

# Software for plant Synthetic Biology

**Jim Haseloff**

**University of Cambridge**

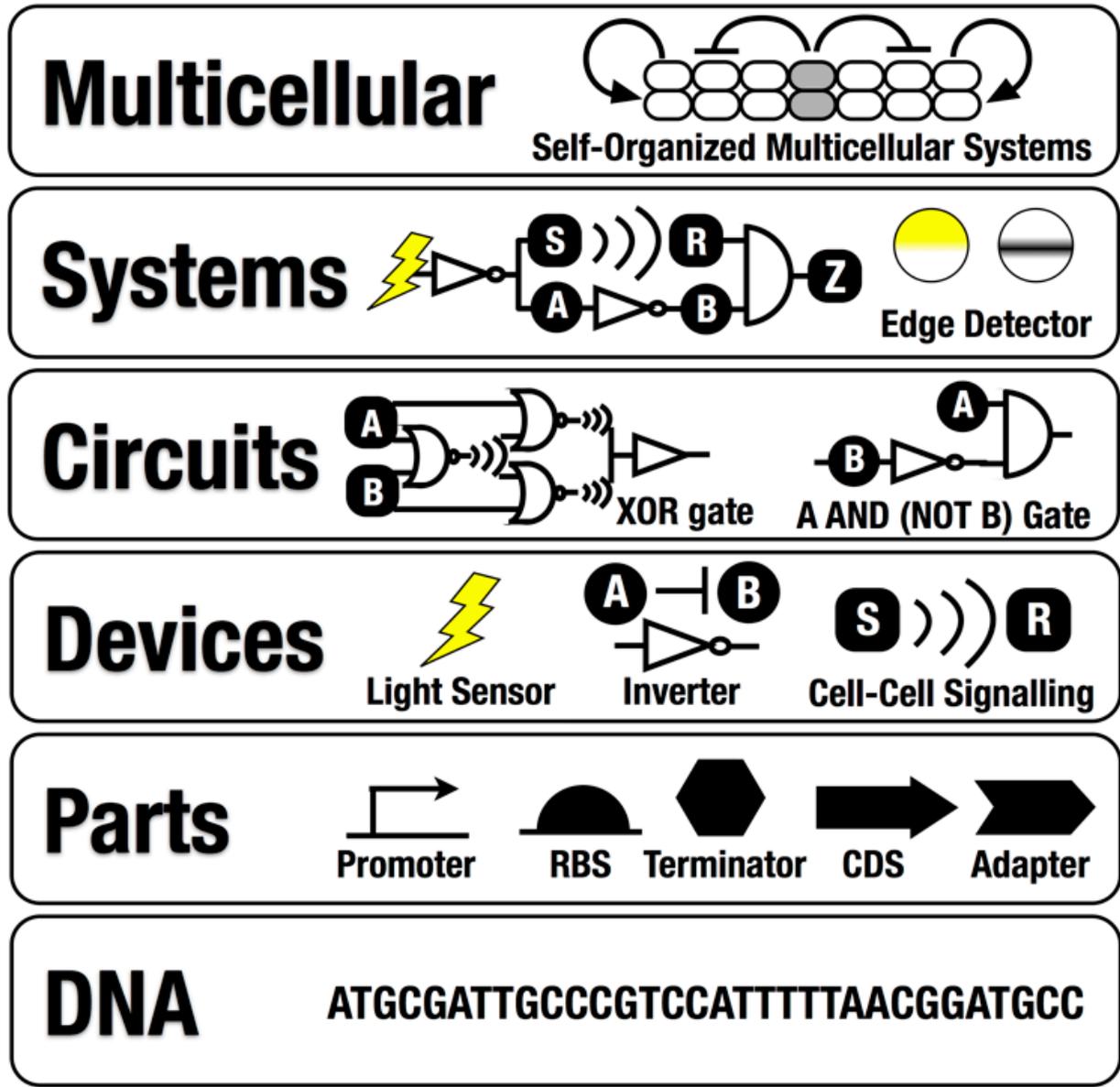
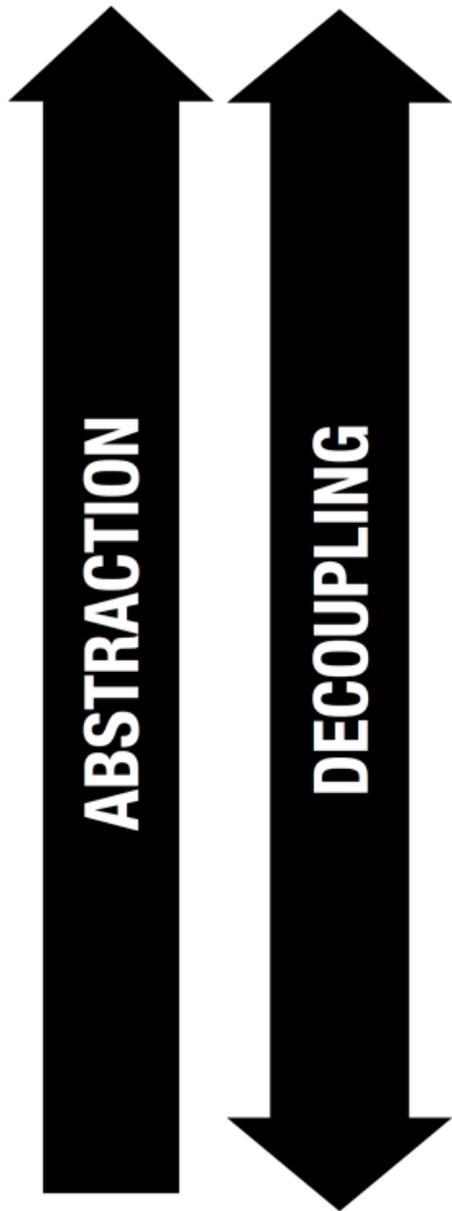
[www.haseloff-lab.org](http://www.haseloff-lab.org)

[www.synbio.org.uk](http://www.synbio.org.uk)

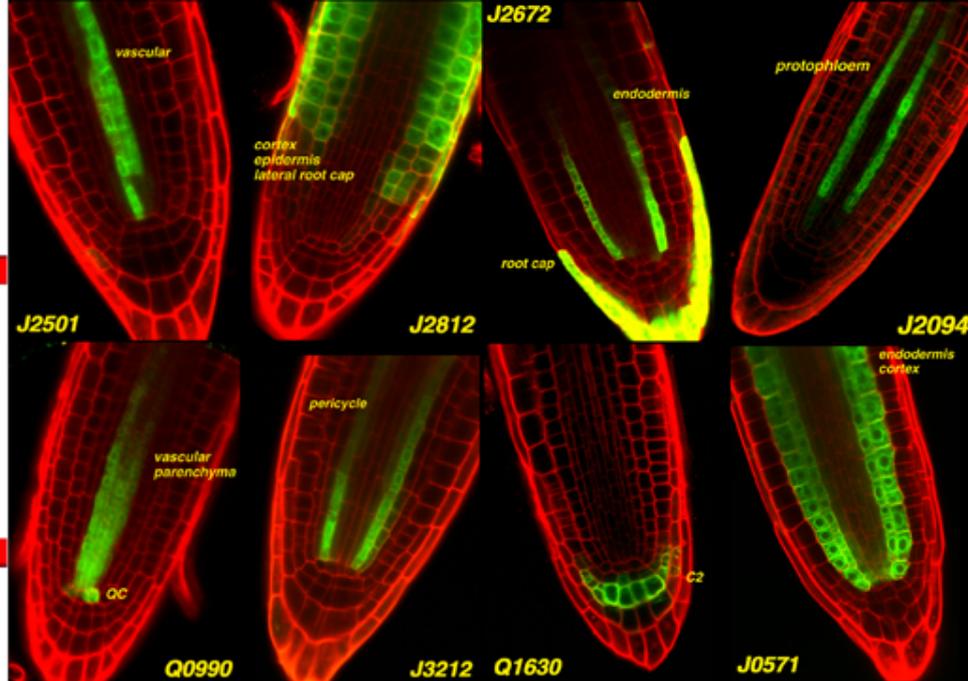
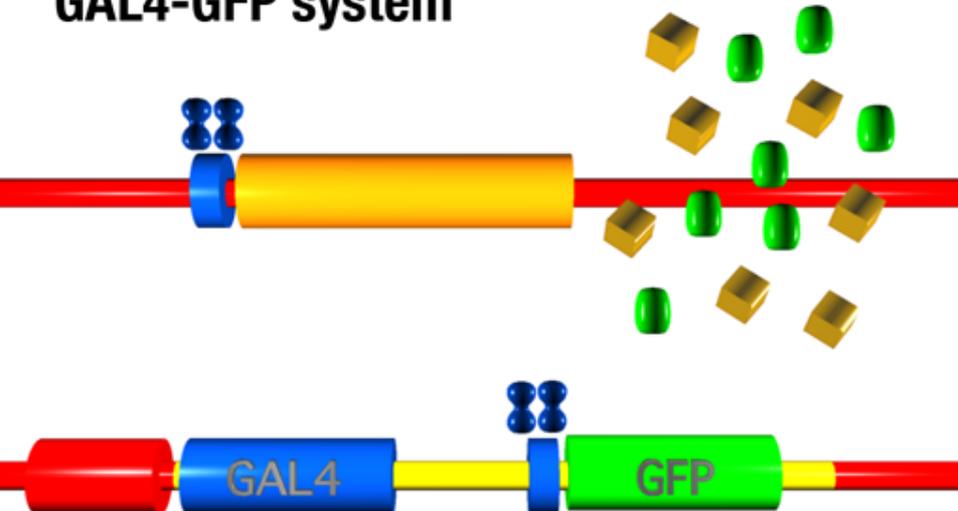
# What is *Synthetic* Biology?

**syn·thet·ic** [sin-thet-ik] –adjective

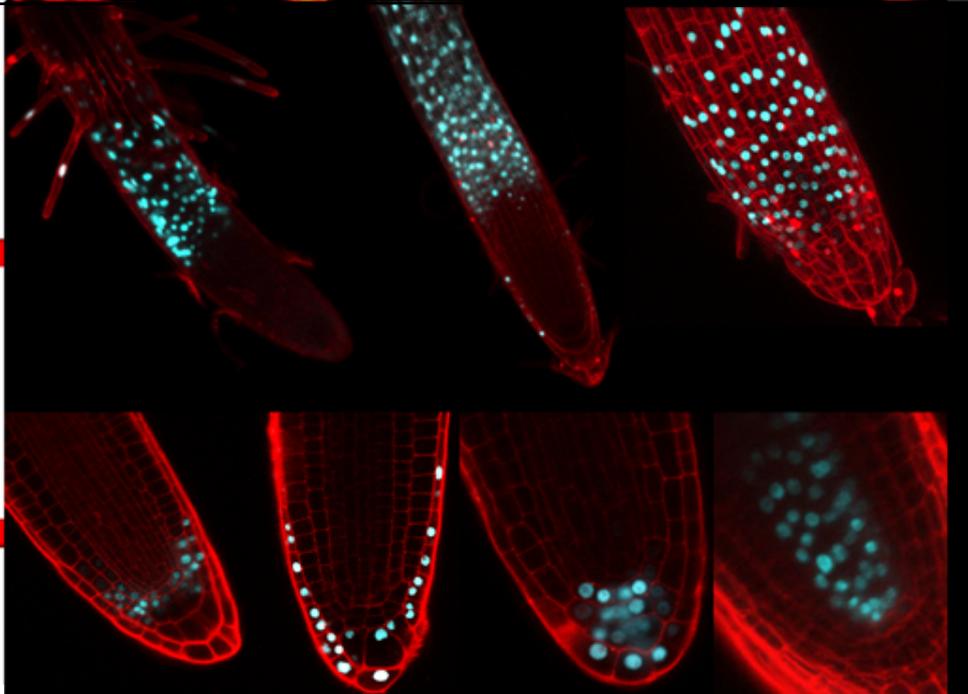
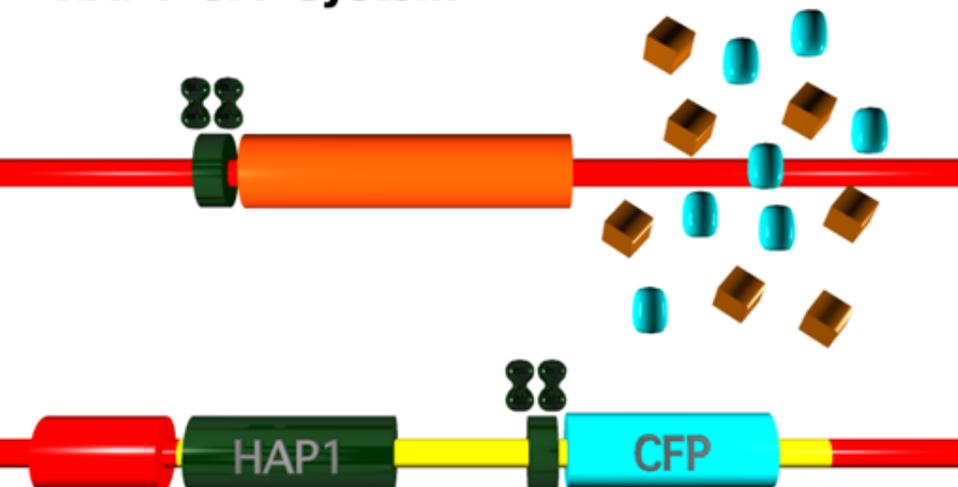
1. Prepared or made artificially, not of natural origin.
2. Relating to, or involving synthesis  
(construction of a coherent whole from  
separate elements)



