Advantages of Using the Common Component Architecture (CCA) for the CSDMS Project

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February 4, 2008

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CSDMS

Community Surface Dynamics Modeling System

CSDMS Cyber Working Group Meeting, Univ. of Colorado at Boulder

NSF

Functional Specs for the CSDMS

Support for multiple operating systems
(especially Linux, Mac OS X and Windows)

Support for parallel (multi-proc.) computation (via MPI standard)

Language interoperability (e.g. CCA is language neutral) to support code contributions written in C & Fortran as well as more modern object-oriented languages (e.g. Java, C++, Python)

Support for both legacy (non-protocol) code and more structured code submissions (procedural and object-oriented)

Should be able to interoperate with other coupling frameworks

Support for both structured and unstructured grids

Platform-independent GUIs where useful (e.g. via wxPython)

Large collection of open-source tools

Types of Model Coupling

Layered = A vertical stack of grids that may represent:

(1) different domains (e.g atm-ocean, atm-surf-subsurf, sat-unsat),

(2) subdivision of a domain (e.g stratified flow, stratigraphy),

(3) different processes (e.g. precip, snowmelt, infil, seepage, ET)

A good example is a ***distributed hydrologic model***.

Nested = Usually a high-resolution (and maybe 3D) model that is embedded within (and may be driven by) a lower-resolution model. (e.g. regional winds/waves driving coastal currents, or a 3D channel flow model within a landscape model)

Boundary-coupled = Model coupling across a natural (possibly moving) boundary, such as a coastline. Usually fluxes must be shared across the boundary.

Component Technology

Advantages of Component vs. Subroutine Programming

Can be written in different languages and still communicate.

Can be replaced, added to or deleted from an app. at run-time via dynamic linking.

Can easily be moved to a remote location (different address space) without recompiling other parts of the application (via RMI/RPC support).

Can have multiple different interfaces and can have state.

Can be customized with configuration parameters when application is built.

Provide a clear specification of inputs needed from other components in the system.

Have potential to encapsulate parallelism better.

Allows for multicasting calls that do not need return values (i.e. sending data to multiple components simultaneously).

CBSE = Component-Based Software Engineering

Component technology is basically "plug and play" technology (think of "plugins")

With components, clean separation of functionality is mandatory vs. optional.

Facilitates code re-use and rapid comparison of different methods, etc.

Facilitates efficient cooperation between groups, each doing what they do best.

Promotes economy of scale through development of community standards.

Scientific “Coupling Frameworks”

ESMF (Earth System Modeling Framework)

www.esmf.ucar.edu, maplcode.org/maplwiki

PRISM (Program for Integrated Earth System Modeling)

www.prism.enes.org (uses OASIS4)

OpenMI (Open Modeling Interface)

www.openmi.org

CCA (Common Component Architecture)

www.cca-forum.org,

www.llnl.gov/CASC/components/babel.html

Others: GoldSim (**www.goldsim.com**) commercial

FMS (**www.gfdl.noaa.gov/~fms**) GFDL

Non-scientific ones include CORBA, .NET, COM, JavaBeans, Enterprise Java Beans (see Appendix slide for links)

Overview of CCA

Widely used at DOE labs (e.g. LLNL, ANL, Sandia) for a wide variety of projects (e.g. fusion, combustion)

Language neutral; Components can be written in C, C++, Fortran 77/90/95/03, Java, or Python; supported via a compiler called **Babel**, using SIDL / XML metadata

Interoperable with ESMF, PRISM, MCT, etc.

Has a rapid application development tool called **BOCCA**

Similar to CORBA & COM, but science application support

Can be used for single or multiple-processor systems, distributed or parallel, MPI, high-performance (HPC)

Structured, unstructured & adaptive grids

Has stable DOE / SciDAC (www.scidac.gov) funding

Key CCA Concepts & Terms

Architecture = A software component technology standard (e.g. CORBA, CCA, COM, JavaBeans. synonym: "component model")

Framework = Environment that holds CCA components as they are connected to form applications and then executed. Provides a small set of standard services, available to all components. Different frameworks are needed for parallel vs. distributed computing (e.g. Ccaffeine, Decaf, XCAT, Legion, SCIRun2; obsolete: Ccain, Mocca)

Components = Units of software functionality (black boxes) that can be connected together to form applications. Components expose well-defined interfaces to other components.

Ports = Interfaces through which components interact.

Interface = The "exposed exterior" of anything, such as a component (arguments), an application (GUI, CLI, API, JNI, MPI, SCSI), etc.

May involve communication between, or represent a boundary between any 2 things (e.g. ocean-atmosphere, land-ocean, application-user).

Discussion of Interface Issues

One of the key tasks that now faces the CSDMS community is how to best define the ***interfaces*** for our components (including models) in order to maximize their interoperability with each other and with components (e.g. PDE solvers, mesh routines, visualization tools) written by people outside of our community. The goal is to create the richest possible collection of shared “**plug-and-play**” components and to ensure that they can also be used in an **HPC context**.

