



**CCA**  
Common Component Architecture

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# Welcome to the Common Component Architecture Tutorial

SC2007  
12 November 2007

**CCA Forum Tutorial Working Group**  
[http://www.cca-forum.org/tutorials/  
tutorial-wg@cca-forum.org](http://www.cca-forum.org/tutorials/tutorial-wg@cca-forum.org)

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  - [CCA Forum Tutorial Working Group, Common Component Architecture Tutorial, 2007, http://www.cca-forum.org/tutorials/](http://www.cca-forum.org/tutorials/)

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## About the Printed Notes

- The printed version of these presentations includes additional slides marked *“Supplementary material for handouts”*
- Additional material to address questions sometimes raised, or provide more detail on a topic
- We are happy to discuss this material if asked

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## Agenda & Table of Contents

Time	Title	Slide No.	Presenter
8:30-8:35am	Welcome	1	David Bernholdt, ORNL
8:35-9:30am	What Can Component Technology do for Scientific Computing	6	David Bernholdt, ORNL
	An Intro to Components & the CCA	17	David Bernholdt, ORNL
9:30-10:00am	CCA Tools	72	Rob Armstrong, SNL
10:00-10:30am	Break		
10:30-11:10am	Language Interoperable CCA Components with Babel	109	Gary Kumfert, LLNL
11:10am-11:55am	Using CCA: Approaches & Experience	136	Boyana Norris, ANL
11:55am-12:00n	Closing	183	Boyana Norris, ANL
12:00-1:30pm	Lunch		
1:30-3:00pm	Hands-On	Hands-On Guide	Rob Armstrong, SNL
3:00-3:30pm	Break		
3:30-5:00pm	Hands-On (continued)		

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## Who We Are: The Common Component Architecture (CCA) Forum

- Combination of standards body and user group for the CCA
- Define [specifications](#) for high-performance scientific components & frameworks
- Promote and facilitate development of [tools](#) for component-based software development, [components](#), and component [applications](#)
- Open membership, quarterly meetings...

General mailing list: [cca-forum@cca-forum.org](mailto:cca-forum@cca-forum.org)

Web: <http://www.cca-forum.org/>

- Center for Technology for Advanced Scientific Component Software (TASCS)
  - Funded by the US DOE SciDAC program
  - Core development team for CCA technologies



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## What Can Component Technology do for Scientific Computing?

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## Managing Code Complexity

**Some Common Situations:**

- Your code is so large and complex it has become fragile and hard to keep running
- You have a simple code, and you want to extend its capabilities
  - rationally
- You want to develop a computational “toolkit”
  - Many modules that can be assembled in different ways to perform different scientific calculations
  - Gives users w/o programming experience access to a flexible tool for simulation
  - Gives users w/o HPC experience access to HPC-ready software

**How CCA Can Help:**

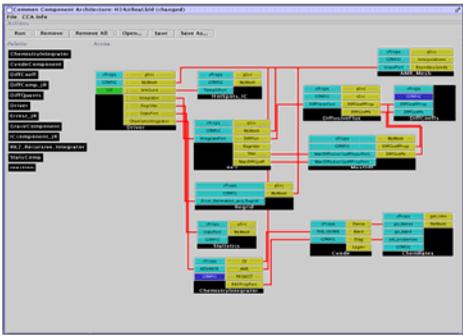
- Components help you think about software in manageable chunks that interact only in well-defined ways
- Components provide a “plug-and-play” environment that allows easy, flexible application assembly

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## Example: Computational Facility for Reacting Flow Science (CFRFS)

- A toolkit to perform simulations of unsteady flames
- Solve the Navier-Stokes with detailed chemistry
  - Various mechanisms up to ~50 species, 300 reactions
  - Structured adaptive mesh refinement
- CFRFS today:
  - 61 components
  - 7 external libraries
  - 9 contributors



*“Wiring diagram” for a typical CFRFS simulation, utilizing 12 components.*

**CCA tools used:** Ccaffeine, and ccafe-gui

**Languages:** C, C++, F77

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## Helping Groups Work with Software

**Some Common Situations:**

- Many (geographically distributed) developers creating a large software system
  - Hard to coordinate, different parts of the software don't work together as required
- Groups of developers with different specialties
- Forming communities to standardize interfaces or share code

**How CCA Can Help:**

- Components are natural units for
  - Expressing software architecture
  - Individuals or small groups to develop
  - Encapsulating particular expertise
- Some component models (including CCA) provide tools to help you think about the *interface* separately from the *implementation*