## GAL4-GFP system



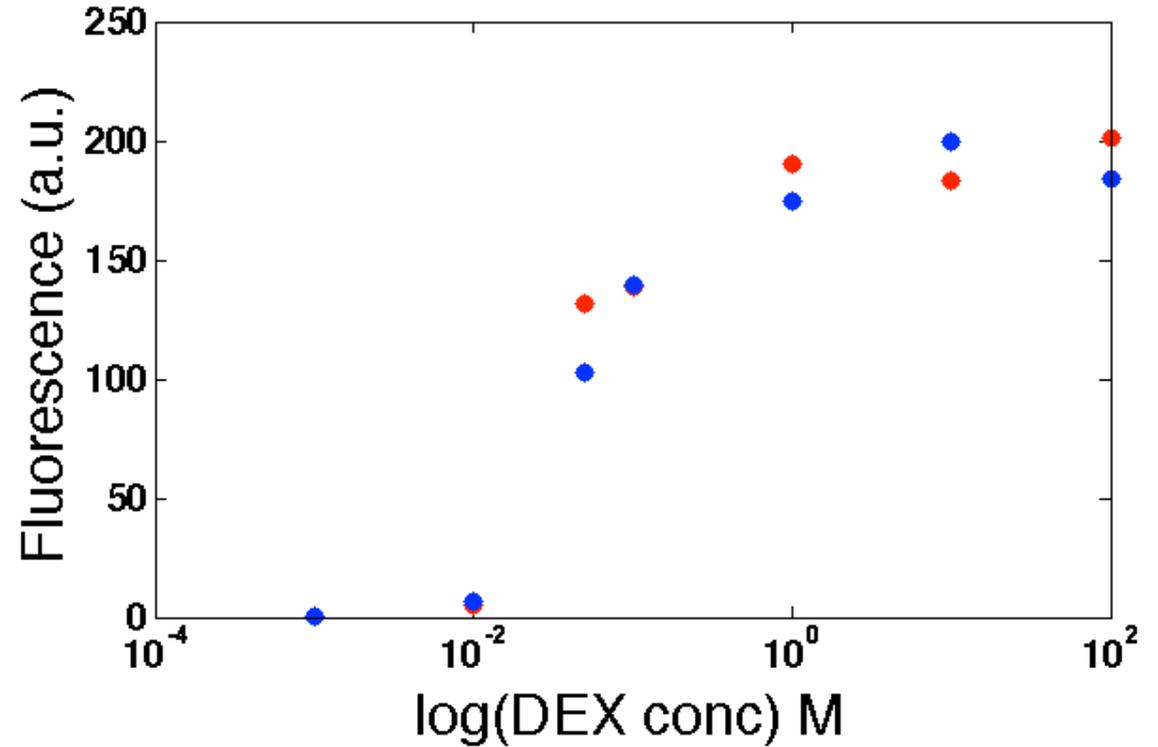
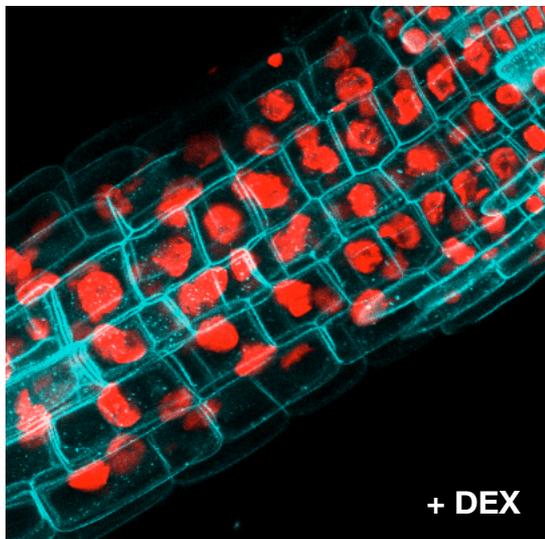
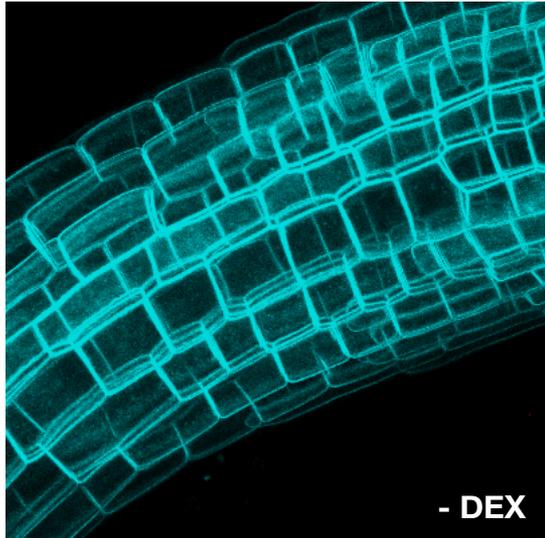
## HAP1-CFP system



Triggers for gene expression

# Temporal switching

Inducible control of HAPI-mediated gene expression

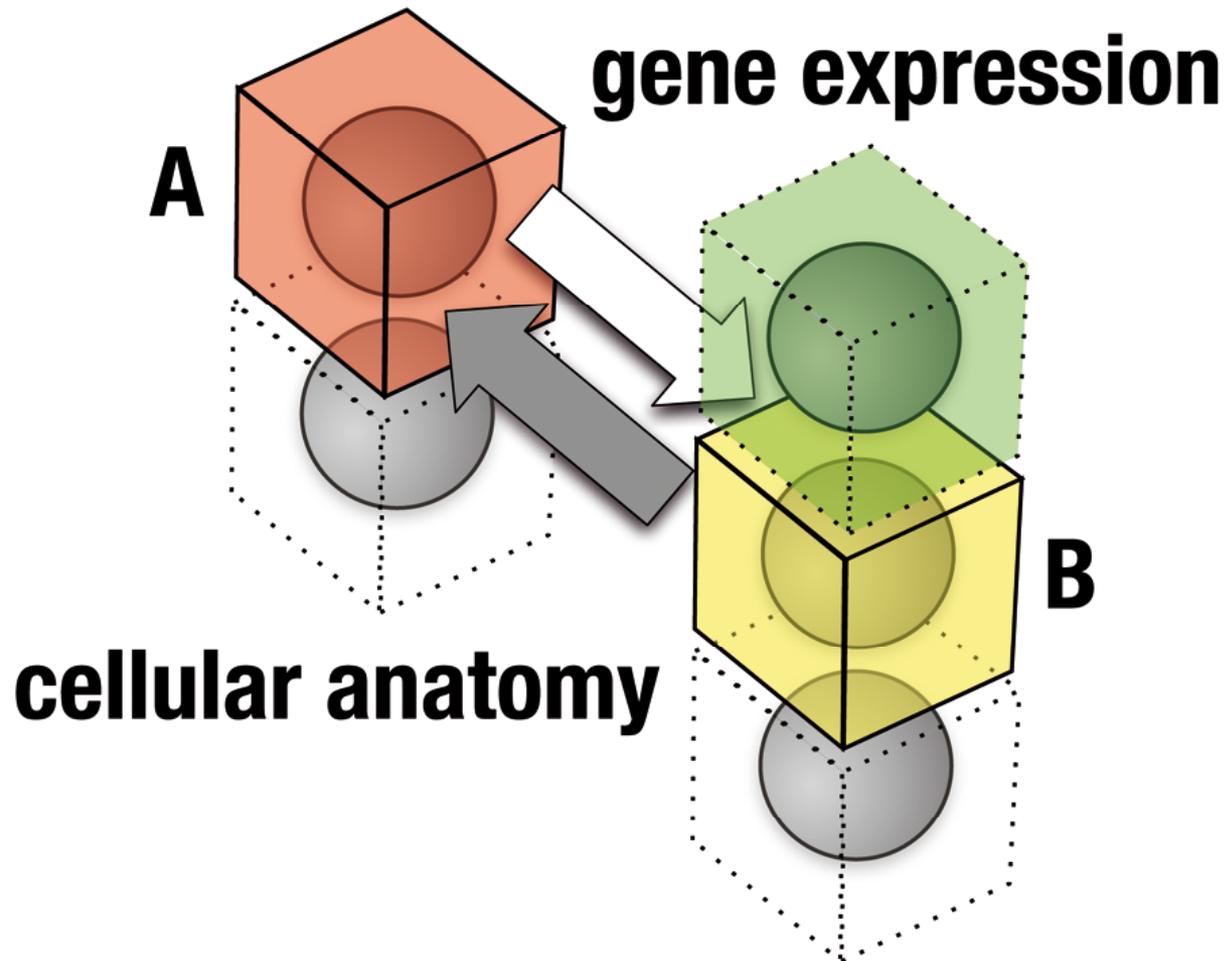


# Testbed for synthetic biology in plants



*Marchantia polymorpha*

# The properties of living systems are governed by parallelism and feedback



# Design cycle for Synthetic Biology systems

1.

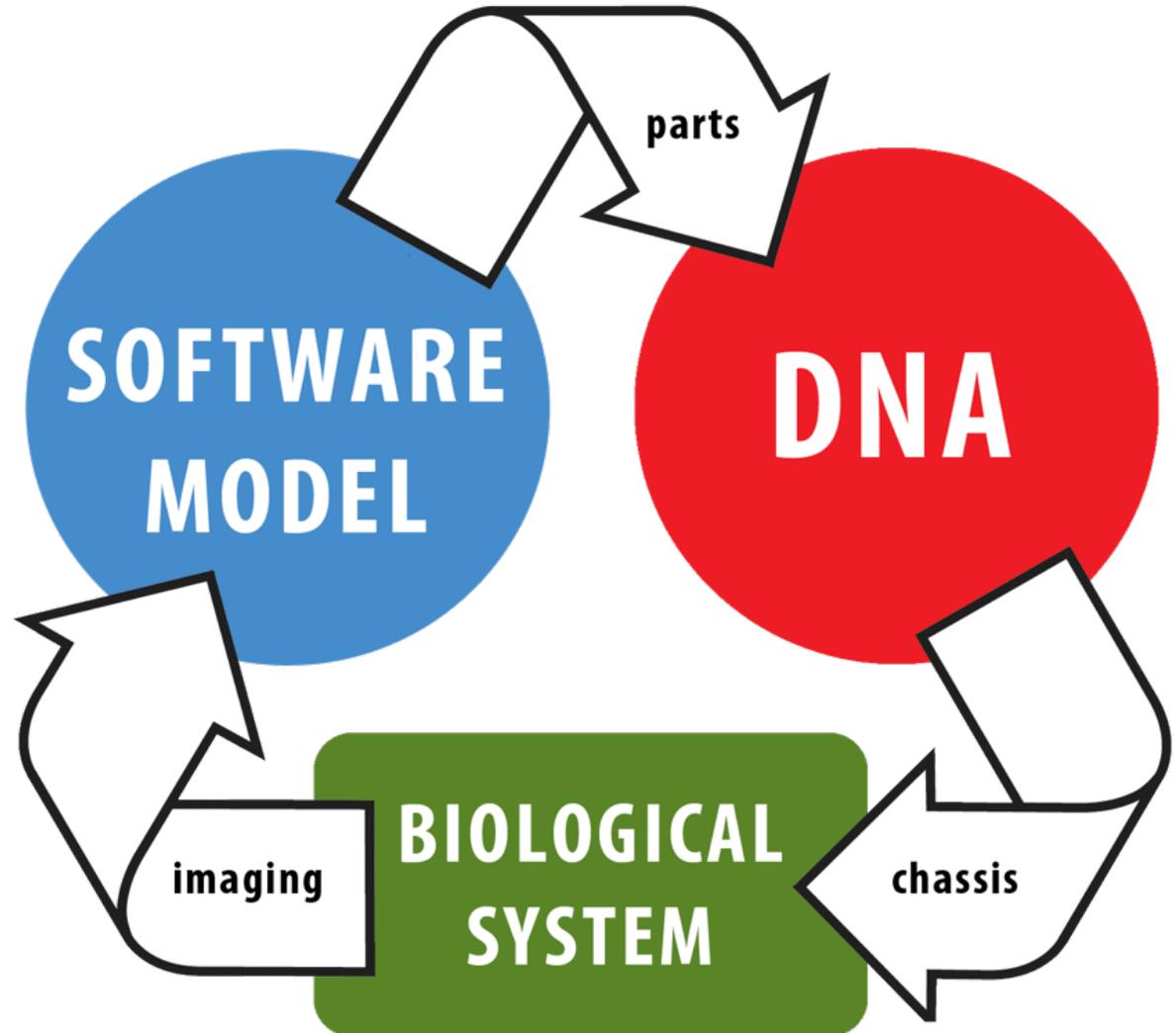
Specification and design of the system using computer models of the biological system

2.

Construction of genetic circuits using standard DNA parts and high throughput assembly techniques

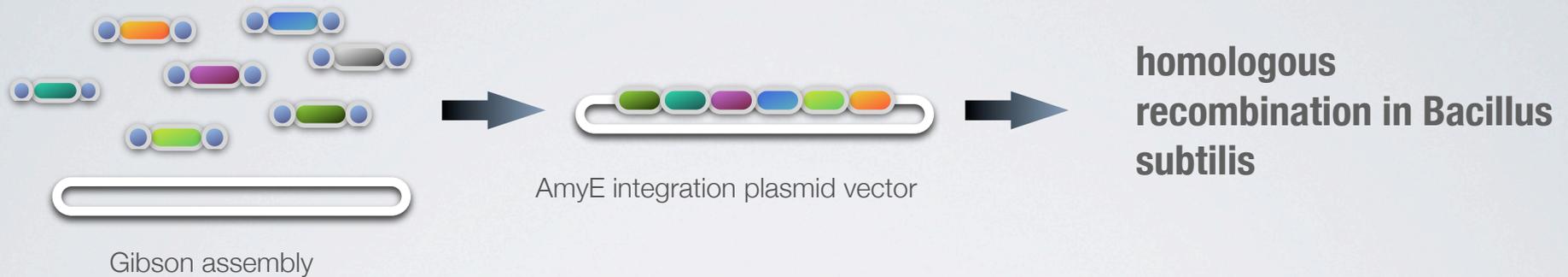
3.