In an **object-oriented context**, this includes defining robust object classes and methods. (e.g. string class and associated methods, “grid class” and associated methods [total, average, histogram, smooth, regrid, rescale, display])

To better appreciate interface issues, try to imagine how you could create “plug and play” meshing and discretization components. What would be inside the black box and what would be passed in and out? There are several groups working on these issues.

Discussion of Interface Issues

Component architectures like CCA allow you to think about the ***interface*** and ***implementation*** of components separately.

Interface-related issues

- Exterior of a "black box" (and its "shape" or size, etc.)
- What can it connect to & how?
- Defined by SIDL in a language-neutral way (args & data types)
- Communication (local / remote)
- Application skeleton

Implementation-related issues

- Contents of a "black box"
- What does it do and how?
- Algorithms, source code
- Efficiency, accuracy, stability
- Numerical schemes

Interface Analogies to Ponder: (think about issues in each case)

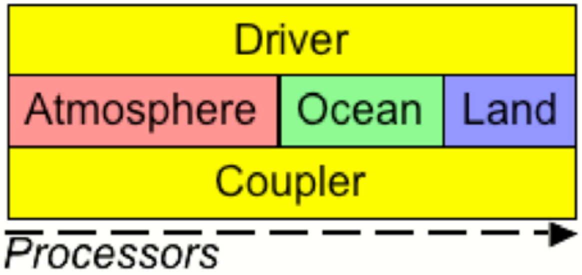
An **antibody** binds to or locks onto the surface of a particular **antigen**, tagging it for destruction or neutralizing it. (more components = better immunity)

Ways in which joints link bones together (e.g. ball and socket) and why.

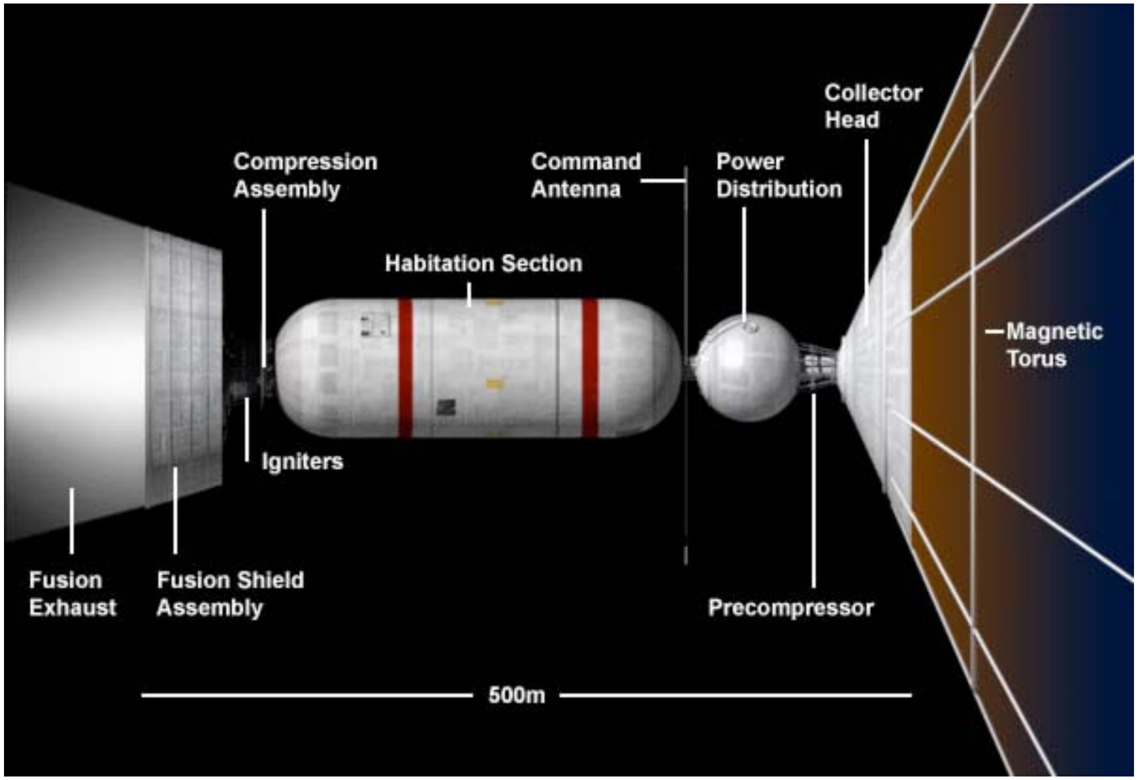
Connecting a computer or stereo to peripheral "components" via "ports".

Discussion of Interface Issues

The decomposition of models into **Initialize**, **Run** (one step) and **Finalize** components is another example of an interface issue. Time-stepping is taken out of models and is left to a separate Driver component.



