

## Paper 43: Morphogenic Shape Grammars for the Design of Engineering Structures

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# Introduction

 <b>KING POST</b> LATE 19TH-EARLY 20TH CENTURY LENGTH: 10'-00" TO 20'-00"	 <b>PRATT</b> LATE 19TH-EARLY 20TH CENTURY LENGTH: 10'-00" TO 20'-00"	 <b>BALTIMORE (PETIT)</b> LATE 19TH-EARLY 20TH CENTURY LENGTH: 10'-00" TO 20'-00"	 <b>WARREN</b> LATE 19TH-EARLY 20TH CENTURY LENGTH: 10'-00" TO 20'-00"
 <b>QUEEN POST</b> LATE 19TH-EARLY 20TH CENTURY LENGTH: 10'-00" TO 20'-00"	 <b>PRATT HALF-BIRD</b> LATE 19TH-EARLY 20TH CENTURY LENGTH: 10'-00" TO 20'-00"	 <b>PENNSYLVANIA (PETIT)</b> LATE 19TH-EARLY 20TH CENTURY LENGTH: 10'-00" TO 20'-00"	 <b>WARREN</b> LATE 19TH-EARLY 20TH CENTURY LENGTH: 10'-00" TO 20'-00"
 <b>BURR ARCH TRUSS</b> LATE 19TH-EARLY 20TH CENTURY LENGTH: 10'-00" TO 20'-00"	 <b>TRUSS LEO BEADSTAPLE</b> LATE 19TH-EARLY 20TH CENTURY LENGTH: 10'-00" TO 20'-00"	 <b>LENTICULAR (PARABOLIC)</b> LATE 19TH-EARLY 20TH CENTURY LENGTH: 10'-00" TO 20'-00"	 <b>DOUBLE INTERSECTION WARREN</b> LATE 19TH-EARLY 20TH CENTURY LENGTH: 10'-00" TO 20'-00"
 <b>TOWN LATTICE</b> LATE 19TH-EARLY 20TH CENTURY LENGTH: 10'-00" TO 20'-00"	 <b>PARKER</b> LATE 19TH-EARLY 20TH CENTURY LENGTH: 10'-00" TO 20'-00"	 <b>GREINER</b> LATE 19TH-EARLY 20TH CENTURY LENGTH: 10'-00" TO 20'-00"	 <b>PEGRAM</b> LATE 19TH-EARLY 20TH CENTURY LENGTH: 10'-00" TO 20'-00"
 <b>HOWE</b> LATE 19TH-EARLY 20TH CENTURY LENGTH: 10'-00" TO 20'-00"	 <b>CAMELBACK</b> LATE 19TH-EARLY 20TH CENTURY LENGTH: 10'-00" TO 20'-00"	 <b>DOUBLE INTERSECTION PRATT</b> LATE 19TH-EARLY 20TH CENTURY LENGTH: 10'-00" TO 20'-00"	 <b>POST</b> LATE 19TH-EARLY 20TH CENTURY LENGTH: 10'-00" TO 20'-00"
 <b>BOWSTRING ARCH-TRUSS</b> LATE 19TH-EARLY 20TH CENTURY LENGTH: 10'-00" TO 20'-00"	 <b>CAMELBACK</b> LATE 19TH-EARLY 20TH CENTURY LENGTH: 10'-00" TO 20'-00"	 <b>SCHWEDER</b> LATE 19TH-EARLY 20TH CENTURY LENGTH: 10'-00" TO 20'-00"	 <b>BOLLMAN</b> LATE 19TH-EARLY 20TH CENTURY LENGTH: 10'-00" TO 20'-00"
 <b>WADCELL 'A' TRUSS</b> LATE 19TH-EARLY 20TH CENTURY LENGTH: 10'-00" TO 20'-00"	 <b>KELLOGG</b> LATE 19TH-EARLY 20TH CENTURY LENGTH: 10'-00" TO 20'-00"	 <b>K-TRUSS</b> LATE 19TH-EARLY 20TH CENTURY LENGTH: 10'-00" TO 20'-00"	 <b>FINK</b> LATE 19TH-EARLY 20TH CENTURY LENGTH: 10'-00" TO 20'-00"
 <b>WICHERT</b> LATE 19TH-EARLY 20TH CENTURY LENGTH: 10'-00" TO 20'-00"	<b>TRUSSES</b> HISTORIC AMERICAN ENGINEERING RECORD LATE 19TH-EARLY 20TH CENTURY LENGTH: 10'-00" TO 20'-00"		 <b>STEERING</b> LATE 19TH-EARLY 20TH CENTURY LENGTH: 10'-00" TO 20'-00"
<b>TRUSS IDENTIFICATION - BRIDGE TYPES</b>			

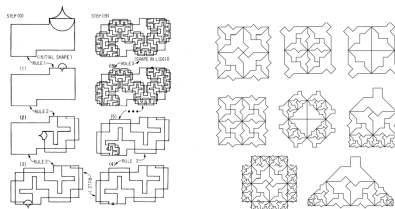
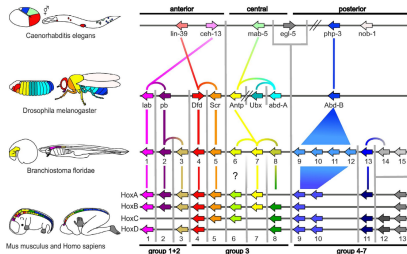


Figure 8-3. Generation of a shape using SDF.