Transformation of chassis and visualisation of gene expression, cell states and phenotype



# High throughput chromosome engineering

## Bacterial chromosome integration

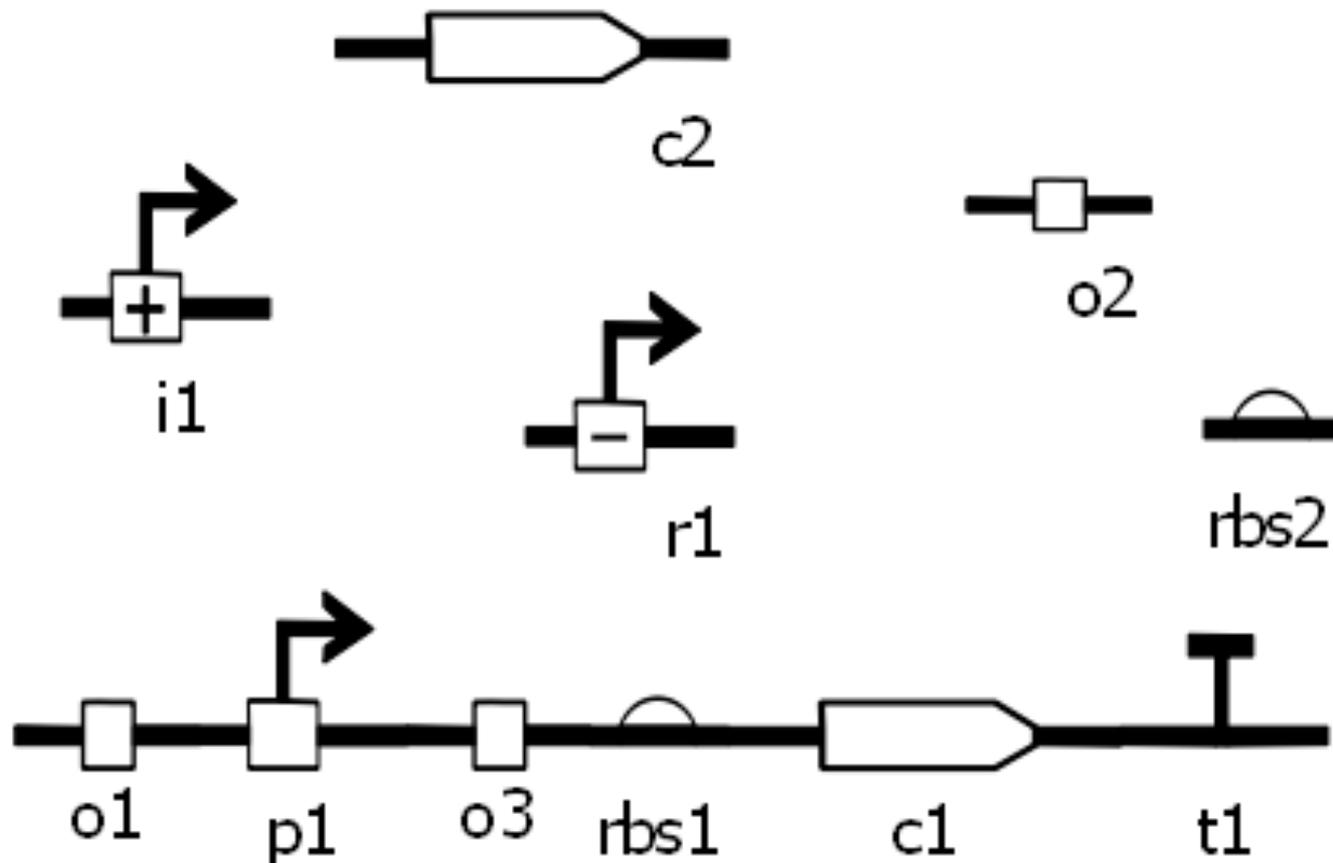


## Plant chromosome integration



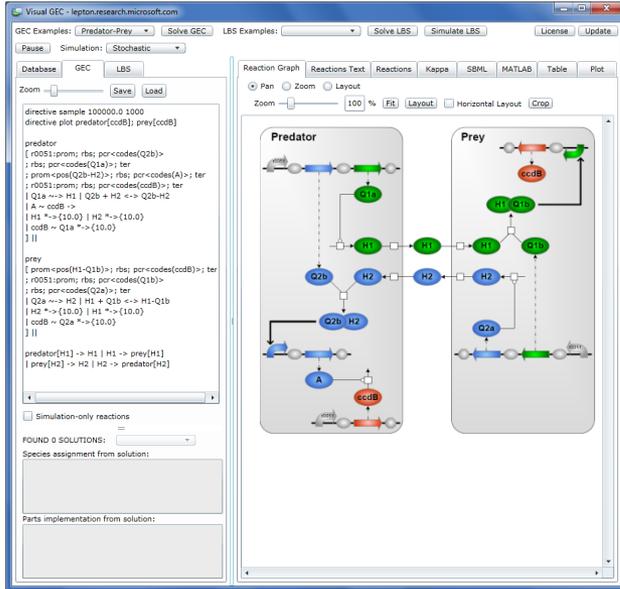
# SBOL: symbolic description of DNA parts

Synthetic Biology Open Language: is a software standard for the electronic exchange of specifications and descriptions of genetic parts, genetic devices, genetic modules, genetic systems, and engineered genomes.

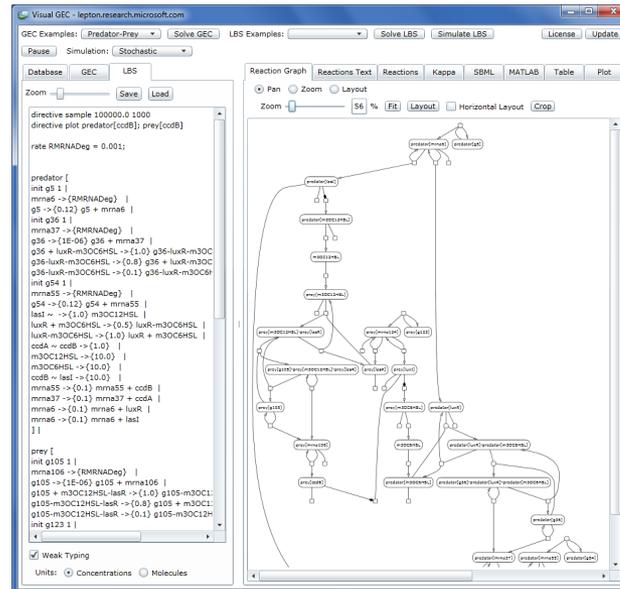


# Software for compilation of DNA circuits

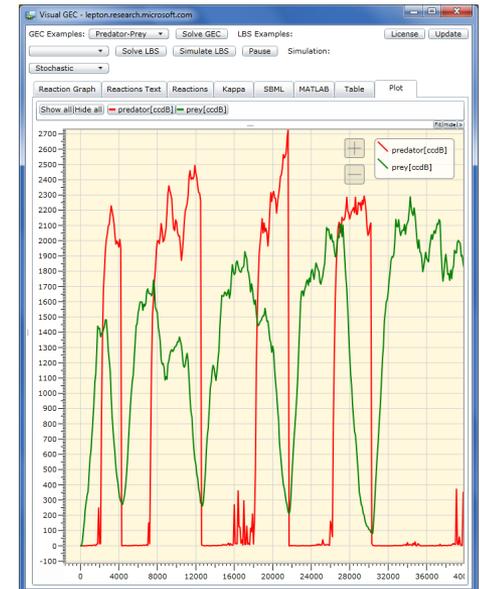
Step 1: Program device design



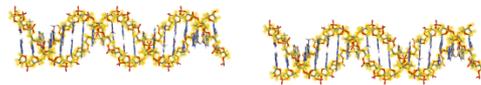
Step 2: Compile device behaviour



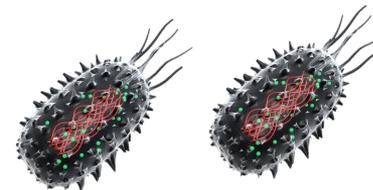
Step 3: Simulate device



Step 4: Compile device to DNA



Step 5: Insert DNA into cells



Genetic Engineering of Cells (GEC): a tool for programming cells

Microsoft Research Cambridge

Pedersen & Phillips. Royal Society Interface, 2009

# CELLMODELLER

## Software framework for modelling cell interactions

### CellModeller version 4

CellModeller is a framework for modelling multicellular systems, including biophysics, regulatory dynamics, intercellular signalling, and rule-based behaviours. It is implemented using OpenCL, a parallel computation standard, allowing very large numbers of cells to be simulated

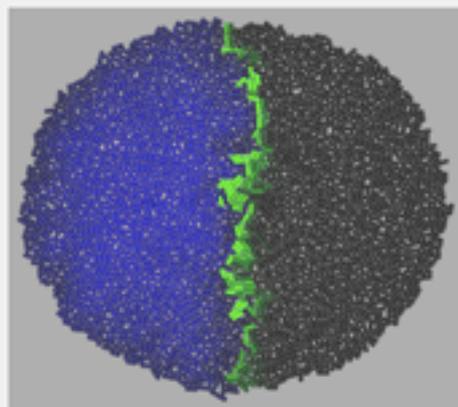


Morphogenesis is the process of creating and maintaining form through coordinated cell-division and growth. We have developed a software environment for modelling plant morphogenesis – an interactive virtual laboratory with a front-end called CellModeller4.

We have implemented cellular models of rod-shaped bacteria (3D) and plant tissues (2D). The bacterial model is a novel growing rigid-body method, described here. The plant model is a finite element method based on the work of Lionel Dupuy in the lab, and implemented using a matrix-free approach. The plant model is in the final testing stage, and will be released soon. The bacterial model is a constraint solver, and so can incorporate growth conditions like a flat substrate or microfluidic chamber by including additional constraints.

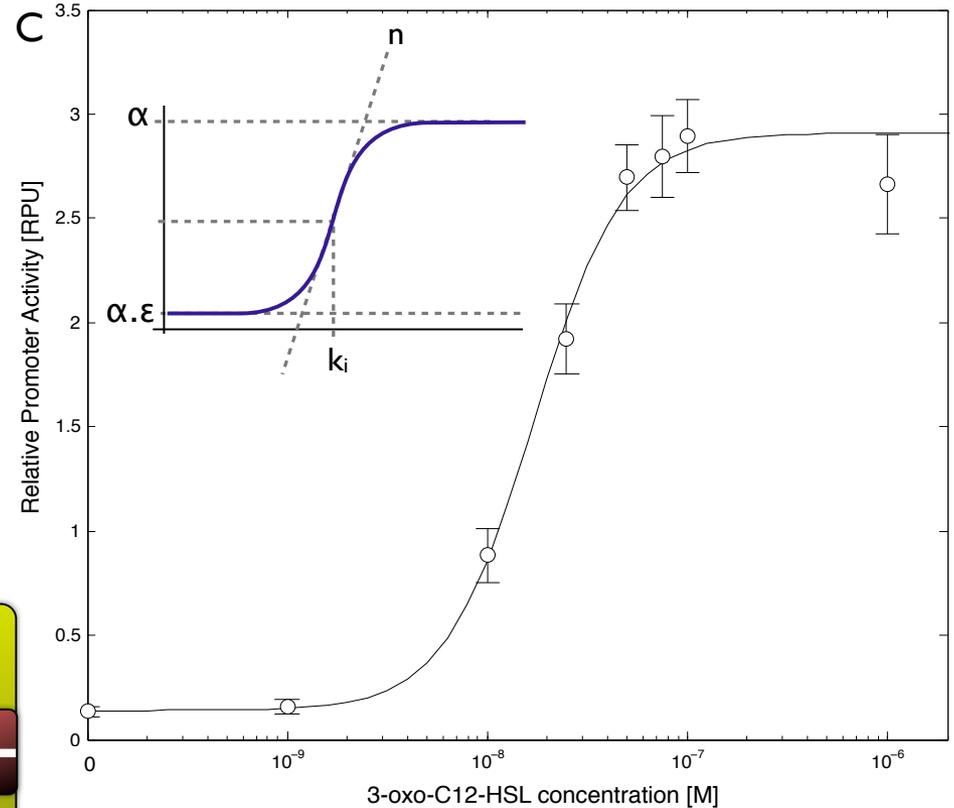
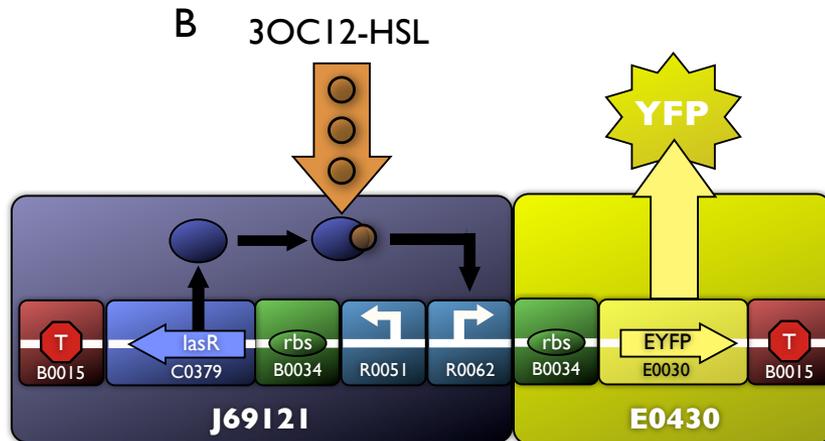
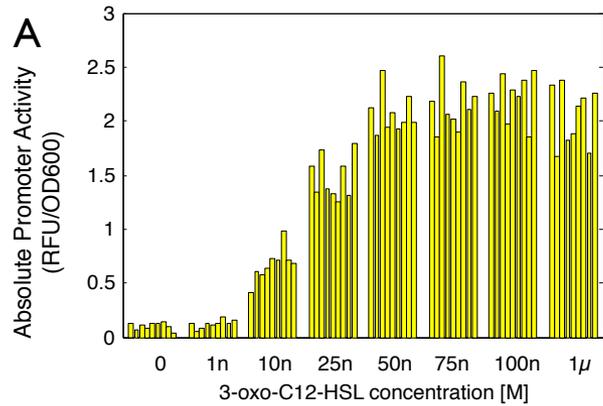
This is based on a spatial/mechanical model of cells coupled to an arbitrary user-defined set of reaction-diffusion systems and a genetic script. Essentially the system allows us to grow plant-like synthetic tissue which generates patterns of morphogens. The morphogens influence the behaviour, growth and division of the cells via the genetic script, forming a feedback loop between patterning and growth.