Imagine designing an application from a set of "black box components that haven't actually been implemented yet. (Everything is a "place-holder.) Which arguments should be passed in and out of each component? What capabilities (black boxes) are actually required to do the current job, similar future jobs or some given set of jobs? SIDL and Bocca allow us to experiment with different interface prototypes. *Somewhat similar to designing an* ***interstellar spacecraft****, where some of the required components don't exist yet, but if they did, it would work.*



Dr. Robert W. Bussard

1928-2007

Designer of the Bussard Ramjet, the Polywell Fusion Reactor and nuclear thermal rocket for Project Rover. Died on October 7th, 2007 in Santa Fe.

Some Key CCA Tools

Babel = A "multi-language" compiler for building HPC applications from components written in different languages. (**http://www.llnl.gov/CASC/components/babel.html**)

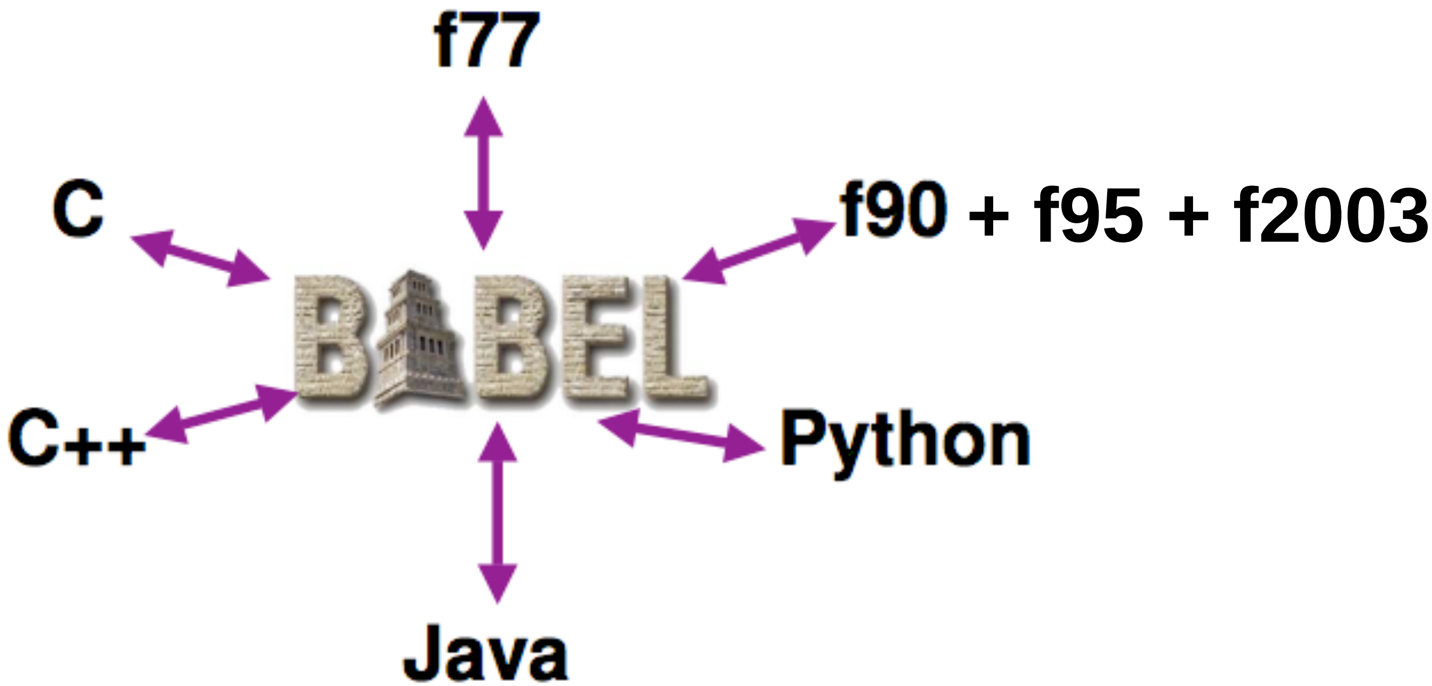
SIDL = Scientific Interface Definition Language (used by Babel). Allows language-independent descriptions of interfaces.

Bocca = A user-friendly tool for rapidly building applications from CCA components (RAD = Rapid Application Development) (**http://portal.acm.org/citation.cfm?id=1297390**)

Ccaffeine = A CCA component framework for parallel computing (**http://www.cca-forum.org/ccafe/ccaffeine-man**)

New CCA build system = Unnamed, user-friendly build system for the complete CCA "tool chain". It uses a Python-based tool called Contractor.

