::paramtab[] =
{
 { "n" , 0, CANOMITNAME, "number of chambers", "d 1 15 6", FIELD(number_of_chambers), },
 { "sx", 0, CANOMITNAME, "scale x",      "f 1.0 1.1 1.05", FIELD(scalex), },
 { "sy", 0, CANOMITNAME, "scale y",      "f 1.0 1.1 1.05", FIELD(scaley), },
 { "sz", 0, CANOMITNAME, "scale z",      "f 1.0 1.1 1.05", FIELD(scalez), },
 { "tr", 0, CANOMITNAME, "translation factor", "f -1 1 0", FIELD(translation), },
 { "a1", 0, CANOMITNAME, "angle 1",  "f -3.1415 3.1415 0", FIELD(angle1), },
 { "a2", 0, CANOMITNAME, "angle 2",  "f -3.1415 3.1415 0", FIELD(angle2), },
};
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```

Sample genotypes:

- /*F*/ 6, 1.05, 1.05, 1.05, 0.0, 0.0, 0.0

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};
```

Sample genotypes:

- /*F*/ 6, 1.05, 1.05, 1.05, 0.0, 0.0, 0.0
- /*F*/ 6, 1.05, 1.05, 1.05, 0.312, 0.0, 0.0

Foraminiferal genotype in Framsticks (C++)


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- /*F*/ 6, 1.05, 1.05, 1.05, 0.0, 0.0, 0.0
- /*F*/ 6, 1.05, 1.05, 1.05, 0.312, 0.0, 0.0
- /*F*/ 6, 1.05, 1.05, 1.038, 0.312, 0.0, 0.0

Foraminiferal genotype in Framsticks (C++)


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ParamEntry fF_growth_params::paramtab[] =
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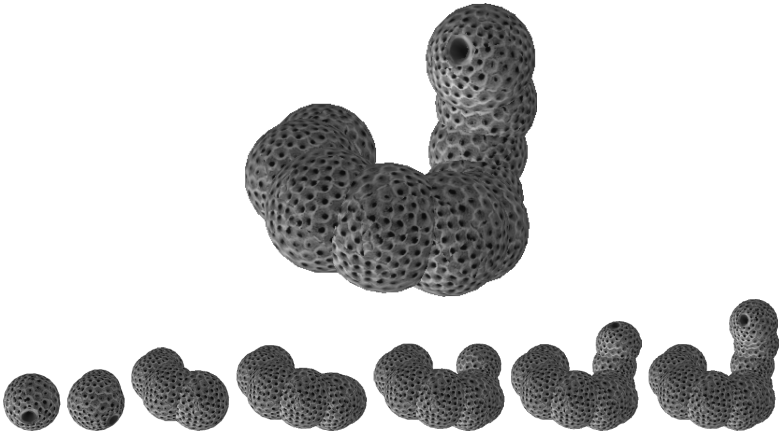
- /*F*/ 6, 1.05, 1.05, 1.05, 0.312, 0.0, 0.0
- /*F*/ 6, 1.05, 1.05, 1.038, 0.312, 0.0, 0.0

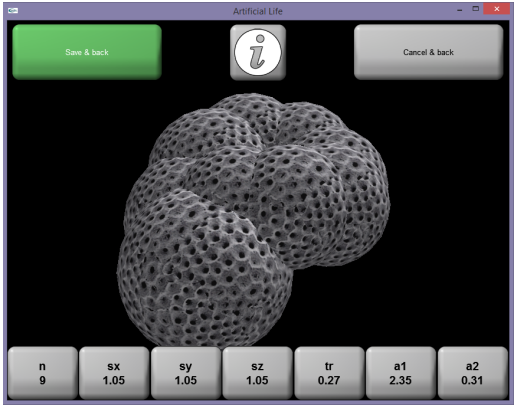
Source code: https://www.framsticks.com/trac/framsticks/browser/cpp/frams/genetics/fF/fF_genotype.cpp

Foraminifera genotype and phenotype

N	K_x	K_y	K_z	TF	$\Delta\phi$	$\Delta\beta$
10	1	1	1	-0.02	0.64	0.72



Genotype → Phenotype



The phenotype development process and its properties are described in more detail in [Kom+16].

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- . . . affect fitness of the corresponding phenotype (in phenotype space)
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- . . . affect fitness of the corresponding phenotype (in phenotype space)
- "fitness landscape"

- Genotype consists of values (numbers)
- Mutation: creep
- Crossing over: average

- Fitness:
  - model: length, width, depth, body volume, surface area, . . .
  - simulation: height, speed, . . .

Putting it all together

Genetics, morphology, simulation, evolution

Let's see how it works!

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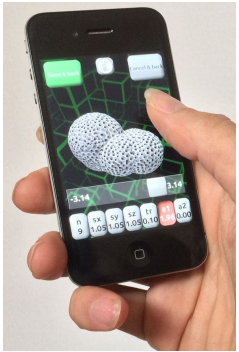

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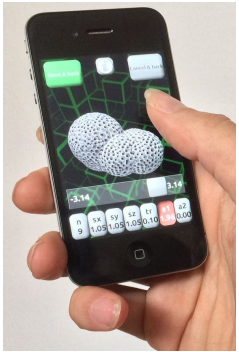

References I

[Kom+16] Maciej Komosinski et al. "Application of a morphological similarity measure to the analysis of shell morphogenesis in Foraminifera". In: *Man–Machine Interactions 4*. Ed. by Aleksandra Gruca et al. Vol. 391. Advances in Intelligent Systems and Computing. Springer, 2016, pp. 215–224. ISBN: 978-3-319-23436-6. DOI: 10.1007/978-3-319-23437-3_18. URL: http://www.framsticks.com/files/common/ForaminiferaGenotypePhenotypeMapping.pdf.

[Łab+03] Paweł Łabaj et al. "2D and 3D numerical models of the growth of foraminiferal shells". In: *LNCS 2657 (ICCS 2003: International Conference Proceedings)*. Springer. 2003, pp. 669–678.