The 2D model is a matrix of linear walls controlled by the adjacent cells. Using the model we can design patterns, shapes and structures by constructing genetic scripts, effectively a kind of genetic sculpture. This is of great value in testing hypotheses about how genes and signalling molecules direct the growth and development of

[CellModeller](#)[Design](#)[Plant biophysics](#)[Cellular automata](#)[Genetic system](#)[Download software](#)[Cambridge-Microsoft](#)[Archiroot site](#)

# Measurement of circuit behaviour *in vivo*

## I22:pSB3K3CI Las Receiver



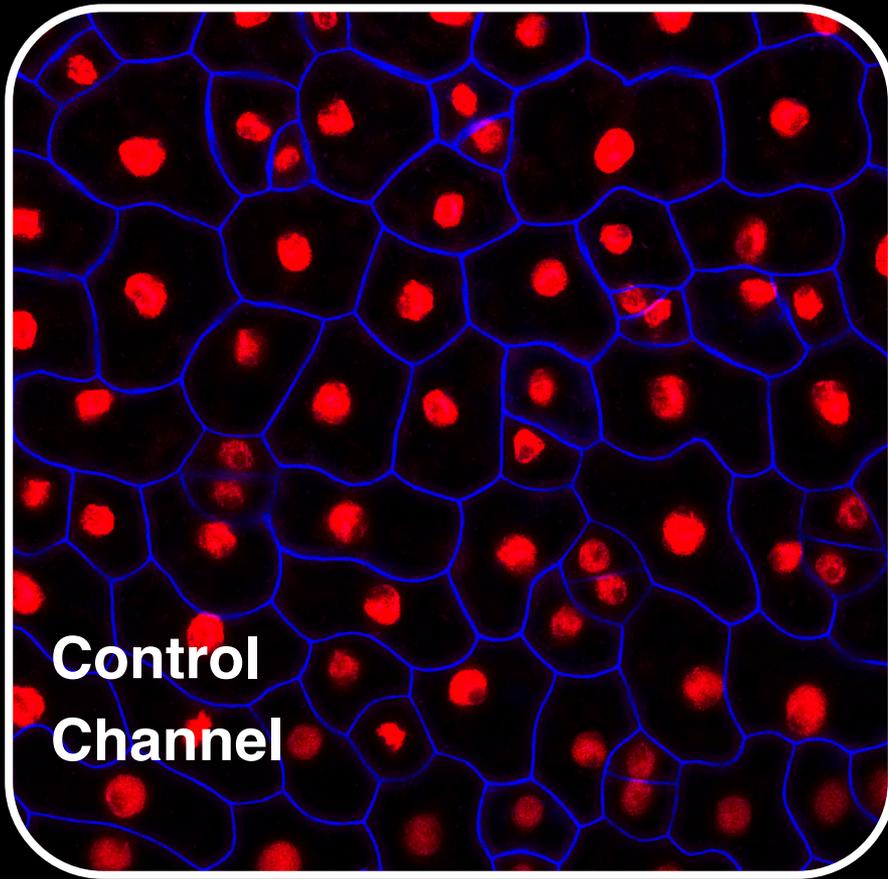
# Characterisation of DNA parts for plants



In planta cytometry



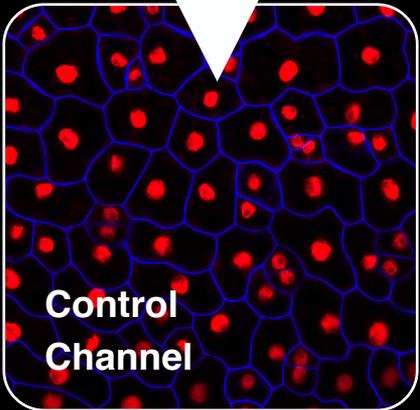
**Plant  
embryo**



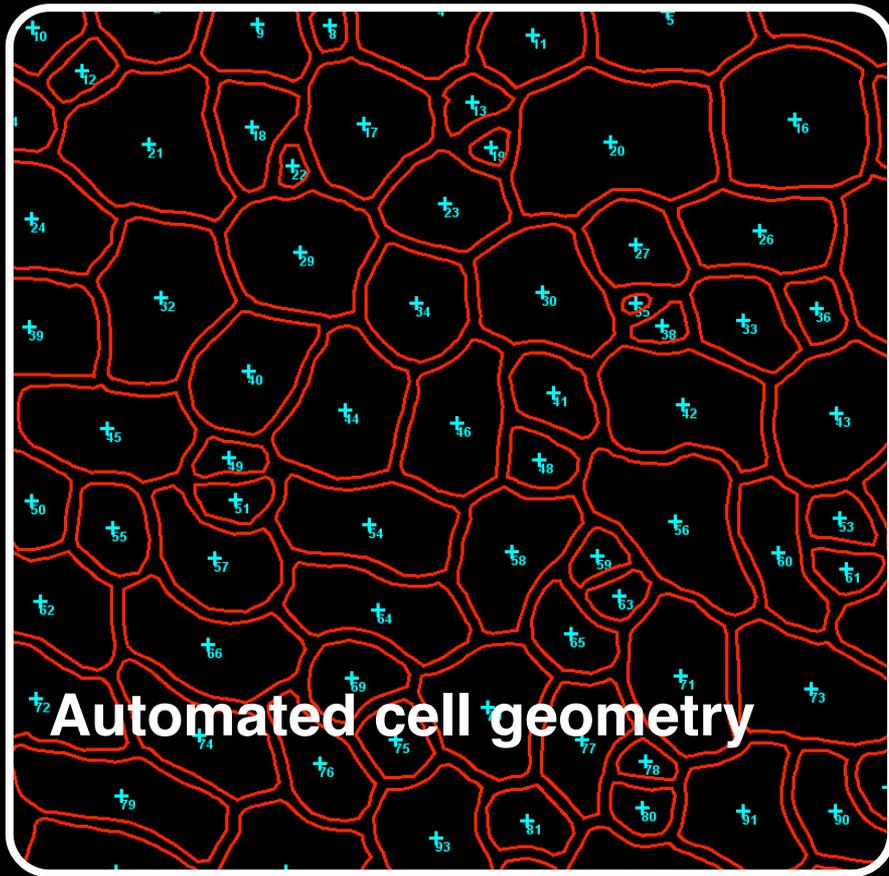
**Control  
Channel**



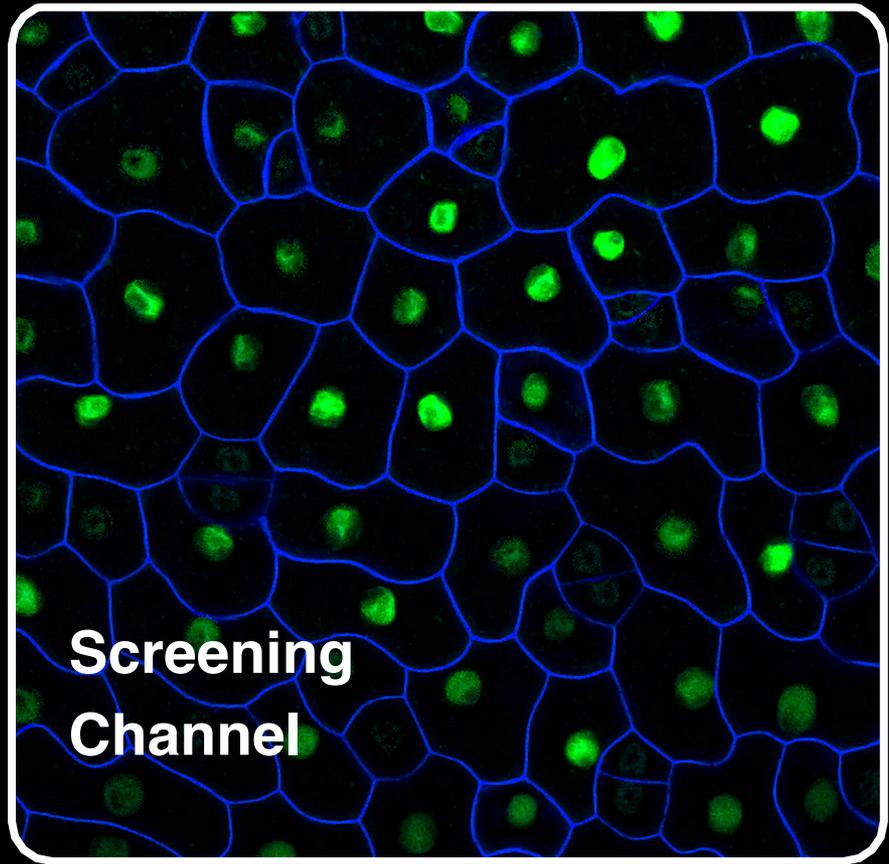
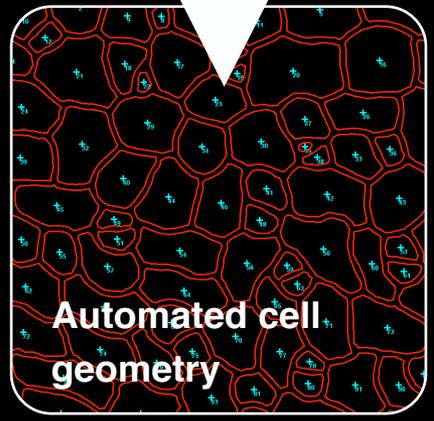
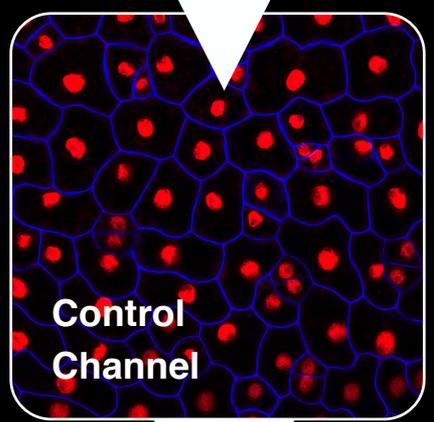
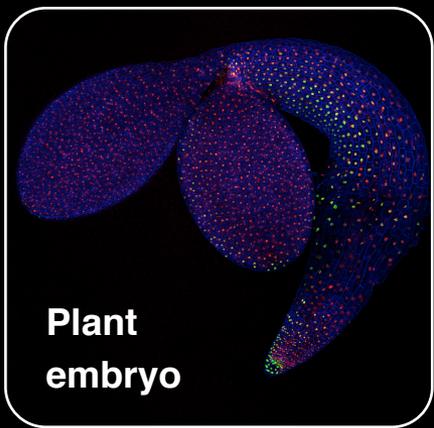
**Plant embryo**

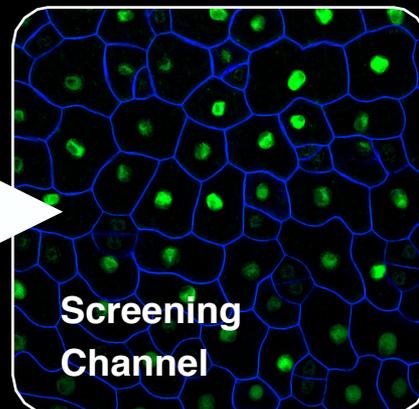
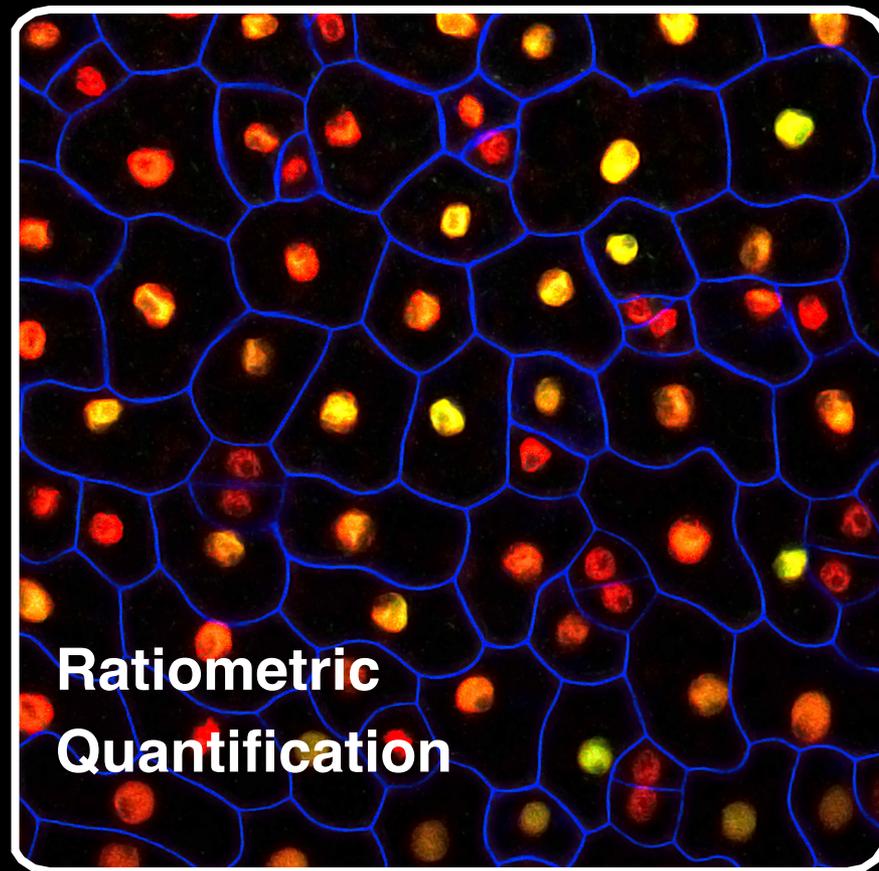
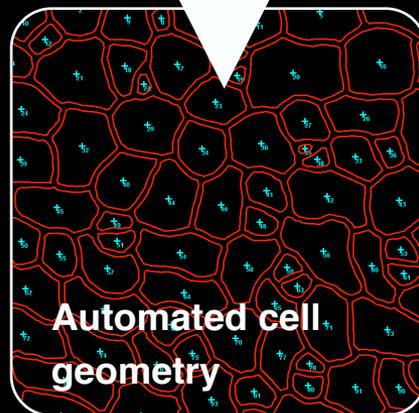
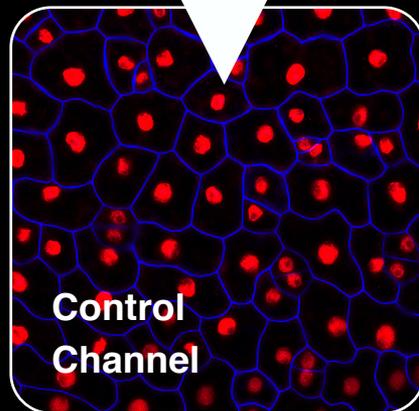
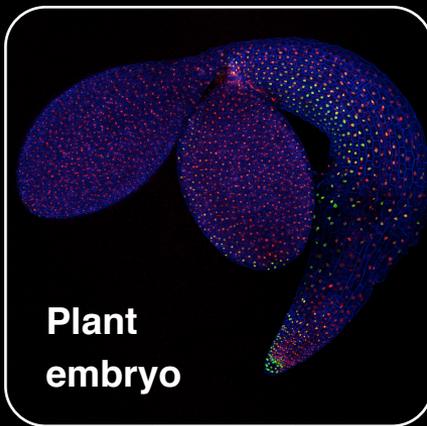