CCA: The Babel Tool



Language interoperability is a powerful feature of the CCA framework. Components written in different languages can be rapidly linked in HPC applications with hardly any performance cost. This allows us to “shop” for open-source solutions (e.g. libraries), gives us access to both procedural and object-oriented strategies (legacy and modern code), and allows us to add graphics & GUIs at will.

CCA: The Babel Tool

Minimal performance cost: A widely used rule of thumb is that environments that impose a performance penalty in excess of 10% will be summarily rejected by HPC software developers.

Babel's architecture is general enough to support **new languages**, such as Matlab, IDL and C# once bindings are written for them.

More than a least-common-denominator solution; it **provides object-oriented capabilities** in languages like C, F77, F9X where they aren't natively available.

Has intrinsic support for **complex numbers** and flexible **multi-dimensional arrays** (& provides for languages that don't have these).   Babel arrays can be in row-major, column-major or arbitrary ordering. This allows data in large arrays to be transferred between languages without making copies.

Babel opens scientific and engineering libraries to a wider audience.

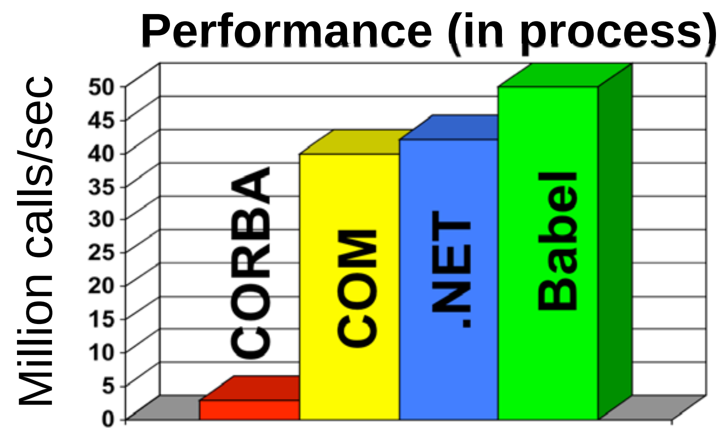
Babel **supports RPC** (remote procedure calls or RMI) over a network.

CCA: The Babel Tool

BABEL is Middleware for HPC

"The world's most rapid communication among many programming languages in a single application."

R&D 100 2006



	CORBA	COM	.NET	Babel
BlueGene, Cray, Linux, AIX, & OS X	No	No	No	Yes*
Fortran	No	Limited	Limited	Yes
Multi-Dim Arrays	No	No	No	Yes
Complex Numbers	No	No	No	Yes
Licensing	Vendor Specific	Closed Source	Closed Source	Open Source

Python Support in CCA / Babel

Support for **Java & Python** makes it possible to add components with GUIs, graphics or network access anywhere in the application (e.g. via **wxPython or PyQT**). Python code can be compiled to Java with **Jython**. (See **www.jython.org** for details)

NumPy is a fairly new Python package that provides fast, array-based processing similar to Matlab or IDL. **SciPy** is a closely related package for scientific computing. **Matplotlib** is a package that allows Python users to make plots using Matlab syntax.

Python is used by Google and is the new ESRI scripting language. It can be expected that this will result in new GIS-related packages/plug-ins. Python is entirely open-source and a large number of components are available (e.g. XML parser). Currently has over one million users and is growing.

GIS tools are often useful for earth-surface modeling and visualization.

python™

MAY/JUNE 2007 Volume 9, Number 3

Computing in SCIENCE & ENGINEERING

PYTHON: BATTERIES INCLUDED

Statement of Purpose

Computing in Science & Engineering aims to support and promote the emerging discipline of computational science and engineering and to foster the use of computers and computational techniques in scientific research and education. Every issue contains broad-interest theme articles, departments, news reports, and editorial comment. Collateral materials such as source code are made available electronically over the Internet. The intended audience comprises physical scientists, engineers, mathematicians, and others who would benefit from computational methodologies.

All articles and technical notes in CiSE are peer-reviewed.

