



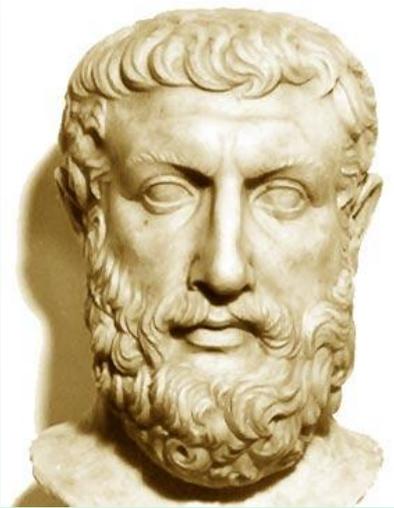
# ***Bridging Plant Anatomy and Genomics in the Digital Era: Recent Advances at The Plant Ontology***

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## Ontology

From the Greek ὄν, "of being" and  
-λογία, -logia: "*science or study*"

- The philosophical study of ***being, existence or reality*** as well as the **basic categories of being and their relations**
- Part of a major branch of philosophy known as **metaphysics**
- An ontology is a **controlled vocabulary** written as a **set of definitions** with given hierarchical relationships to one another

(From Wikipedia)



# What is Plant Ontology?

- A structured vocabulary for plants that covers:
  - Anatomy and morphology
  - Growth and developmental stages
- A source for:
  - standard definitions reviewed by experts
  - links to annotations from multiple genome databases

A tool for annotation of plant phenotypes,  
genes and gene expression patterns across  
all plant species

[www.plantontology.org](http://www.plantontology.org)

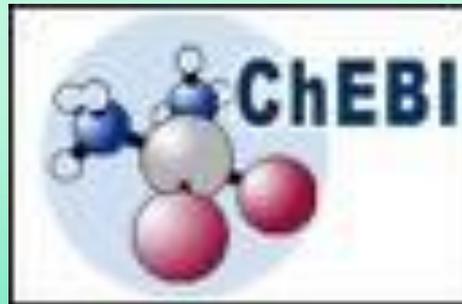
# Ontologies for Plant Sciences:



Gene  
Ontology



Plant  
Ontology



Chemical Entities of  
Biological Interest

**PATO**

Phenotypic Attribute  
Ontology

**TO**

Trait Ontology

<http://www.obofoundry.org/>

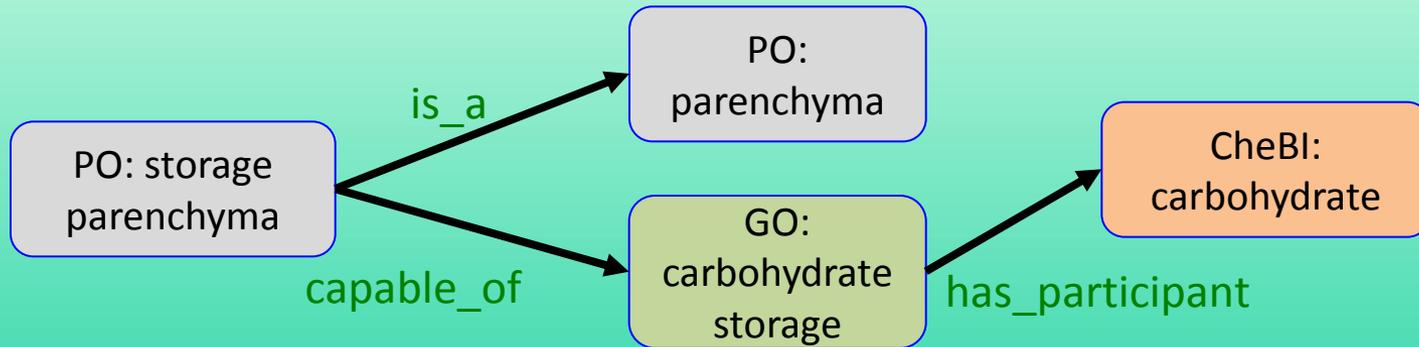
<http://bioportal.bioontology.org/>

# Ontologies facilitate data sharing and automated analyses through:



Consistent use of vocabulary

needle = frond = **vascular leaf**



Explicit, logical definitions and relationships among concepts

# Plant genomic data is rapidly expanding:

Sample of genomic data available from the National Center for Biotechnology Information under the taxon *Viridiplantae* (green plants)

NCBI data type	# of records
Genome sequences	312
Genome projects	366
Nucleotide EST	21,521,544
Nucleotide GSS	11,247,307
Nucleotide	4,164,700
Protein	1,558,053
SNP	5,418,373
Gene	351,910