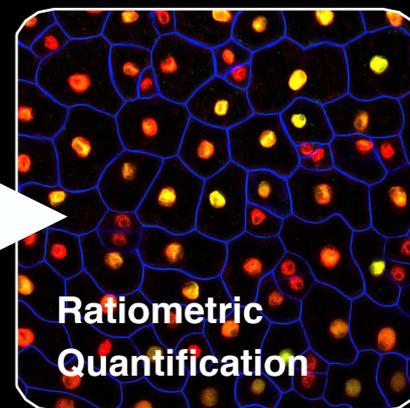
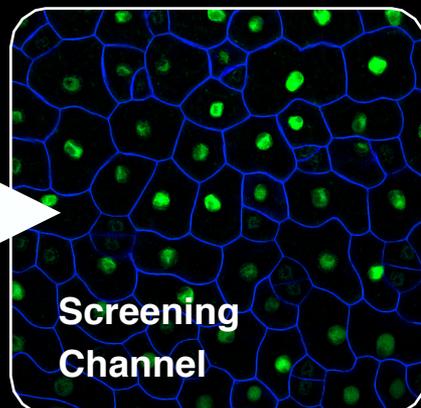
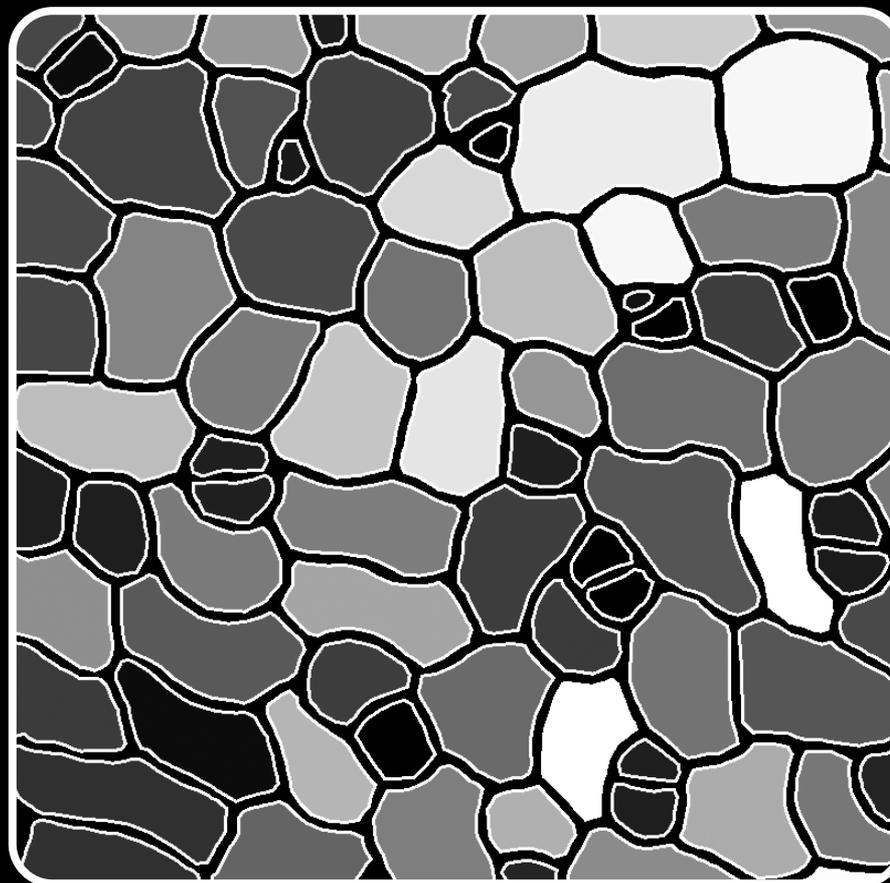
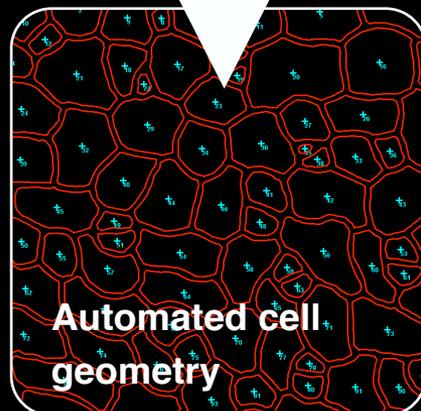
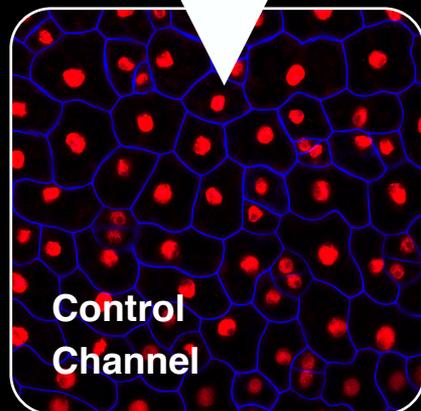
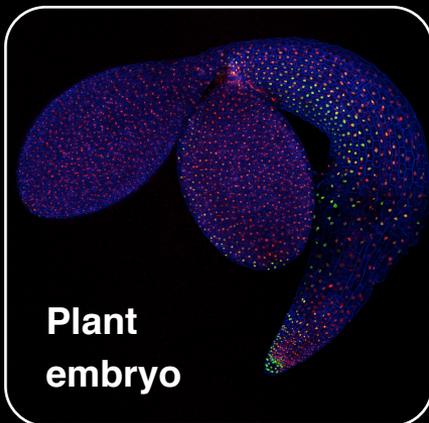
**Control Channel**



**Automated cell geometry**

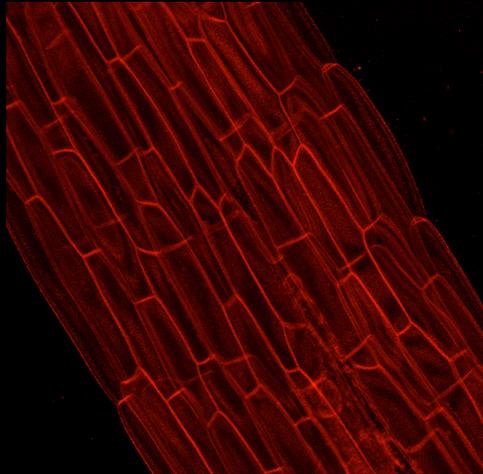






# In planta cytometry II

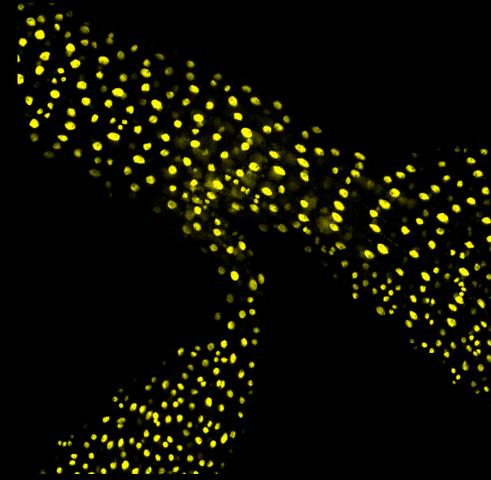
## Sharing numbers



mKate2-LTI6b

TagRFP-T-LTI6b

sfGFP-LTI6b



H2B-mKate2

H2B-mTurquoise2

H2B-sfGFP

H2B-Venus

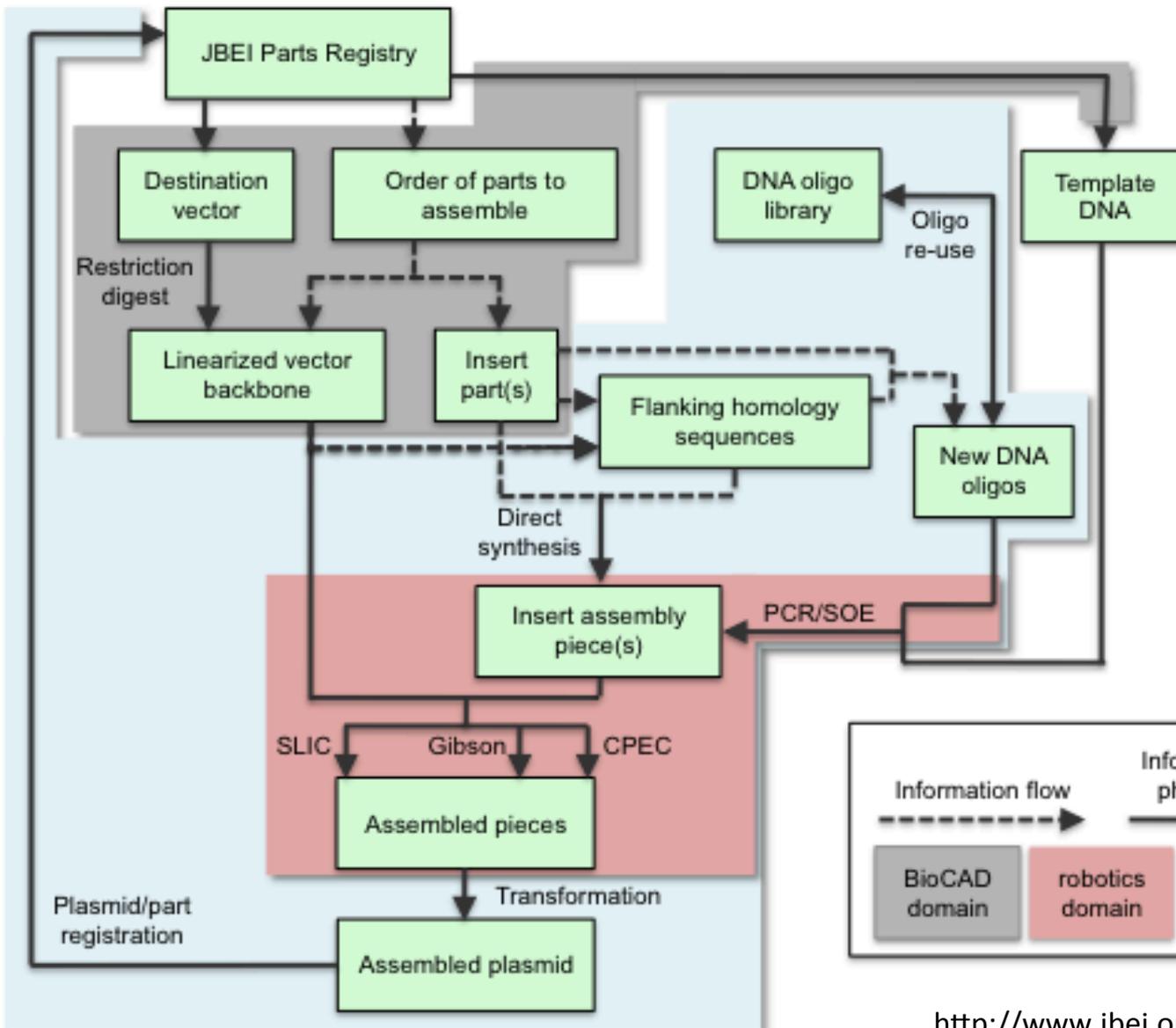
## Reference Standard Promoters for Plants

**UBQ10**

Calculation of transcription rate

$$p^{ss} = \frac{\gamma_M (a + \gamma_I + \mu)(\gamma_F + \mu)[F]_{cell}^{ss}}{\rho_{an}}$$

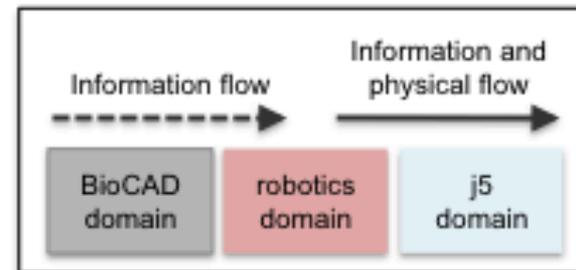
# Smart Registry for DNA parts



## JBEI Inventory for Composable Elements (ICE)

Open source registry software for DNA parts

Nathan Hillson  
Tim Hamm



Plasmid: pJ241:33268 violacein biobrick - Plantfab Registry

https://registry.plantfab.org/entry/view/8

plantfab

Plasmid: pJ241:33268 violacein bi... Recent Advances in HCS Laser Sc... Arrayit ArrayPix™ Microplate Micr...

# PlantFab

Cambridge

As of Sunday, December 25, 2011  
there are 8 Entries available

Welcome, Jim Haseloff | Log Out

Home Collections Add new entry Bulk Import

Search Advanced Search

## Plasmid: pJ241:33268 violacein biobrick

General Seq. Analysis (36)

General Information | Edit Report a Problem

Attachments (2) | Edit  
QC\_33268\_64663.pdf  
PM\_33268\_SEQ\_64662.p...

Samples | Edit  
No Samples

Permissions | Edit  
Read Allowed:  
Everyone  
Read and Write Allowed:  
Only you

Part ID: PLANTFAB\_00008  
Name: pJ241:33268 violacein biobrick  
Markers:  
Backbone:  
Origin of Replication:  
Promoters:  
Strains:  
Created: Dec 14, 2011  
Modified: Dec 14, 2011

Creator: Jim Haseloff  
Status: Complete  
Owner: Jim Haseloff

Keywords:  
Summary: The complete violacein biosynthesis operon synthesized by DNA2.0 for the Cambridge iGEM2009 team.