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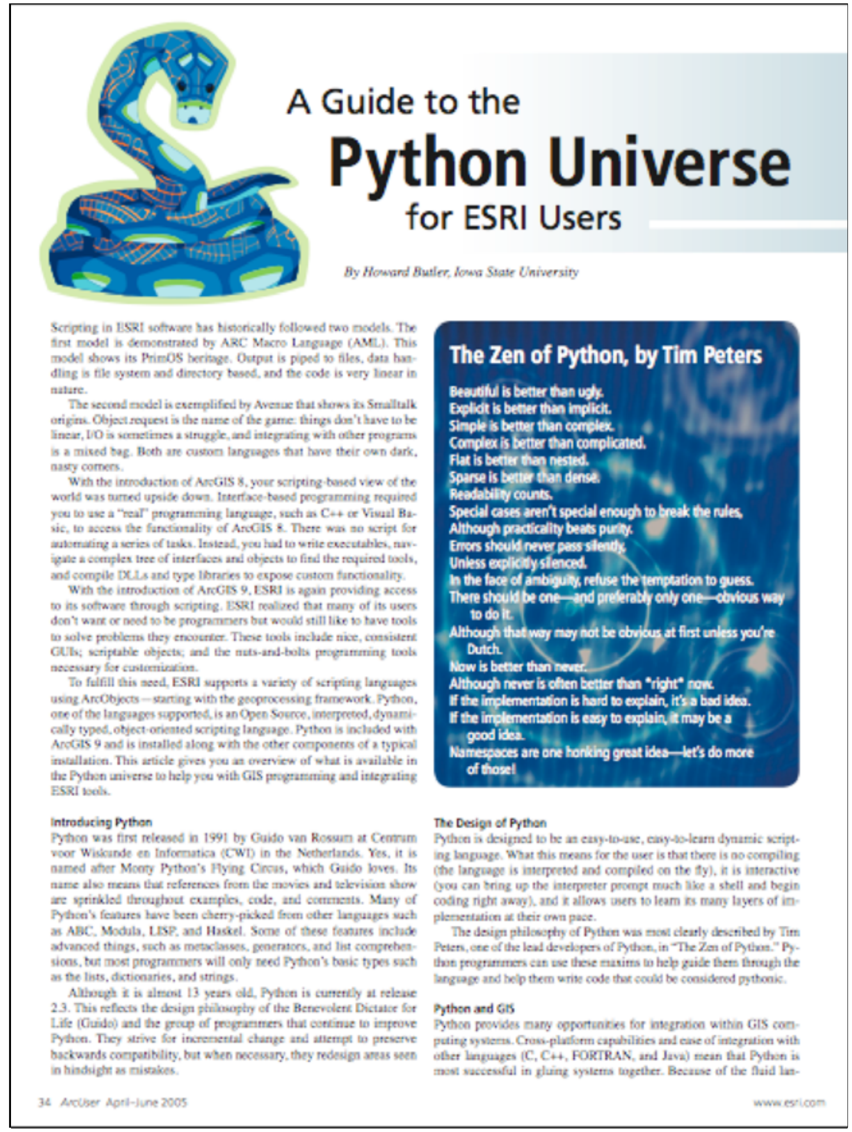
Python: Batteries Included, special issue of "Computing in Science & Engineering devoted to Python, May-June 2007, vol. 9(3), 66 pp. Nice collection of articles, incl. papers on ipython, matplotlib, GIS, solving PDEs.



A Guide to the Python Universe for ESRI Users

By Howard Butler, Iowa State University

Scripting in ESRI software has historically followed two models. The first model is demonstrated by ARC Macro Language (AML). This model shows its PrimOS heritage. Output is piped to files, data handling is file system and directory based, and the code is very linear in nature.

The second model is exemplified by Avenue that shows its Smalltalk origins. Object request is the name of the game: things don't have to be linear, I/O is sometimes a struggle, and integrating with other programs is a mixed bag. Both are custom languages that have their own dark, nasty corners.

With the introduction of ArcGIS 8, your scripting-based view of the world was turned upside down. Interface-based programming required you to use a "real" programming language, such as C++ or Visual Basic, to access the functionality of ArcGIS 8. There was no script for automating a series of tasks. Instead, you had to write executables, navigate a complex tree of interfaces and objects to find the required tools, and compile DLLs and type libraries to expose custom functionality.

With the introduction of ArcGIS 9, ESRI is again providing access to its software through scripting. ESRI realized that many of its users don't want or need to be programmers but would still like to have tools to solve problems they encounter. These tools include nice, consistent GUIs; scriptable objects; and the nuts-and-bolts programming tools necessary for customization.

To fulfill this need, ESRI supports a variety of scripting languages using ArcObjects—starting with the geoprocessing framework. Python, one of the languages supported, is an Open Source, interpreted, dynamically typed, object-oriented scripting language. Python is included with ArcGIS 9 and is installed along with the other components of a typical installation. This article gives you an overview of what is available in the Python universe to help you with GIS programming and integrating ESRI tools.

The Zen of Python, by Tim Peters

Beautiful is better than ugly.
Explicit is better than implicit.
Simple is better than complex.
Complex is better than complicated.
Flat is better than nested.
Sparse is better than dense.
Readability counts.
Special cases aren't special enough to break the rules.
Although practicality beats purity.
Errors should never pass silently.
Unless explicitly silenced.
In the face of ambiguity, refuse the temptation to guess.
There should be one—and preferably only one—obvious way to do it.
Although that way may not be obvious at first unless you're Dutch.
Now is better than never.
Although never is often better than *right* now.
If the implementation is hard to explain, it's a bad idea.
If the implementation is easy to explain, it may be a good idea.
Namespaces are one honking great idea—let's do more of those!