**The PO facilitates the integration of and access to genomic data.**

# Joint Genome Institute Site

phytozome

JGI Joint Genome Institute

Center for Integrative Genomics

Search

BLAST

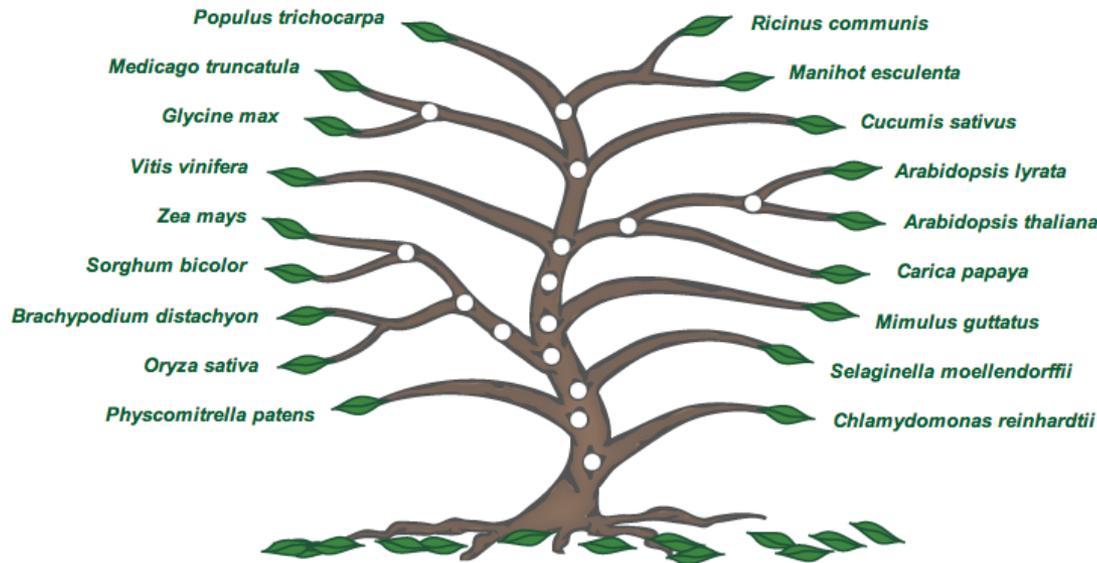
Info

BioMart

Help

Contact

## Phytozome: a tool for green plant comparative genomics



Explore a genome:

Select an organism:

- or -

Find a gene family:

Select node

### News

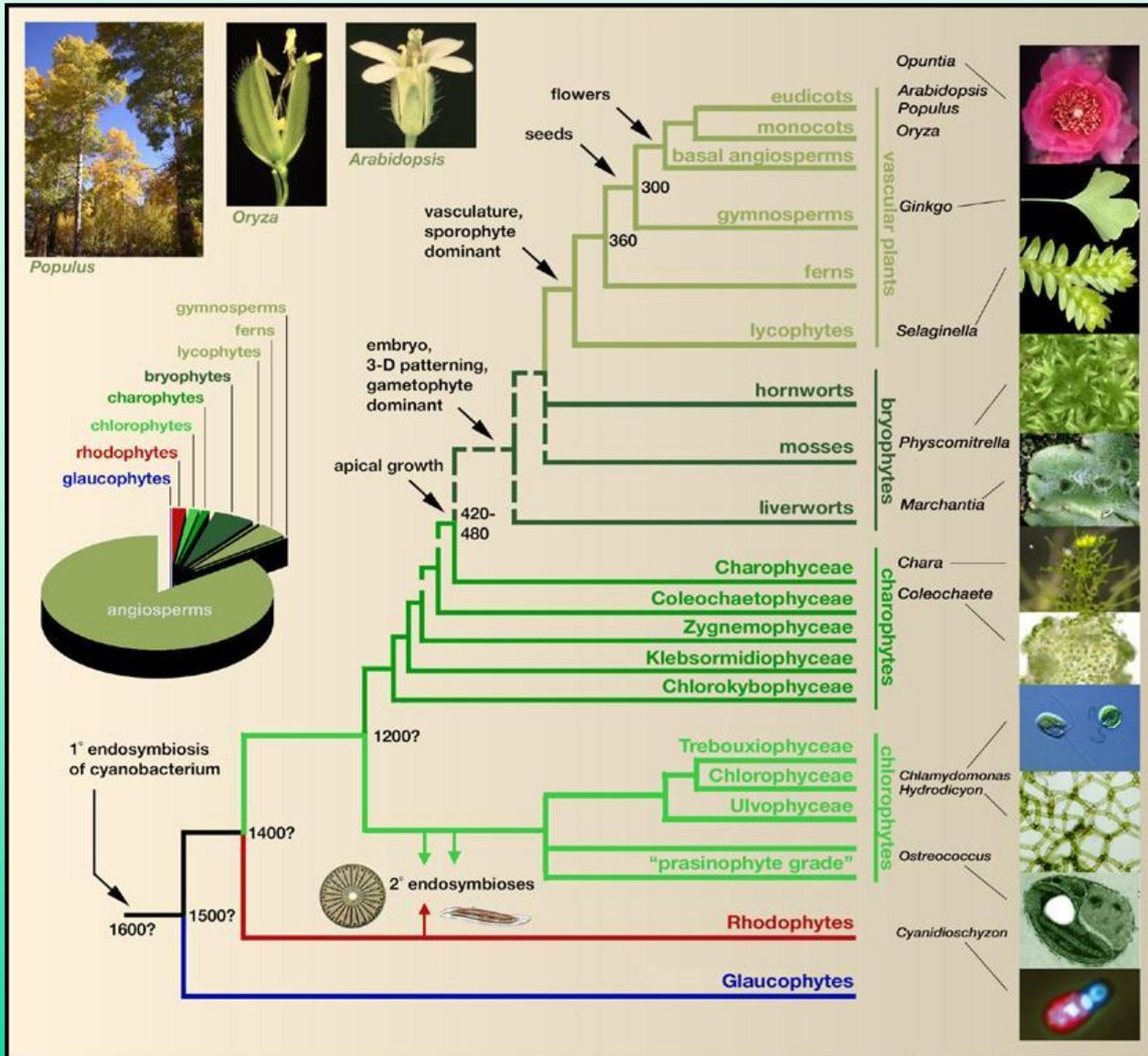
- 11 May 2010 **BLAST interface and Browser released for latest maize B73 genome assembly** The Maize Genome Sequencing Consortium has released the BLAST interface and Browser for the latest maize B73 genome assembly. [\[more\]](#)
- 1 Apr 2010 **Peach genome released.** Access to the Assembled Peach Genome is now available via Gbrowse and BLAST at Phytozome, the [\[more\]](#)
- 8 Jan 2010 **Phytozome v5.0 released.** Version 5.0 of Phytozome is now available, and incorporates both updated and newly released plant [\[more\]](#)
- 23 Nov 2009 **Pseudomolecule maize assembly and annotation now available at Phytozome.** Maize version 4a.53 Pseudomolecule assembly and [\[more\]](#)
- 9 Nov 2009 **Cassava genome released.** Version 1.1 of the Cassava (*Manihot esculenta*) assembly and annotation is now available for download. [\[more\]](#)