References:  
Bio Safety: 1

IP Information:  
Principal Investigator: Haseloff, Ajoka and Moklem  
Funding Source:

Parameters:  
Samples:

Download: (Original) | GenBank | FASTA  
Open in VectorEditor Delete

Done Read only 10135

Notes

registry.plantfab.org  
DNA parts for Synthetic Biology in Plants and Microbes  
Haseloff Laboratory - University of Cambridge

© JBEI Registry  
All rights reserved.  
Feature Request | Report a Bug | Feedback | API

Display page for a plasmid entry in the PlantFab Registry.

# Import/export compatibility with Genbank sequence annotations.

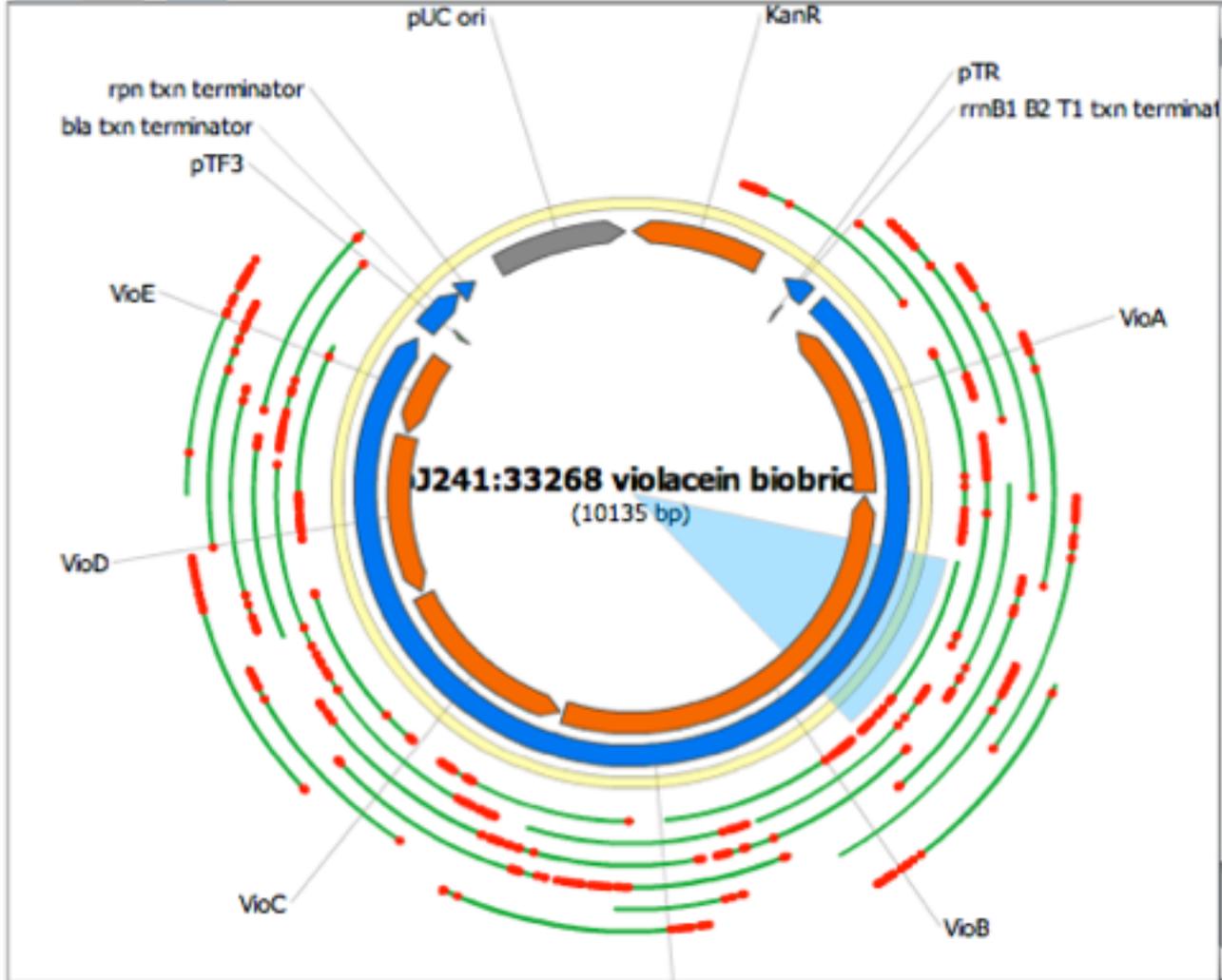
The screenshot displays the PlantFab Vector Editor web interface. The main window shows a circular plasmid map for '41:33268 violacein biotik (10135 bp)'. The map is annotated with various features, including promoters (pUC ori, pTF3, pTR), terminators (rpn txn terminator, bla txn terminator, rrnB1 B2 T1 txn terminator), and coding sequences (KanR, VioB, VioA, VioC, VioD, VioE). Restriction enzyme sites are also indicated around the map.

A 'Properties' window is open, showing the 'GenBank' tab. The window contains a table of features with the following data:

Name	Type	Position	Strand
Synthetic vio operon	misc_feature	1238 - 8623	+
pUC ori	rep_origin	9292 - 10095	+
rpn txn terminator	misc_feature	9007 - 9120	+
bla txn terminator	misc_feature	8700 - 9000	+
rrnB1 B2 T1 txn terminator	misc_feature	988 - 1162	-
pTF3	promoter	8791 - 8816	-
pTR	promoter	1063 - 1079	-
KanR	CDS	9 - 803	-
VioB	CDS	2549 - 5545	-
VioA	CDS	1275 - 2531	-
VioC	CDS	5569 - 6858	-
VioD	CDS	6882 - 8003	-
VioE	CDS	8027 - 8602	-

The 'Properties' window also includes a search field 'Enter Name or Type' and buttons for 'New', 'Edit', 'Remove', and 'OK'. The background shows the DNA sequence with annotations for features like 'pUC ori', 'pTR', 'KanR', and various CDS regions (VioA-E).

# Storage and automatic display of sequence trace files.



Name	Score	
1657501.ab1	1866	<input checked="" type="checkbox"/>
1669855.ab1	1938	<input checked="" type="checkbox"/>
1669858.ab1	1922	<input checked="" type="checkbox"/>
1674875.ab1	1760	<input checked="" type="checkbox"/>
1657494.ab1	1866	<input checked="" type="checkbox"/>
1657504.ab1	1802	<input checked="" type="checkbox"/>
1669837.ab1	1880	<input checked="" type="checkbox"/>
1669848.ab1	1886	<input checked="" type="checkbox"/>
1669849.ab1	1990	<input checked="" type="checkbox"/>
1657482.ab1	1892	<input checked="" type="checkbox"/>
1657490.ab1	1734	<input checked="" type="checkbox"/>
1669846.ab1	1984	<input checked="" type="checkbox"/>
1669850.ab1	1956	<input checked="" type="checkbox"/>
1669856.ab1	1944	<input checked="" type="checkbox"/>
1674872.ab1	1774	<input checked="" type="checkbox"/>
1657500.ab1	1810	<input checked="" type="checkbox"/>
1669838.ab1	1972	<input checked="" type="checkbox"/>
1669847.ab1	966	<input checked="" type="checkbox"/>
1669852.ab1	1910	<input checked="" type="checkbox"/>

```

Expected 2876: GGTGACGGTCTGGTCGGTGCTCGTTTGGCACTGTGGGGTCACTACAATGATTATCTGCGT
Trace      28: GGTGNNGGTCTGGTCGGTGCTCGTTTGGCACTGTGGGGTCACTACAATGATTATCTGCGT

ACCACCTTCAATCGTGCTCGTTGGGTCGACAGCGACCCGACGCGCCGTGACGCTGCACAA
ACCACCTTCAATCGTGCTCGTTGGGTCGACAGCGACCCGACGCGCCGTGACGCTGCACAA
    
```

# Built-in vector editing functions.

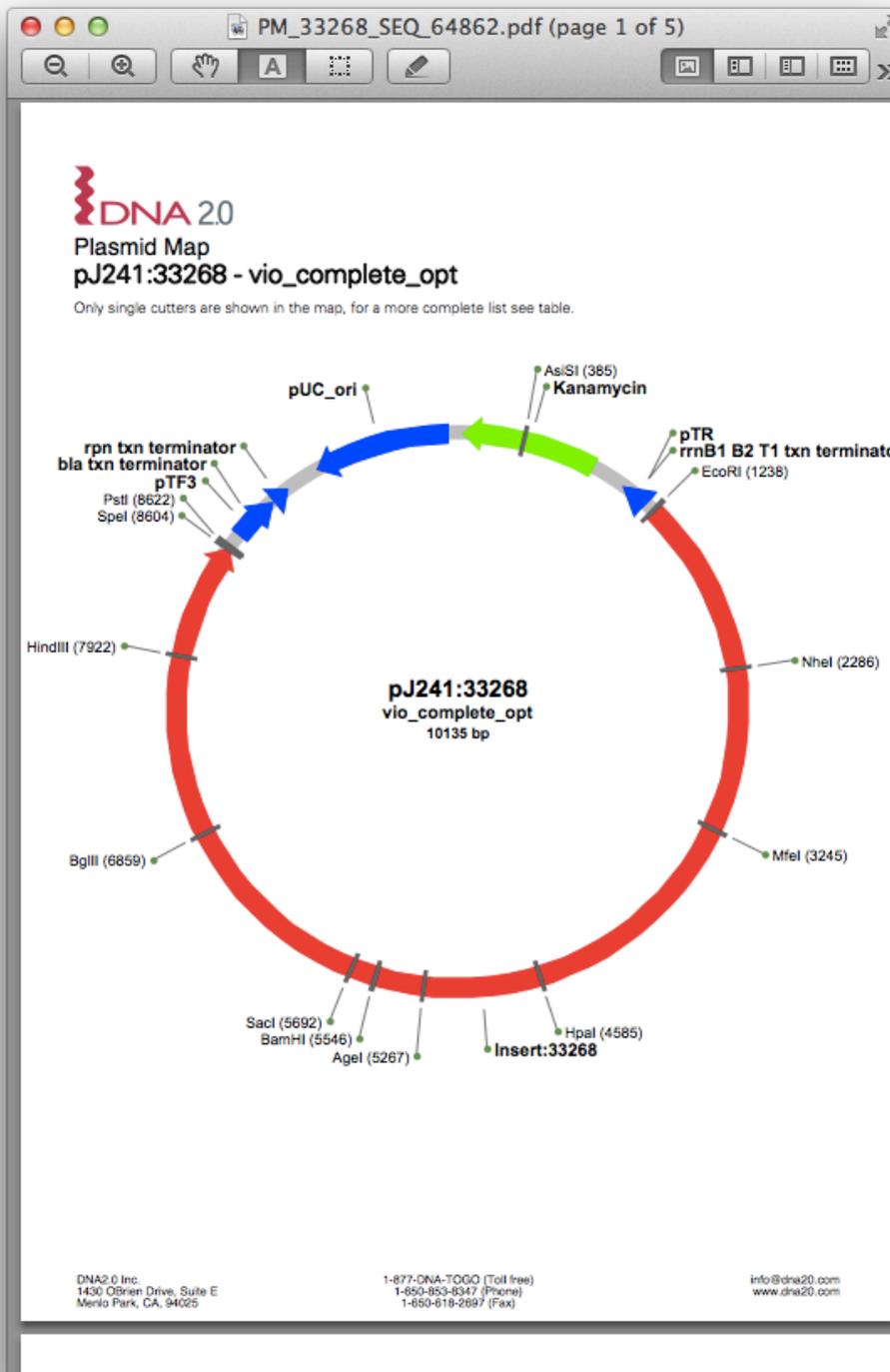
Browser address bar: <https://registry.plantfab.org/7wicket:bookmarkablePage=:org.jbel.ice.web.pages.VectorEditorPage&entryId=da34b8c5-3fe6-46f1-ae1>