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## Example: Quantum Chemistry

- Integrated state-of-the-art optimization technology into two quantum chemistry packages to explore effectiveness in chemistry applications
- Geographically distributed expertise:
  - California - chemistry
  - Illinois - optimization
  - Washington – chemistry, parallel data management
- Effective collaboration with minimal face-to-face interaction

*Schematic of CCA-based molecular structure determination quantum chemistry application.*

**Components based on:** MPQC, NWChem (quantum chem.), TAO (optimization), Global Arrays, PETSc (parallel linear algebra)

**CCA tools used:** Babel, Ccaffeine, and ccafe-gui

**Languages:** C, C++, F77, Python

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## Example: TSTT Unstructured Mesh Tool Interoperability

- Common interface for unstructured mesh geometry and topology
  - 7 libraries: FMDB, Frontier, GRUMMP, Mesquite, MOAB, NWGrid, Overture
  - 6 institutions: ANL, BNL/SUNY-Stony Brook, LLNL, PNNL, RPI, SNL
- Reduces need for  $N^2$  pairwise interfaces to just  $N$

*Illustration of geometry domain hierarchy used in TSTT mesh interface.*

**CCA tools used:** Babel (SIDL), Chasm  
**Library languages:** C, C++, F77, F90

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## Language Interoperability

**Some Common Situations:**

- Need to use existing code or libraries written in multiple languages in the same application?
- Want to allow others to access your library from multiple languages?
- Technical or sociological reasons for wanting to use multiple languages in your application?

**How CCA Can Help:**

- Some component models (including CCA) allow transparent mixing of languages
- Babel (CCA's language interop. tool) can be used separately from other component concepts

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L	A	P	A	C	K			
L	-	A	P	-	A	C	-	K
L	A	P	A	C	K			
L	-	A	P	-	A	C	-	K
L	A	P	A	C	K			
L	-	A	P	-	A	C	-	K



**hypre**  
High-performance preconditioners

## Examples

**hypre**

- High performance preconditioners and linear solvers
- Library written in C
- Babel-generated object-oriented interfaces provided in C, C++, Fortran

**LAPACK07**

- Update to LAPACK linear algebra library
  - To be released 2007
  - Library written in F77, F95
- Will use Babel-generated interfaces for: C, C++, F77, F95, Java, Python
- Possibly also ScaLAPACK (distributed version)

*"I implemented a Babel-based interface for the hypre library of linear equation solvers. The Babel interface was straightforward to write and gave us interfaces to several languages for less effort than it would take to interface to a single language."*

-- Jeff Painter, LLNL. 2 June 2003

**CCA tools used:** Babel, Chasm



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## Coupling Codes

**Some Common Situations:**

- Your application makes use of numerous third-party libraries
  - Some of which interact (version dependencies)
- You want to develop a simulation in which your code is coupled with others
  - They weren't designed with this coupling in mind
  - They must remain usable separately too
  - They are all under continual development, individually
  - They're all parallel and need to exchange data frequently

**How CCA Can Help:**

- Components are isolated from one another
  - Interactions via well-defined interfaces
  - An application can include multiple versions of a component
- Components can be composed flexibly, hierarchically
  - Standalone application as one assembly, coupled simulation as another
- CCA can be used in SPMD, MPMD, and distributed styles of parallel computing
- CCA is developing technology to facilitate data and functional coupling of parallel applications

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# An Introduction to Components and the Common Component Architecture

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## Goals of This Module

- Introduce basic **concepts and vocabulary** of component-based software engineering and the CCA
- Highlight the special **demands of high-performance scientific computing** on component environments
- Give you sufficient **understanding** of the CCA to begin **evaluating** whether it would be useful to you





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## What are Components?