## Goals of Plant Ontology:

- Encompass all plants: include terms and annotations from non-flowering plants: Gymnosperms, lycopods, ferns and mosses
- Facilitate comparative genomics across plant taxa
- Outreach Activities and collaborations
- Develop teaching tools
- Create mappings to other ontologies such as GO, PATO and TO

# The PO expanding to covers all plants:



Seed plants

Pteridophytes

Bryophytes

Algae

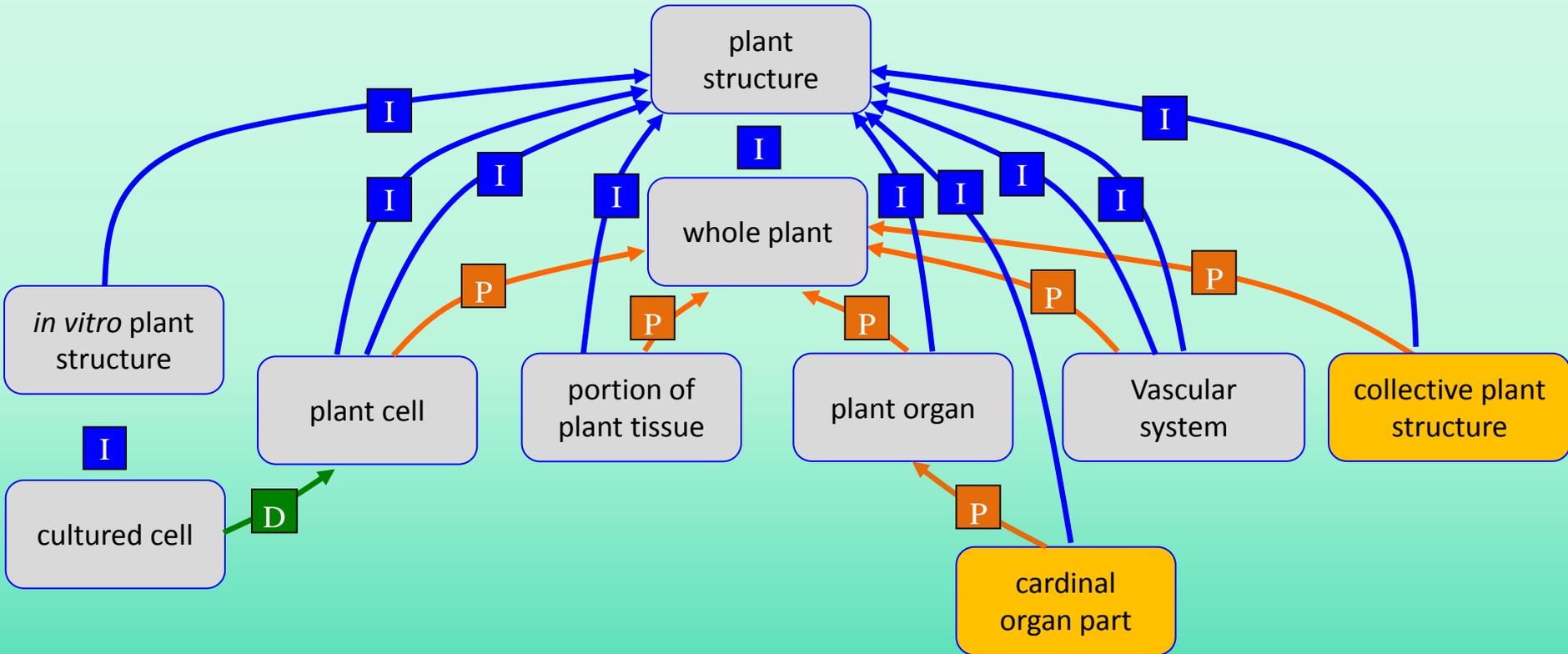
Bowman et al, Cell, 2007



# What's New at Plant Ontology?

- Major database revision released this week
- Revised ontological framework that will encompass terms from all plants
- Previous versions covered only flowering plants- -primarily rice, maize and *Arabidopsis*
- Added 83 new terms, revised definitions and modified child-parent relationships

# Top level re-organization of the Plant Structure Ontology:



- New or renamed top-level terms provide is\_a parents for terms from all taxa
- Extensive revision of the second and third level child terms (not shown)

# How can I use the Plant Ontology?

**Links to PO annotations allow researchers to ask and answer questions:**

- Are homologous genes expressed in similar structures in other species?
- What mutants have similar phenotypes?
- What other genes are expressed in the same plant structure, eg endosperm (PO:0009009)?