File Edit View Tools Help

**pJ241:33268 violacein biobrick (10135 bp)**

1	TAGAAAACT	CATCGAGCAT	CAAATGAAAC	TGCAATTTAT	TCATATCAGG	ATTATCAATA
	ATCTTTTTGA	GTAGCTCGTA	GTTTACTTTG	ACGTTAAATA	AGTATAGTCC	TAATAGTTAT
61	CCATATTTT	GAAAAAGCCG	TTTCTGTAAT	GAAGGAGAAA	ACTCACCGAG	GCAGTTCCAT
	GGTATAAAAA	CTTTTTCGGC	AAAGACATTA	CTTCTCTTT	TGAGTGGCTC	CGTCAAGGTA
121	AGGATGGCAA	GATCCTGGTA	TCGGTCTGCG	ATTCCGACTC	GTCCAACATC	AATACAACCT
	TCCTACCGTT	CTAGGACCAT	AGCCAGACGC	TAAGGCTGAG	CAGGTTGTAG	TTATGTTGGA
181	ATTAATTTCC	CCTCGTCAAA	AATAAGGTTA	TCAAGTGAGA	AATCACCATG	AGTGACGACT
	TAATTAAGG	GGAGCAGTTT	TTATTCCAAT	AGTTCACTCT	TTAGTGGTAC	TCACTGCTGA
241	GAATCCGGTG	AGAATGGCAA	AAGTTTATGC	ATTTCTTTCC	AGACTTGTTT	AACAGGCCAG
	CTTAGGCCAC	TCTTACCGTT	TTCAAATACG	TAAAGAAAGG	TCTGAACAAG	TTGTCCGGTC
301	CCATTACGCT	CGTCATCAAA	ATCACTCGCA	TCAACCAAAC	CGTTATTCAT	TCGTGATTGC
	GGTAATGCGA	GCAGTAGTTT	TAGTGAGCGT	AGTTGGTTTTG	GCAATAAGTA	AGCACTAACG
361	GCCTGAGCGA	GGCGAAATAC	GCGATCGCTG	TAAAAAGGAC	AATTACAAC	AGGAATCGAG
	CGGACTCGCT	CCGCTTTATG	CGCTAGCGAC	AATTTTCTG	TTAATGTTG	TCCTTAGCTC
421	TGCAACCGGC	GCAGGAACAC	TGCCAGCGCA	TCAACAATAT	TTTCACCTGA	ATCAGGATAT
	ACGTTGGCCG	CGTCTTGTG	ACGGTCCGCT	AGTTGTTATA	AAAGTGGACT	TAGTCTATA
481	TCTTCTAATA	CCTGGAACGC	TGTTTTTCCG	GGGATCGCAG	TGGTGAGTAA	CCATGCATCA
	AGAAGATTAT	GGACCTTGGC	ACAAAAAGGC	CCCTAGCGTC	ACCACTCATT	GGTACGTAGT
541	TCAGGAGTAC	GGATAAAATG	CTTGATGGTC	GGAAAGTGGA	TAAATCCGT	CAGCCAGTTT
	AGTCCTCATG	CCTATTTTAC	GAACCTACCAG	CCTTACCCTG	ATTTAAGGCA	GTCGGTCAAA
601	AGTCTGACCA	TCTCATCTGT	AACATCATTG	GCAACGCTAC	CTTTGCCATG	TTTCAGAAAC
	TCAGACTGGT	AGAGTAGACA	TTGTAGTAAC	CGTTGCGATG	GAAACGGTAC	AAAGTCTTTG
661	AACTCTGGCG	CATCGGGCTT	CCCATAACAAG	CGATAGATTG	TCGCACCTGA	TTGCCCGACA
	TTGAGACCGC	GTAGCCCGAA	GGGTATGTTT	GCTATCTAAC	AGCGTGGACT	AACGGGCTGT
721	TTATCGCGAG	CCCATTTATA	CCCATATAAA	TCAGCATCCA	TGTTGGAATT	TAATCGCGGC
	AATAGCGCTC	GGGTAATAT	GGGTATATTT	AGTCGTAGGT	ACAACCTTAA	ATTAGCGCCG
781	CTCGACGTTT	CCCGTTGAAT	ATGGCTCATA	TCTTCTCTT	TTCAATATTA	TTGAAGCATT
	GAGCTGCAA	GGGCAACTTA	TACCGAGTAT	AAGAAGGAAA	AAGTTATAAT	AACTTCGTAA
841	TATCAGGGTT	ATTGTCTCAT	GAGCGGATAC	ATATTTGAAT	GATTTTAGAA	AAATAAACAA
	ATAGTCCCAA	TAACAGAGTA	CTCGCCTATG	TATAAACTTA	CATAAATCTT	TTTATTTGTT
901	ATAGGGGTCA	GTGTTACAAC	CAATTAACCA	ATTCTGAACA	TTATCGCGAG	CCCATTTATA

Writable | - | 10135



**Documents can be attached to sequence entries.**

# www.plantfab.org

## Registry of DNA parts for Plants



### DNA parts for the fabrication of new genetic systems in plants and related microbes.

(construction in progress, Dec 2011)



#### Registry of DNA parts

A new resource for sharing details of DNA parts for use in Synthetic Biology experiments in plants.

The recent development of **genome-scale DNA assembly techniques** allows fast, efficient multiplex fabrication of large-scale DNA assemblies - with no need for restriction enzymes or low-efficiency ligation reactions. This places new demands on the availability of reliable and well characterised DNA parts for assembly.

This site contains a registry of DNA parts dedicated to use in plant and related microbial systems. The formation of the registry was driven by the lab's need to keep our own DNA parts in an orderly manner - many of the parts will be "work-in-progress", and not accessible without password. Details of published DNA constructs will be available.

The PlantFab Registry is based on the **Inventory for Composable Elements (ICE)**, developed as an open source registry for biological parts by the Joint Bio Energy Institute (JBEI), UC Berkeley (with many thanks to Tim Ham



biofab

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## about the biofab

The BIOFAB: International Open Facility Advancing Biotechnology (BIOFAB) was founded in December 2009 as the world's first biological design-build facility. This professionally staffed public-benefit facility was initiated by a grant from the National Science Foundation (NSF) and is led by bioengineers from UC Berkeley and Stanford University. The BIOFAB is operated in partnership with [Lawrence Berkeley National Laboratory \(LBNL\)](#), the [BioBricks Foundation \(BBF\)](#), and the [Synthetic Biology Engineering Research Center \(SynBERC\)](#).

BioFab projects will be designed to produce broadly useful collections of standard biological parts that can be made freely available to both academic and commercial users, while also enabling the rapid design and prototyping of genetic constructs needed to support specific needs of partner efforts such as SynBERC Testbeds. The BioFab will thus also represent the first significant focused investment in the development of open technology platforms underlying and supporting the next generation of biotechnology. Once fully operational the BioFab facility will be capable of producing tens of thousands of professionally engineered, high quality standard biological parts each year.

Read the full announcement here:

[http://www.berkeley.edu/news/media/releases/2010/01/20\\_biofab\\_synthetic\\_biology.shtml](http://www.berkeley.edu/news/media/releases/2010/01/20_biofab_synthetic_biology.shtml)

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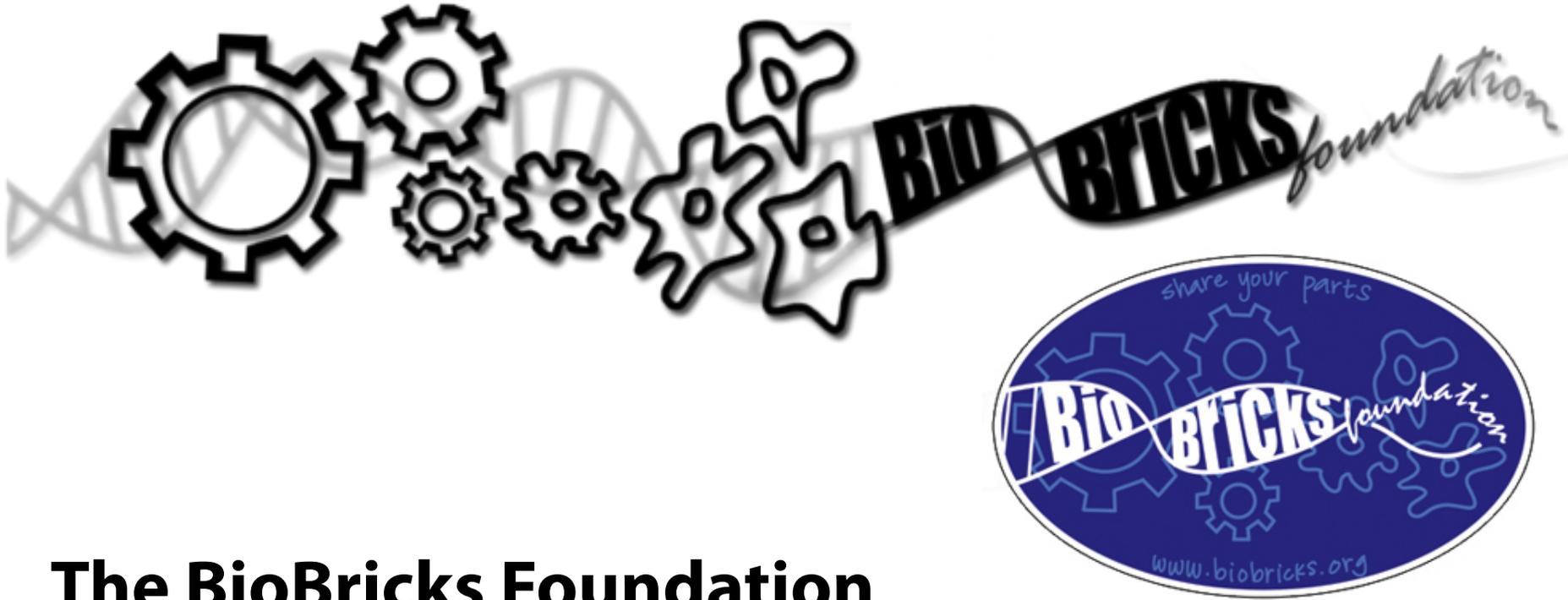
## user login

Username: \*

Password: \*

Log in

<http://www.biofab.org>



# The BioBricks Foundation

- Develop and implement legal strategies to ensure that BioBrick™ standard biological parts remain freely available to the public.
- Support the development of open technical standards that define BioBrick™ standard biological parts.
- Develop and provide educational and scientific materials to allow the public to use and improve existing BioBrick™ standard biological parts, and contribute new BioBrick™ standard biological parts.



BioBricks  
FOUNDATION

Biotechnology in the public interest

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 BioBricks Foundation  
@biobricks

The BioBricks Foundation SB6 Conference registration is now open! Space is limited. <http://t.co/LLLOCaVL>  
25 Jan 2013 · reply · retweet · favorite

Thanks, @GerdMoeBehrens for a really important paper:<http://t.co/FFdN5oTH>  
25 Jan 2013 · reply · retweet · favorite

Tom Knight, BBF Founding Director, Emeritus, profiled in "New Scientist" on @biobricks, @igem & craziest synbio: <http://t.co/FB8yWXpIF>  
16 Dec 2012 · reply · retweet · favorite

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 BioBricks Foundation shared I fucking love science's photo. I know that feeling...

BIOFAB success to continue in partnership with the BBF. [Learn more »](#)



Synthetic Biology 6.0 Conference



BioBrick™ Public Agreement



Stanford BIOFAB



The BBF's mission is to ensure that the engineering of biology is conducted in an open and ethical manner to benefit all people and the planet.

We believe fundamental scientific knowledge belongs to all of us and must be freely available for ethical, open innovation. This is a new paradigm.

JOIN OUR MAILING LIST





LATEST FROM THE BBF BLOG

March 20, 2013  
Free! Reliable! Parts! Use 'Em! Courtesy Drew Endy  
»

January 18, 2013  
Genspace Gives Great TED Talk »

January 17, 2013  
SB6.0 Conference Registration is Now Open! »

[SEE ALL UPDATES »](#)

 The Synthetic Biology Network 

# Applications

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- **open source and free-to-operate tools**
- **open standards to promote innovation**
- **international scientific exchange**





## Cambridge website for Synthetic Biology resources

Compiled by Jim Haseloff at the University of Cambridge.

This site contains details of recent papers and activity in Synthetic Biology, with particular emphasis on: (i) development of standards in biology and DNA parts, (ii) microbial and (iii) plant systems, (iv) research and teaching in the field at the University of Cambridge, (v) hardware for scientific computing and instrumentation, (vi) tools for scientific productivity and collected miscellany.

Similar to the Cambridge-based Raspberry Pi and OpenLabTools initiatives, we promote the use of low cost and open source tools - in our case for use in biological engineering.



### SYNBIO CALENDAR

11  
MAY

#### First International Mammalian Synthetic Biology Workshop

12:00 AM to 12:00 AM

Recognizing the fast emergence and potential significance of this field, the aim of this workshop is to bring together practitioners of mammalian synthetic biology together with experts from other relevant

20  
MAY

#### Introduction to opportunities in plant synthetic biology

07:00 PM to 07:00 PM

This meeting will introduce and showcase the many and varied applications of synthetic biology at the molecular, cell, and whole plant level to introduce synthetic biology to a broad UK plant science base.

### SITE INDEX

### RESEARCH STUDIES

#### PhD Studentships in Cambridge

The Board of Graduate Studies manages admission of the University's graduate students. Prospective students should start [here](#) - for an introduction to the University of Cambridge, the courses we offer, how to apply for postgraduate study, how your



## Scientific instrumentation and computing hardware

Latest news in scientific computing and development of low-cost hardware for laboratory instrumentation. The pages in this section contain links to web sites with DIY instructions for building hardware, specialised components and open-source or low-cost software, with a focus on Arduino and Raspberry Pi.



### Water Cooled Raspberry Pi Case

Hacker Phame has taken a low powered Raspberry Pi mini PC, which is available to purchase for around \$35, and added a pimped up cooling system creating a water cooled Raspberry Pi mini computer. To re-cap the Raspberry Pi mini computer which is manufactured in Wales, UK, is equipped with a a 700 MHz ARM11 processor, which can safely be overclock it to 1 GHz if desired. (...) Original Story...

| 14 hits | [Read more](#)



### Pick the Right Electronics Board for Your DIY Projects

The Arduino, Raspberry Pi, and BeagleBone are all low-cost controllers that are great for your DIY projects, but it's a little confusing when you're trying to figure out which one is best suited for you. Make has a breakdown of all three and what types of projects they're best for. Read more... Pick the Right Electronics Board for Your DIY Projects (Via Lifehacker.)

| 20 hits | [Read more](#)

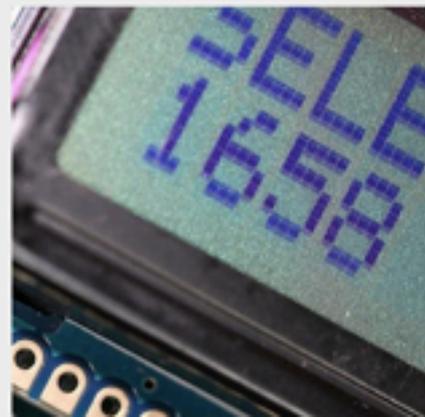


### Eyes-on with Ninja Blocks 'home automation for hackers' (video)

Yet another Kickstarter success story is here on the Hardware Alley Floor

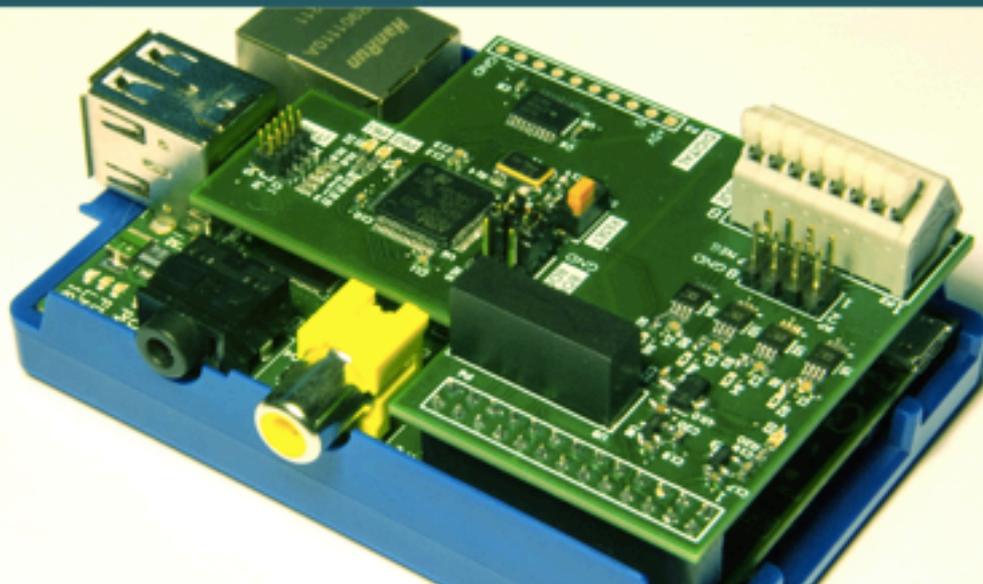
## SITE INDEX

## OPENLABTOOLS IN CAMBRIDGE



# OpenLabTools

Home Projects Resources Contacts



Data acquisition system for Raspberry Pi computers (prototype)

1 of 2

## The OpenLabTools project

The OpenLabTools initiative aims to provide a forum and knowledge centre for the development of low cost and open access scientific tools, with an emphasis on undergraduate and graduate teaching and research. The programme will officially start in October 2013. In order to bootstrap this initiative, a number of MEng projects (4-5 per year) will be offered to establish the core components required for such tools; these include data acquisition, sensing, actuating, processing and 3D manufacturing. Protocols, designs and tutorials will be published on this website. These components will be subsequently combined to establish a documented collection of instruments, to be developed and maintained by a community of undergraduate and graduate students of the University.