Introducing Python

Python was first released in 1991 by Guido van Rossum at Centrum voor Wiskunde en Informatica (CWI) in the Netherlands. Yes, it is named after Monty Python's Flying Circus, which Guido loves. Its name also means that references from the movies and television show are sprinkled throughout examples, code, and comments. Many of Python's features have been cherry-picked from other languages such as ABC, Modula, LISP, and Haskel. Some of these features include advanced things, such as metaclasses, generators, and list comprehensions, but most programmers will only need Python's basic types such as the lists, dictionaries, and strings.

Although it is almost 13 years old, Python is currently at release 2.3. This reflects the design philosophy of the Benevolent Dictator for Life (Guido) and the group of programmers that continue to improve Python. They strive for incremental change and attempt to preserve backwards compatibility, but when necessary, they redesign areas seen in hindsight as mistakes.

The Design of Python

Python is designed to be an easy-to-use, easy-to-learn dynamic scripting language. What this means for the user is that there is no compiling (the language is interpreted and compiled on the fly), it is interactive (you can bring up the interpreter prompt much like a shell and begin coding right away), and it allows users to learn its many layers of implementation at their own pace.

The design philosophy of Python was most clearly described by Tim Peters, one of the lead developers of Python, in "The Zen of Python." Python programmers can use these maxims to help guide them through the language and help them write code that could be considered pythonic.

Python and GIS

Python provides many opportunities for integration within GIS computing systems. Cross-platform capabilities and ease of integration with other languages (C, C++, FORTRAN, and Java) mean that Python is most successful in gluing systems together. Because of the fluid lan-

34 ArcUser April–June 2005 www.esri.com

Butler, H. (2005) A guide to the Python universe for ESRI users, ArcUser (April-June 2005), p. 34-37. (tools for ellipsoids, datums, file formats like shapefiles)

CCA: The Bocca Tool

Provides project management and comprehensive build environment for creating and managing applications composed of CCA components

The purpose of Bocca is to let the user create and maintain useful HPC components without the need to learn the intricacies of CCA (and Babel) and waste time and effort in low-level software development and maintenance tasks. Can be abandoned at any time without issues.

Bocca lays down the scaffolding for a complete componentized application without any atttendent scientific or mathematical implementation.

Built on top of Babel; is language-neutral and further automates tasks related to component "glue code"

Supports short time to first solution in an HPC environment

Easy-to-make, stand-alone executables coming in March 2008
(automatically bundles all required libraries; RC + XML -> EXE)

CCA: The Bocca Tool

General usage:

bocca [options] <verb> <subject type> [suboptions] <target name>

Examples:

bocca create project myproj --language=f90
bocca create component
bocca edit component

Current verbs:

create, change, remove, rename, edit, display, whereis, help, config, export

Subject types (CCA entity classes):

port, component, interface, class, package

Target names are SIDL type names:

e.g. mypkg.MyComponent, mypkg.ports.Kelvinator

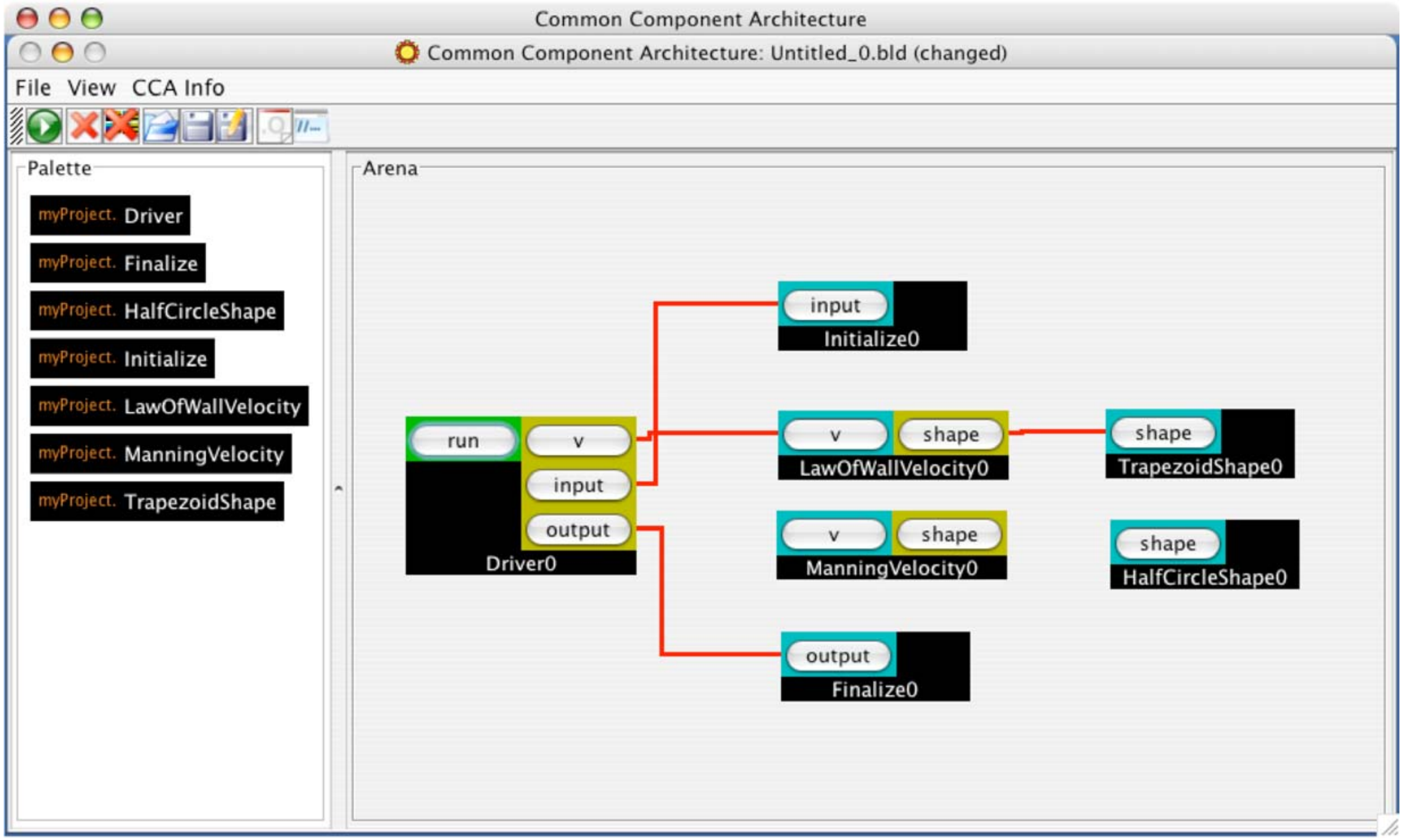
A good paper on Bocca is available at:
http://portal.acm.org/citation.cfm?id=1297390 (pdf)