# View Annotations in PO (Gene products)

## endosperm

Term annotations [↓](#) Term information [→](#) Term lineage [→](#) External references [→](#)

### Current filters

Database: Gramene Genes

### Filter annotations displayed [?](#)

Filter annotations

Species	Data source	Evidence Code
All	All	All Curator Approved
A. thaliana	Gramene Genes	
C. annuum	Gramene OTI	IDA
Datura	MaizeGDB	IEP

View annotations

All annotations
  Direct annotations

Set filters

Remove all filters

### Annotations to endosperm ; PO:0009089 and its children

Get this data as [RDF-XML](#).

#### endosperm ; PO:0009089 [\[show def\]](#)

Qualifier	Name / Symbol	Information	Evidence	Reference	Assigned by	Associated to
<input type="checkbox"/>	<a href="#">ae1</a> amylose extender-1	gene from <i>Oryza sativa</i>	<a href="#">TAS</a>	<a href="#">GR ref:5683</a>	Gramene (via Gramene Genes)	
<input type="checkbox"/>	<a href="#">ae2</a> amylose extender-2	gene from <i>Oryza sativa</i>	<a href="#">TAS</a>	<a href="#">GR ref:5694</a>	Gramene (via Gramene Genes)	

Click to view the annotation details

# The PO facilitates access to and integration of plant genomic data

## Annotations to leaf primordium ; PO:0000017 and its children

Get this data as [RDF-XML](#).

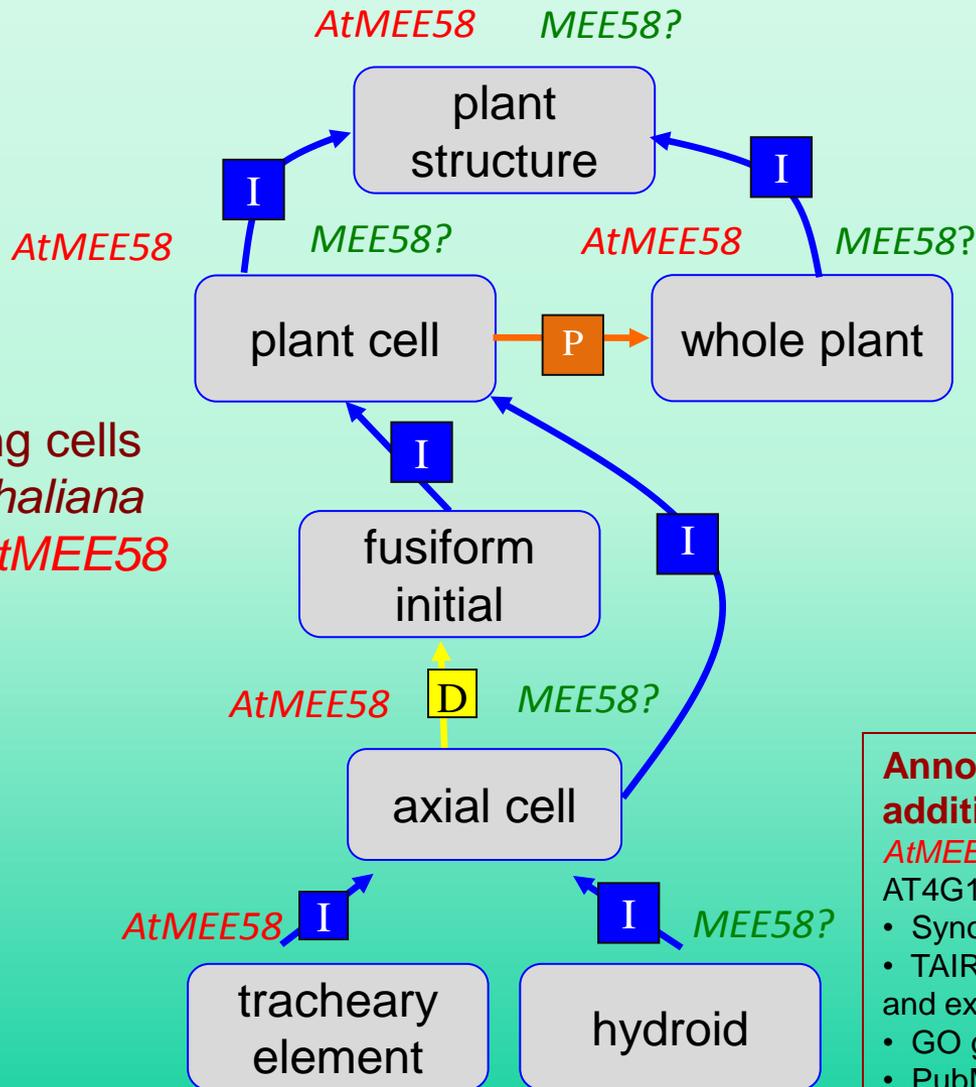
[leaf primordium ; PO:0000017](#) [\[show def\]](#)