We anticipate that the core tools will be rolled out in undergraduate laboratories from 2014 onwards. We would like to invite anybody interested in this programme to get in touch with us and explore ways to contribute, either by using the tools (once ready) or

## Academic team

**Anurag Agarwal**

*(Fluids - Acoustics)*

**Oliver Haderl**

*(CamBridgeSens)*

**Jim Haseloff**

*(Synthetic Biology)*

**Simone Hochgreb**

*(Fluids - Reacting flows)*

**Alexandre Kabla**

## Related initiatives

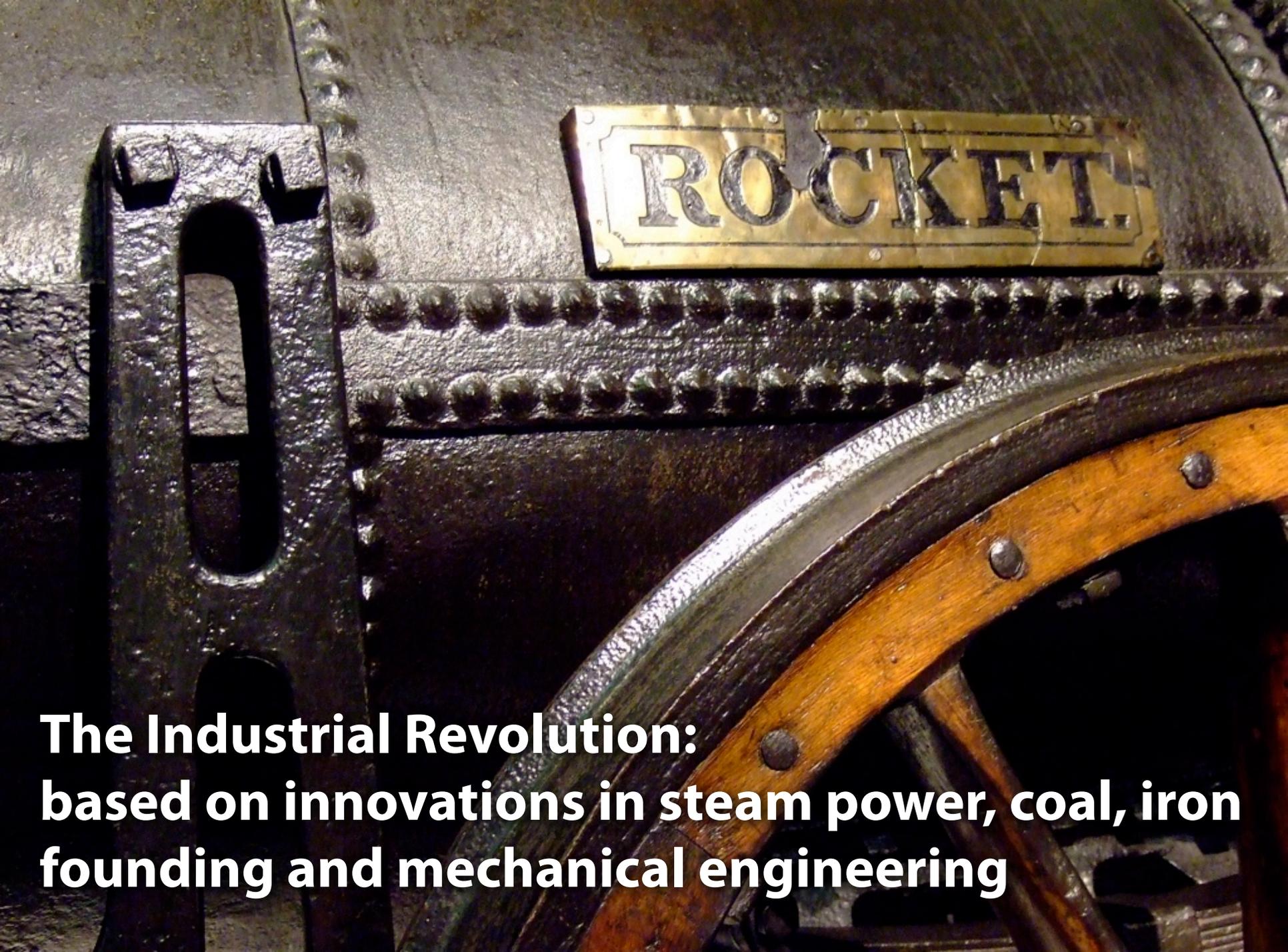
[The Raspberry Pi foundation](#)

[Arduino](#)

[Synbio.ork.uk](#)

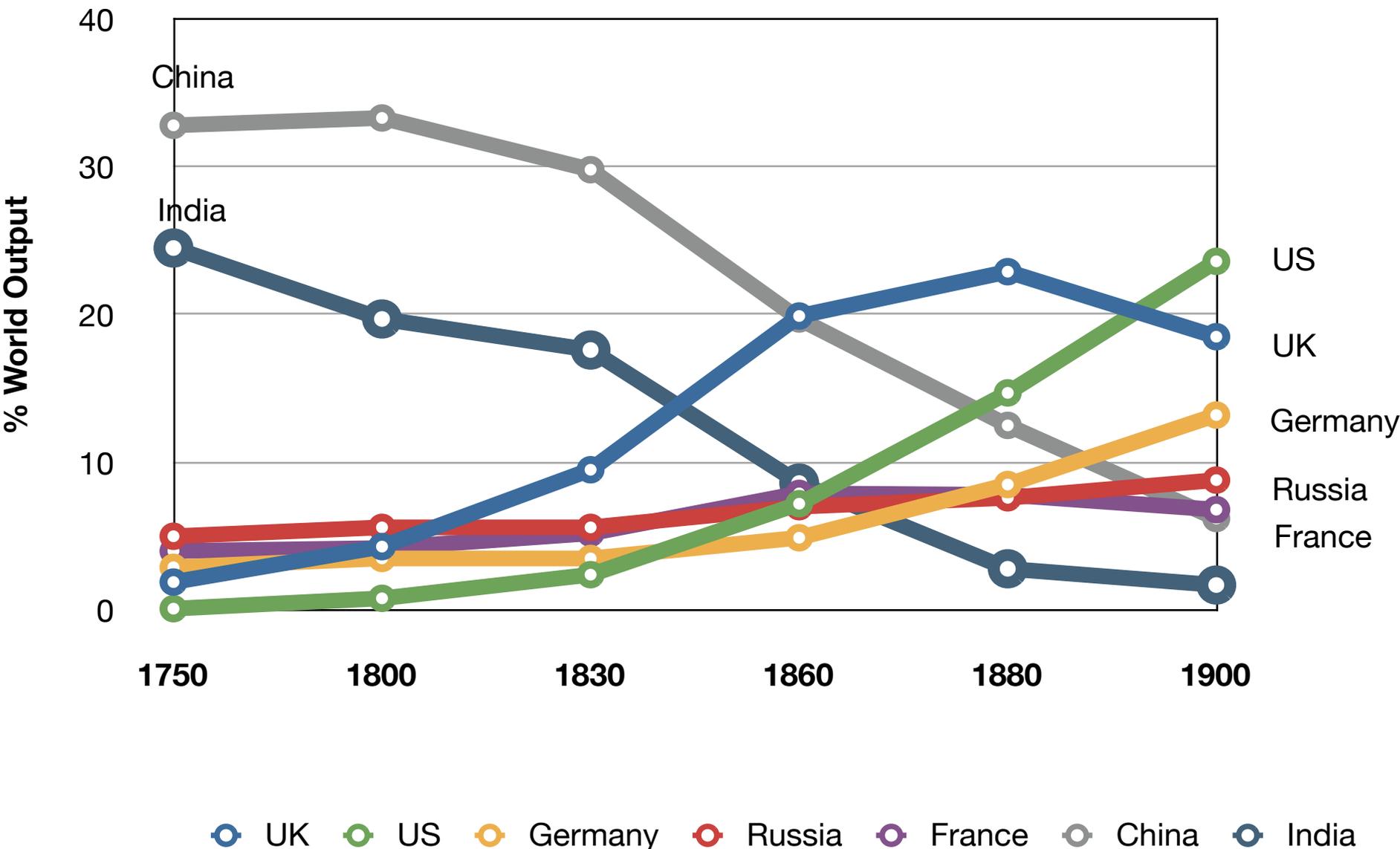
[Makespace \(Cambridge, UK\)](#)

[CamBridgeSens](#)

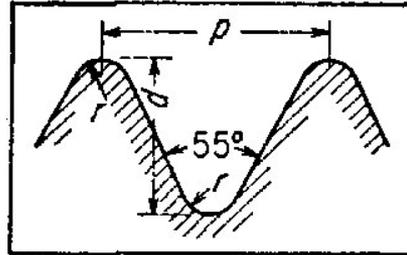
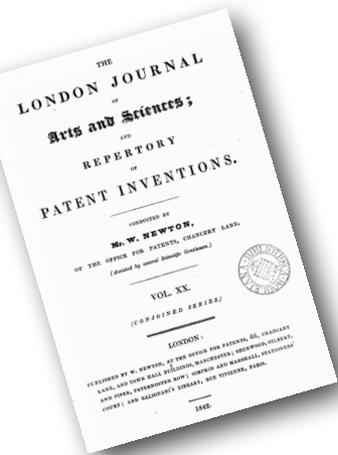


**The Industrial Revolution:  
based on innovations in steam power, coal, iron  
founding and mechanical engineering**

# Relative shares of world manufacturing output 1750-1900



# Standardisation of parts for construction

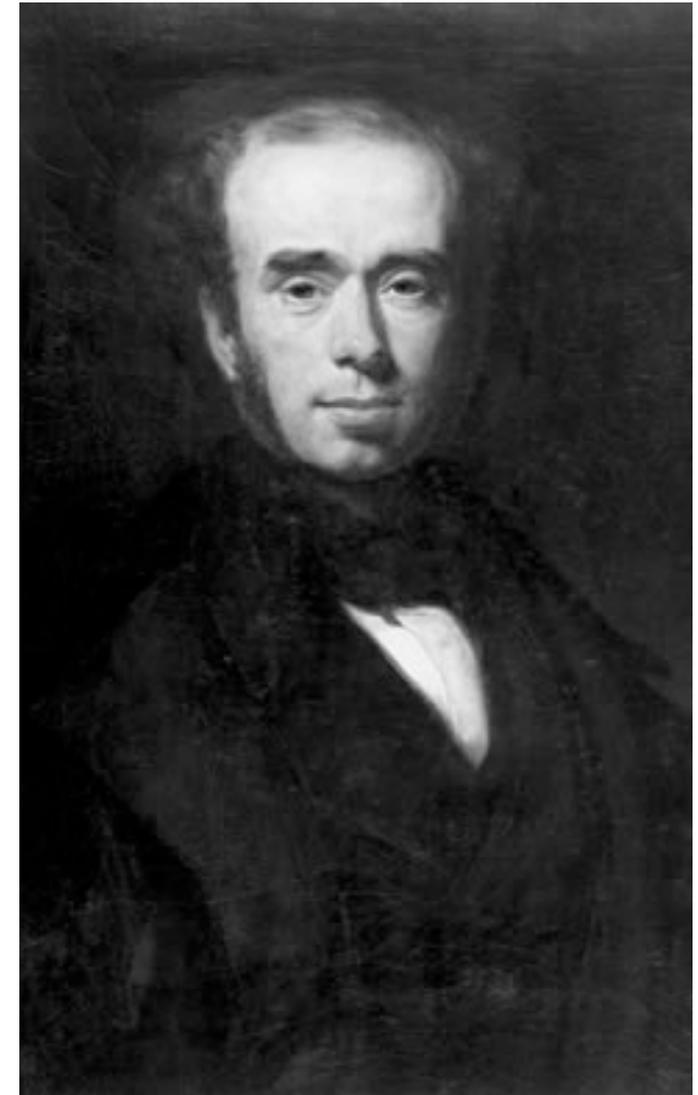


“On an uniform system of Screw Threads.”

By Joseph Whitworth, Assoc. Inst. C. E.

The subject considered in this paper, is the importance of having a constant thread for a given diameter in all screws used in fitting up steam engines and other machinery. It is argued, that uniformity of thread would be productive of economy, both in the use of screwing apparatus, and in the consumption of bolts and nuts. The refitting shop of a railway or steam packet company, affords a striking instance of the advantage to be derived from the application of this principle. If the same system of screw threads were common to the different engines, a single set of screwing tackle would suffice for any repairs.

No attempt appears to have been hitherto made to attain this important object. Engineers have adopted their threads without reference to a common standard. Any such standard must be in a great measure arbitrary, and hence its absence may be accounted for.



Joseph Whitworth 1842

**Interchangeable parts led to continuous production methods**