A Bocca Script Example

```
#! /bin/bash
#  Use BOCCA to create a CCA test project.
#  October 23, 2007.   S.D. Peckham
#-----------------------
#  Set necessary paths
#-----------------------
source $HOME/.bashrc
echo "============================================"
echo "  Building example CCA project with BOCCA  "
echo "============================================"

#-------------------------------------
#  Create a new project with BOCCA and
#     Python as the default language
#--------------------------------------
cd $HOME/Desktop
mkdir cca_ex2;  cd cca_ex2
bocca create project myProject --language=python
cd myProject

#-------------------------------
#  Create some ports with BOCCA
#-------------------------------
bocca create port InputPort
bocca create port vPort
bocca create port ChannelShapePort
bocca create port OutputPort

#----------------------------------------
#  Create a Driver component with BOCCA
#---------------------------------------
bocca create component Driver \
             --provides=gov.cca.ports.GoPort:run \
             --uses=InputPort:input \
             --uses=vPort:v \
             --uses=OutputPort:output
```

```
#----------------------------------
#  Create an Initialize component
#----------------------------------
bocca create component Initialize \
             --provides=InputPort:input

#-----------------------------------------------
#  Create two components that compute velocity
#-----------------------------------------------
bocca create component ManningVelocity \
             --provides=vPort:v \
             --uses=ChannelShapePort:shape
bocca create component LawOfWallVelocity \
             --provides=vPort:v \
             --uses=ChannelShapePort:shape

#------------------------------------------------
#  Create some channel cross-section components
#------------------------------------------------
bocca create component TrapezoidShape \
             --provides=ChannelShapePort:shape
bocca create component HalfCircleShape \
             --provides=ChannelShapePort:shape

#-------------------------------------
#  Create a Finalize component
#-------------------------------------
bocca create component Finalize \
             --provides=OutputPort:output

#--------------------------------------
#  Configure and make the new project
#--------------------------------------
./configure; make
```

CCA: The Ccaffeine-GUI Tool



A “wiring diagram” for a simple CCA project. The CCA framework called **Ccaffeine** provides a “visual programming” GUI for linking components to create working applications.

CCA: The Ccaffeine Tools

Ccaffeine is the standard CCA framework that supports parallel computing. Three distinct "Ccaffeine executables" are available, namely:

Ccafe-client = a client version that expects to connect to a multiplexer front end which can then be connected to the Ccaffeine-GUI or a plain command line interface.

Ccafe-single = a single-process, interactive version useful for debugging

Ccafe-batch = a batch version that has no need of a front end and no interactive ability

These executables make use of "Ccaffeine resource files" that have "rc" in the filename (e.g. test-gui-rc).

The **Ccaffeine Muxer** is a central multiplexor that creates a single multiplexed communication stream (back to the GUI) out of the many cafe-client streams.