	Qualifier	Name / Symbol	Information	Evidence	Reference	Assigned by	Associated to
<input type="checkbox"/>		<a href="#">AN3</a> <a href="#">AT5G28640</a>	gene from <i>Arabidopsis thaliana</i>	<a href="#">IEP</a>	<a href="#">PMID:15960617</a>	<a href="#">TAIR</a>	<a href="#">GO</a>
<input type="checkbox"/>		<a href="#">ARF4</a> <a href="#">AT5G60450</a>	gene from <i>Arabidopsis thaliana</i>	<a href="#">IDA</a>	<a href="#">PMID:16199616</a>	<a href="#">TAIR</a>	<a href="#">GO</a>
<input type="checkbox"/>		<a href="#">AS2</a> <a href="#">AT1G65620</a>	gene from <i>Arabidopsis thaliana</i>	<a href="#">IDA</a>	<a href="#">PMID:17559509</a>	<a href="#">TAIR</a>	<a href="#">GO</a>
<input type="checkbox"/>		<a href="#">AT1G13400.1</a> <a href="#">AT1G13400</a>	gene from <i>Arabidopsis thaliana</i>	<a href="#">IDA</a>	<a href="#">PMID:16554365</a>	<a href="#">TAIR</a>	<a href="#">GO</a>
<input type="checkbox"/>		<a href="#">AT1G22840.1</a> <a href="#">AT1G22840</a>	gene from <i>Arabidopsis thaliana</i>	<a href="#">IDA</a>	<a href="#">PMID:16113211</a>	<a href="#">TAIR</a>	<a href="#">GO</a>
<input type="checkbox"/>		<a href="#">ATARP6</a> <a href="#">AT3G33520</a>	gene from <i>Arabidopsis thaliana</i>	<a href="#">IDA</a>	<a href="#">PMID:16155178</a>	<a href="#">TAIR</a>	<a href="#">GO</a>
<input type="checkbox"/>		<a href="#">ATGA2OX2</a> <a href="#">AT1G30040</a>	gene from <i>Arabidopsis thaliana</i>	<a href="#">IDA</a>	<a href="#">PMID:16139211</a>	<a href="#">TAIR</a>	<a href="#">GO</a>
<input type="checkbox"/>		<a href="#">ATGA2OX4</a>	gene from <i>Arabidopsis</i>	<a href="#">IDA</a>	<a href="#">PMID:16139211</a>	<a href="#">TAIR</a>	<a href="#">GO</a>

>500,000 associations for >1100 terms

<input type="checkbox"/>		<a href="#">ATHB-12</a>	gene from <i>Arabidopsis</i>	<a href="#">IDA</a>	<a href="#">PMID:15604708</a>	<a href="#">TAIR</a>	<a href="#">GO</a>
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# Analyses across taxa using the PO:



Water conducting cells in *Arabidopsis thaliana* express gene *AtMEE58*

Do water conducting cells in mosses express *MEE58*, a homolog of *AtMEE58*?