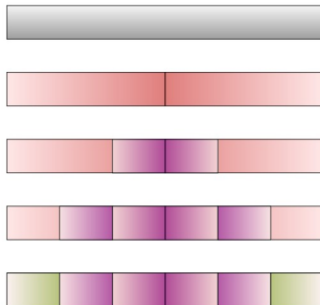
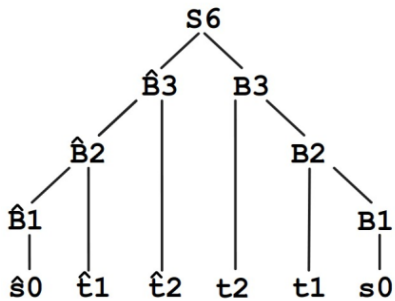
Stiny & Gips (1972)

Grasl & Economou (2018)



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# Morphogen Analogy



Warren V Truss



Warren Truss



Pratt Truss



K Truss



# Example grammar - all steps

Gradient



Production

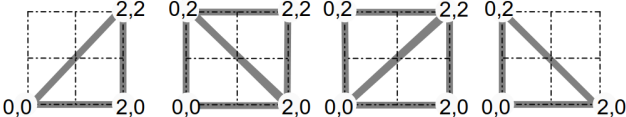
$\hat{s}_0$

$\hat{t}_1$

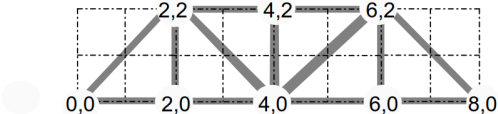
$t_1$

$s_0$

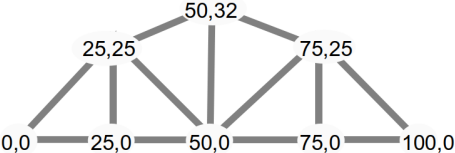
Local shape



Global shape

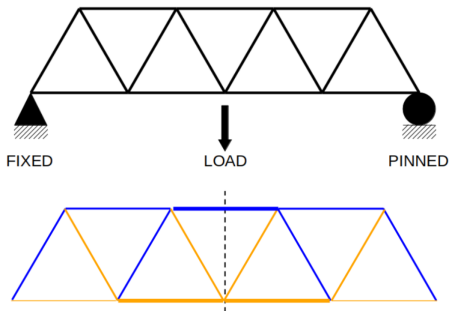


Physical structure

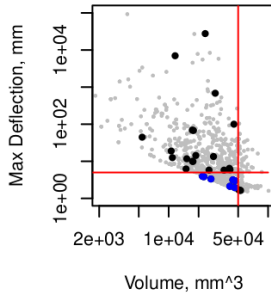
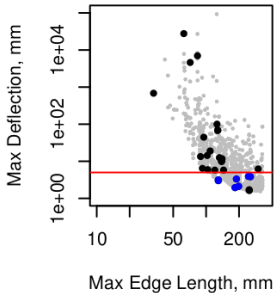
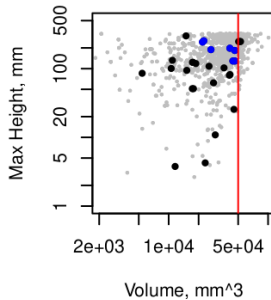
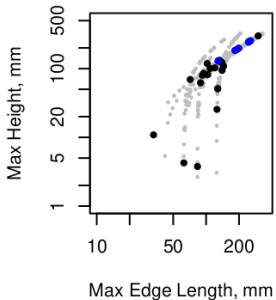


# Evolutionary search

- NSGA II algorithm, with 4 objectives to minimise:
  - material volume;**
  - deflection under load;**
  - maximum edge length;**
  - maximum height.**
- Genes for: truss type; member cross-sectional area; number of segments; attribute-to-height ratio
- FEA analysis using Calculix simulation software gives deflection value
- population 200, run for 100 generations

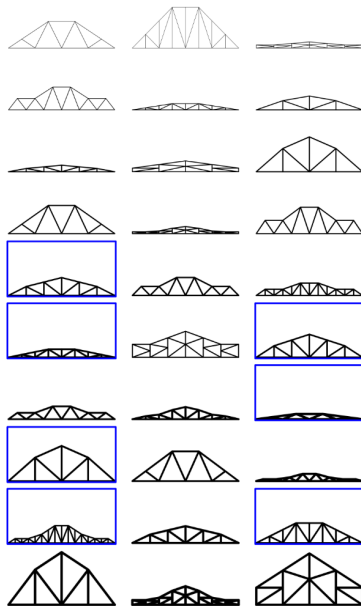


# Fitness Landscape

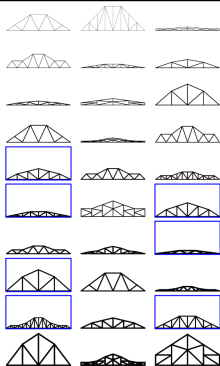
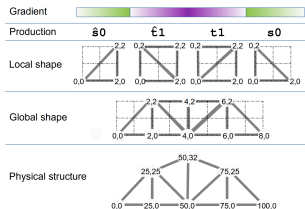


# Pareto structures

- Wide range of structures generated
- Real engineering considerations can drive the search
- Search over a *range* of topologies made possible. Scope for topology optimisation beyond this stage.



# Summary



- The complexity of real engineering structures can be described via shape grammars with attributes that emulate chemical gradients
- A genetic encoding of these grammars allows evolutionary search for suitable structures
- This approach allows feedback from FEA simulations to influence the gestalt form of engineering designs



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