For more information, see: **http://www.cca-forum.org/ccafe/ccaffeine-man/**

Other CCA-Related Projects

CASC = Center for Applied Scientific Computing
(https://computation.llnl.gov/casc/)

TASCS = The Center for Technology for Advanced Scientific Computing Software
(http://www.tascs-scidac.org) (focus is on CCA and associated tools; was CCTTSS)

PETSc = Portable, Extensible Toolkit for Scientific Computation
(http://www.mcs.anl.gov/petsc) (focus is on linear & nonlinear PDE solvers; HPC/MPI)

ITAPS = The Interoperable Technologies for Advanced Petascale Simulations Center
(http://www.itaps-scidac.org) (focus is on meshing & discretization; was TSTT)

PERI = Performance Engineering Research Institute
(http://www.peri-scidac.org) (focus is on HPC quality of service & performance)

TOPS = Terascale Optimal PDE Solvers
(http://www.scidac.gov/ASCR/ASCR_TOPS.html) (focus is on solvers)

SCIRun = CCA framework from Scientific Computing and Imaging Institute
(http://software.sci.utah.edu/scirun.html) (this is a CCA framework)

Conclusions

The Common Component Architecture (CCA) is a mature and powerful environment for component-based software engineering (CBSE) and building high-performance computing (HPC) applications.

Some of its most powerful tools include Babel, Bocca, Ccafe-GUI and the Ccaffeine framework. Each of these tools fulfills a particular need in an elegant manner in order to greatly simplify the effort that is required to build an HPC application.

The CCA framework currently meets most of the requirements of CSDMS and native Windows support (vs. Cygwin) is likely in the near future.

CCA has been shown to be interoperable with ESMF and should also be interoperable with a Java version of OpenMI.

For more information, please see the “CCA Recommended Reading List” at http://csdms.colorado.edu   (Products tab)

Other Component Architecture Links

(Commercial, non-HPC, non-scientific computing)

CORBA (Object Management Group)
http://www.omg.org/gettingstarted
http://www.omg.org/gettingstarted/history_of_corba.htm

COM (Component Object Model, Microsoft, incl. COM+, DCOM & ActiveX)
http://www.microsoft.com/com/default.mspx

.NET (Microsoft Corp.)
http://www.microsoft.com/net

JavaBeans (Sun Microsystems)
http://java.sun.com/products/javabeans

Enterprise JavaBeans (Sun Microsystems)
http://java.sun.com/products/ejb

Overview of ESMF

Widely used by U.S. climate modelers

Based on **Fortran90** (efforts underway for C coupling)

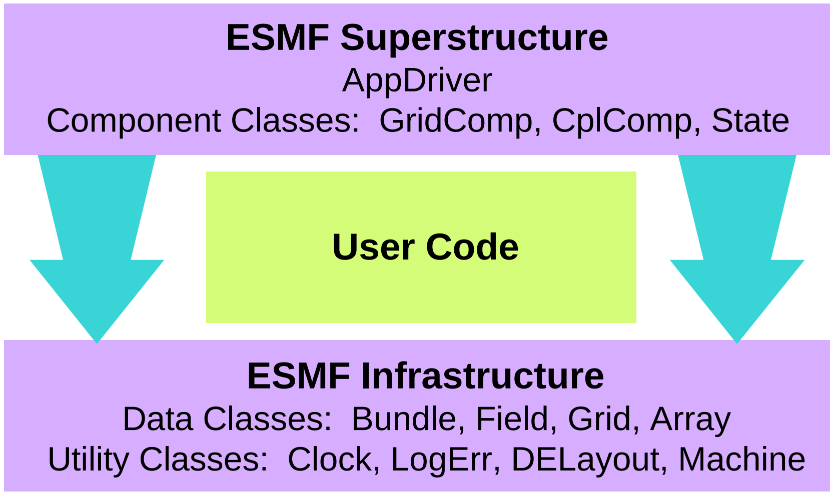
Components follow the **Initialize, Run, Finalize** scheme

Has a new development tool called **MAPL**

Started with NASA, now has buy-in from NOAA, DoD, DOE, NSF. May be adopted by CCSM; see:

www.ccsm.ucar.edu/cseg/Projects/Working_Groups/soft/esmf

- Parallel-computing friendly (MPI)
- Compatible with PRISM & CCA.
- Many useful tools in its Infra-structure & Superstructure
- Mainly structured grids so far



Overview of OpenMI

Emerged from **hydrologic community** in Europe with corporate buy-in (e.g. Delft Hydraulics, DHI, HR Wallingford)

Based on **Microsoft's C#** (similar to Java) and support for Java is under development by HydroliGIS (Italy)

Components follow the **Initialize, Run, Finalize** scheme

Emphasizes support for data formats (e.g. WML)

Currently incompatible with non-Windows computers, so language and platform specific

Designed for a single-processor (PC) environment

Funding future is currently uncertain beyond 2010

Does not seem to have the maturity or buy-in of ESMF & CCA.