## Annotations provide links to additional information:

*AtMEE58*- *Arabidopsis thaliana* AT4G13940

- Synonyms: SAAH1, HOG1, MEE58
- TAIR Locus: 2129256 –protein coding and expression data
- GO gene product page
- PubMed ID: 17272833

**I** is\_a

**P** part\_of

**D** develops\_from

# The PO as a teaching tool: eg tepal

## Term Information

<b>Accession</b>	PO:0009033
<b>Ontology</b>	plant structure
<b>Synonyms</b>	None
<b>Definition</b>	A phyllome that is part of a perianth in which all parts are similar in appearance and are neither petals nor sepals. [source: POC:curators]
<b>Comment</b>	None

## Tree View

- all : all [0]
  - PO:0009011 : plant structure [0]
    - PO:0025007 : collective plant structure [0]
      - PO:0025023 : collective phyllome structure [0]
        - PO:0009058 : perianth [0]
          - PO:0025021 : collective tepal structure [0]
            - PO:0009033 : tepal [0]**

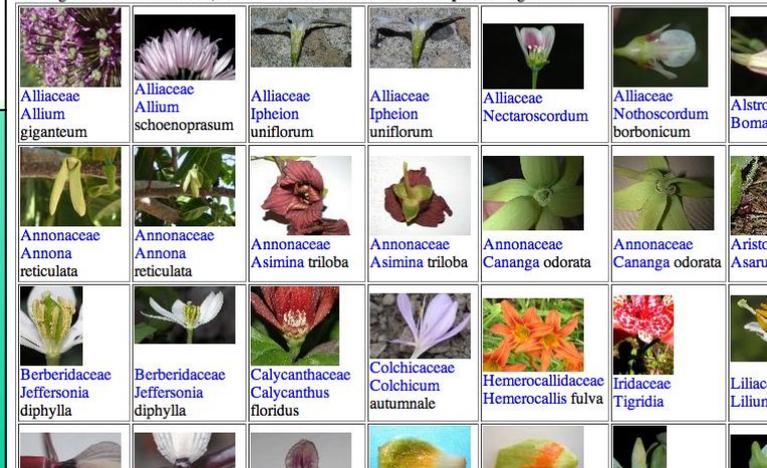
[Back to top](#)

## External References

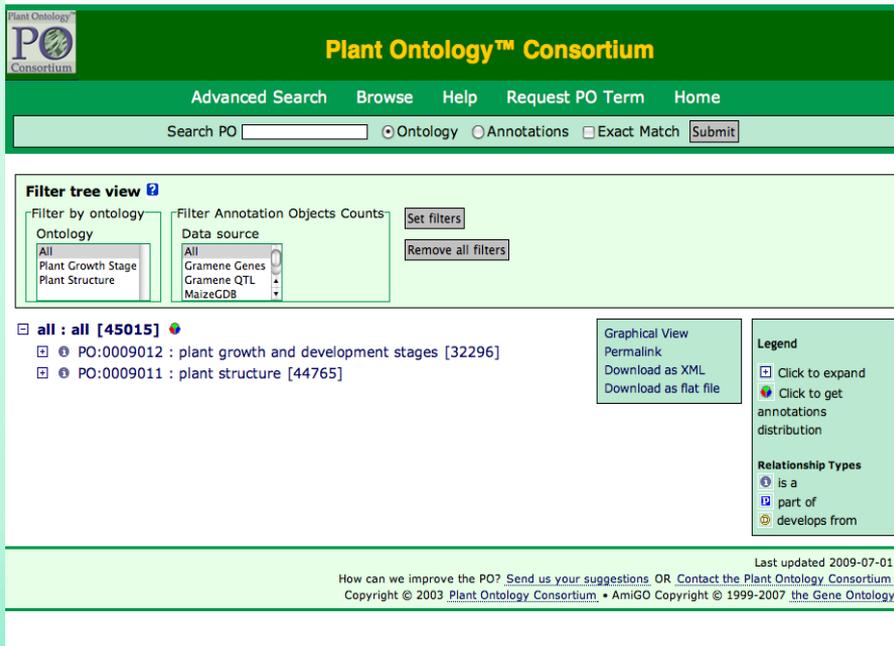
- [PlantSystematics.org \(1\)](#)  
[tepal images](#)
- [SF \(1\)](#)  
2972262

### PlantSystematics.org KEYWORDS SEARCH RESULTS "tepal":

50 images with KEYWORDS, LOCALITY or CAPTION with "tepal": images 1 - 50

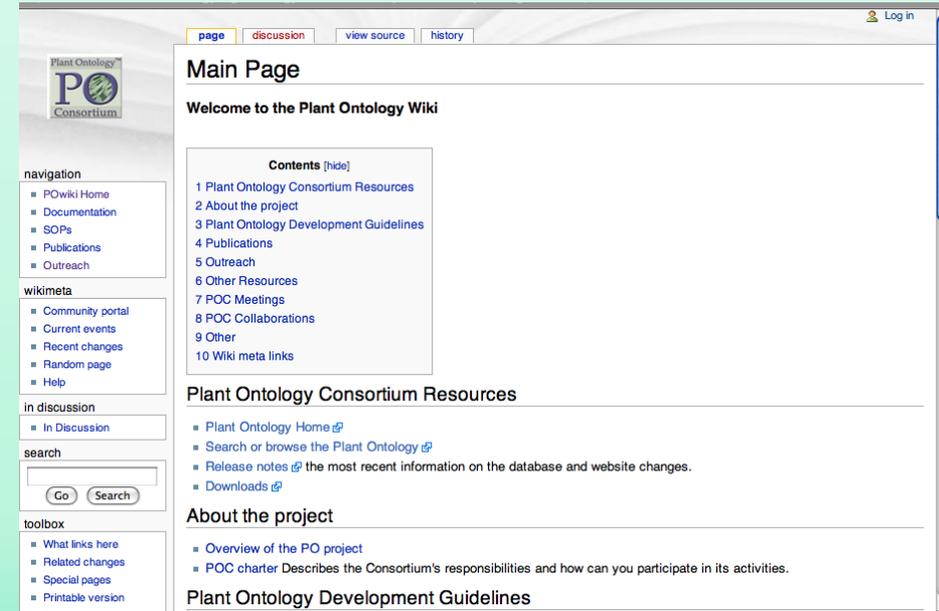


# Outreach: Ontology browser and wiki pages



The screenshot shows the Plant Ontology Consortium website. At the top, there is a green header with the logo and the text "Plant Ontology™ Consortium". Below the header is a navigation bar with links for "Advanced Search", "Browse", "Help", "Request PO Term", and "Home". A search bar is located below the navigation bar, with a "Submit" button. The main content area is titled "Filter tree view" and contains two columns: "Filter by ontology" and "Filter Annotation Objects Counts". The "Filter by ontology" column has a dropdown menu with "All", "Plant Growth Stage", and "Plant Structure". The "Filter Annotation Objects Counts" column has a dropdown menu with "All", "Gramene Genes", "Gramene QTL", and "MaizeCDB". There are buttons for "Set filters" and "Remove all filters". Below the filter tree view, there is a list of results: "all : all [45015]", "PO:0009012 : plant growth and development stages [32296]", and "PO:0009011 : plant structure [44765]". To the right of the results, there is a "Graphical View" section with links for "Permalink", "Download as XML", and "Download as flat file". A "Legend" section is also present, with links for "Click to expand", "Click to get annotations distribution", and "Relationship Types" (is a, part of, develops from). At the bottom, there is a footer with the text "Last updated 2009-07-01" and "How can we improve the PO? Send us your suggestions. OR Contact the Plant Ontology Consortium. Copyright © 2003 Plant Ontology Consortium. • AMIGO Copyright © 1999-2007 the Gene Ontology."

<http://plantontology.org>



The screenshot shows the Plant Ontology Consortium Wiki Main Page. At the top, there is a navigation bar with links for "page", "discussion", "view source", and "history". A "Log in" button is located in the top right corner. The main content area is titled "Main Page" and contains a "Welcome to the Plant Ontology Wiki" message. Below the welcome message, there is a "Contents" section with a list of links: "1 Plant Ontology Consortium Resources", "2 About the project", "3 Plant Ontology Development Guidelines", "4 Publications", "5 Outreach", "6 Other Resources", "7 POC Meetings", "8 POC Collaborations", "9 Other", and "10 Wiki meta links". To the left of the contents, there is a "navigation" section with links for "POwiki Home", "Documentation", "SOPs", "Publications", and "Outreach". Below the navigation, there is a "wikimeta" section with links for "Community portal", "Current events", "Recent changes", "Random page", and "Help". To the right of the wikimeta, there is an "in discussion" section with a link for "In Discussion". Below the in discussion, there is a "search" section with a search bar and "Go" and "Search" buttons. To the right of the search, there is a "toolbox" section with links for "What links here", "Related changes", "Special pages", and "Printable version". Below the toolbox, there is a "Plant Ontology Consortium Resources" section with links for "Plant Ontology Home", "Search or browse the Plant Ontology", "Release notes", and "Downloads". Below the resources, there is an "About the project" section with links for "Overview of the PO project" and "POC charter". Below the about the project, there is a "Plant Ontology Development Guidelines" section.

<http://wiki.plantontology.org>

Web applications such as **VirtualPlant** utilize PO terms and annotations:

<http://virtualplant.bio.nyu.edu>

# Plant Genome Resources Outreach Booth

- A collection of plant genomics databases and projects
- Resources for sequenced genomes, ontology development, genetic mapping, functional annotation of genes, mutants and phenotypes, genetic diversity and bioinformatics tools



GRAMENE



MaizeGDB  
Maize Genetics and Genomics Database



BAR The Bio-Array Resource for Plant Functional Genomics



Solanaceae Genomics Network



[http://wiki.plantontology.org:8080/index.php/Plant\\_Genome\\_Resources](http://wiki.plantontology.org:8080/index.php/Plant_Genome_Resources)

# ASPB Annotation Workshop



# Outreach: Annotation Workshops

The screenshot displays the Phenote browser interface for a file named 'potest.tab'. It is divided into three main sections:

- Annotation Editor (Tab 1):** Contains form fields for:
  - Gene Product Form ID: ARP2
  - DB\_Object\_Type: gene
  - Ontology\_ID: PO (dropdown), fusiform initial (dropdown), and a 'Comp' button.
  - Evidence\_Code: id from direct assay (dropdown)
  - Score qualitative: present (dropdown)
  - Score quantitative: (empty field)
- Term Info: fusiform initial:** Displays details for the selected term:
  - Term: **fusiform initial**
  - ID: PO:0000079
  - Ontology: plant\_structure
  - Definition: An elongated cell with approximately wedge-shaped ends, found in the vascular cambium, which gives rise to the elements of the axial system in the secondary vascular tissues.
  - Definition ref 1: ISBN:0471245208
- Annotation Table (Main):** A table listing annotations for various germplasm samples. The first row is highlighted in blue.

Germplasm	Gene...	DB...	Ontology_ID	Evidence_Code	Score qualitative	Sc...	Reference
Columbia	ARP2	gene	fusiform initial	inferred from direct assay	present		PMID:10561069
Columbia	MEE58	gene	embryo	inferred from mutant phenotype	absent		PMID:18592247
Columbia	MEE58	gene	hormone binding	inferred from mutant phenotype	present		PMID:18592247
Columbia	MEE58	gene	yield trait	inferred from mutant phenotype	increased magnitude		PMID:18592247
Columbia	MEE58	gene	inflorescence branching	inferred from mutant phenotype	branched		PMID:18592247
Columbia	MEE58	gene	seed number	inferred from mutant phenotype	increased magnitude		PMID:18592247
Columbia	MEE58	gene	tracheary element	inferred from expression pattern	present		PMID:18592247

At the bottom of the table, there is a 'Simple Filter' dropdown and radio buttons for 'Exact' and 'Partial' search modes.

Custom Phenote browser allows direct annotation by authors

# Future Directions: Semantic Web Applications

## Community Annotation & Curation

### Semantic Wiki Site

**Edit Annotation: O. sativa - Inflorescence**

Species: *Oryza sativa* Gene: *AWN 4* PO Term: *PO:0009049*

Comments: This gene is expressed under conditions...

Summary: This is a minor edit  Watch this page

**Semantic Data**

```

<rdf:RDF>
  <owl:Ontology rdf:about="http://bioinformatics.org/ontologies/aww/aww.owl#>
    <owl:Class rdf:about="http://bioinformatics.org/ontologies/aww/aww.owl#Inflorescence">
      <owl:hasProperty rdf:resource="http://semantic.wiki.org/aww/aww.owl#PO_Term"/>
    </owl:Class>
    <owl:Class rdf:about="http://bioinformatics.org/ontologies/aww/aww.owl#Oryza_sativa">
      <owl:hasProperty rdf:resource="http://semantic.wiki.org/aww/aww.owl#Species"/>
    </owl:Class>
    <owl:Property rdf:about="http://semantic.wiki.org/aww/aww.owl#PO_Term">
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      <owl:range rdf:resource="http://purl.obolibrary.org/obo/PO.owl#>
    </owl:Property>
    <owl:Property rdf:about="http://semantic.wiki.org/aww/aww.owl#Species">
      <owl:domain rdf:resource="http://bioinformatics.org/ontologies/aww/aww.owl#Oryza_sativa"/>
      <owl:range rdf:resource="http://purl.obolibrary.org/obo/NCIT.owl#>
    </owl:Property>
  </owl:RDF>
  
```

Save page Show preview Show changes Cancel

## Search & Analysis

Wiki searches, and eventually... semantic query tools

e.g. "List species with more than three annotations referencing the gene 'AWN 4' and having inflorescence."

Direct Query and Statistical Analysis

(import:export)

Add something here so I know what to say

### Plant Genome Research Databases

- genomic, proteomic data
- annotations
- ontological cross-references

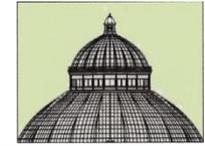
### Plant Ontology

**Plant Ontology**

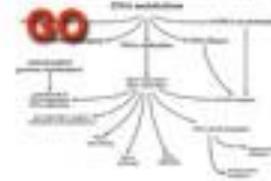
Filter annotations displayed by: Evidence Code, Ontology, Reference, Analyzed By

Qualifier	Term	Ontology	Evidence	Reference	Analyzed By
S full formation	Leaf arrested	plant growth and development stage	TAS	GR:ref:1981	Orphan (use of terms denied)
E budding	Leaf arrested	plant growth and development stage	TAS	GR:ref:1981	Orphan (use of terms denied)
PS de full primary complete	Leaf arrested	plant growth and development stage	TAS	GR:ref:1981	Orphan (use of terms denied)
inflorescence emergence from bud	Leaf arrested	plant growth and development stage	TAS	GR:ref:1981	Orphan (use of terms denied)
ant	Leaf arrested	plant structure	TAS	GR:ref:1981	Orphan (use of terms denied)
ant	Leaf arrested	plant structure	TAS	GR:ref:1981	Orphan (use of terms denied)

# Acknowledgements:



THE NEW YORK  
BOTANICAL GARDEN



Cornell University



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