- No universally accepted definition in computer science research, but key features include...
- A unit of software development/deployment/reuse
  - i.e. has **interesting functionality**
  - Ideally, functionality someone else might be able to **(re)use**
  - Can be **developed independently** of other components
- Interacts with the outside world only through well-defined interfaces
  - **Implementation is opaque** to the outside world
- Can be composed with other components
  - “Plug and play” model to build applications
  - **Composition based on interfaces**



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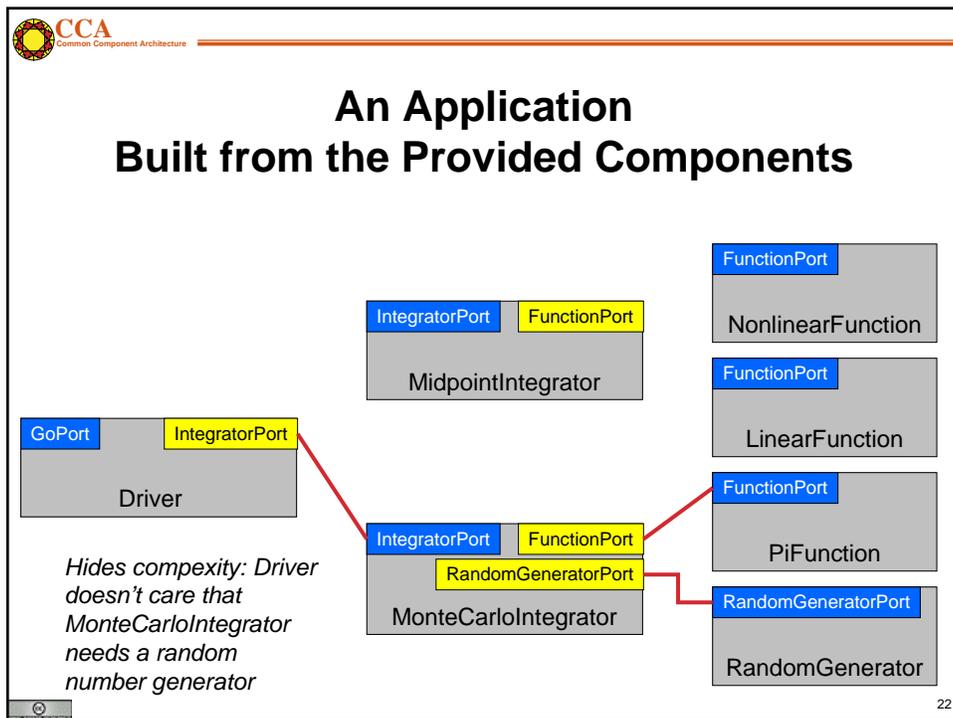
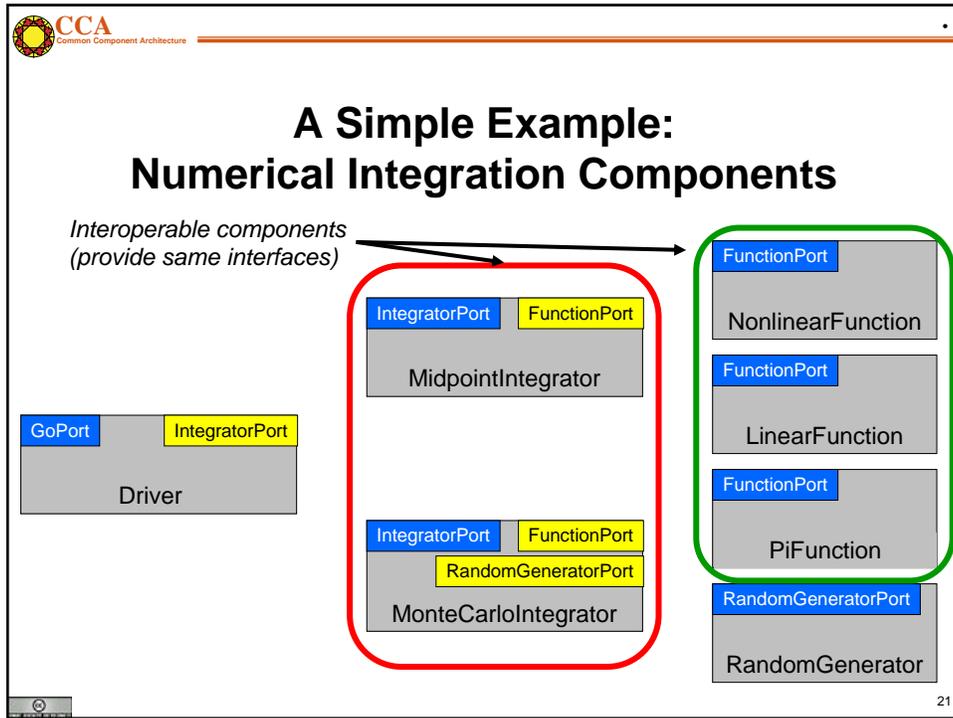
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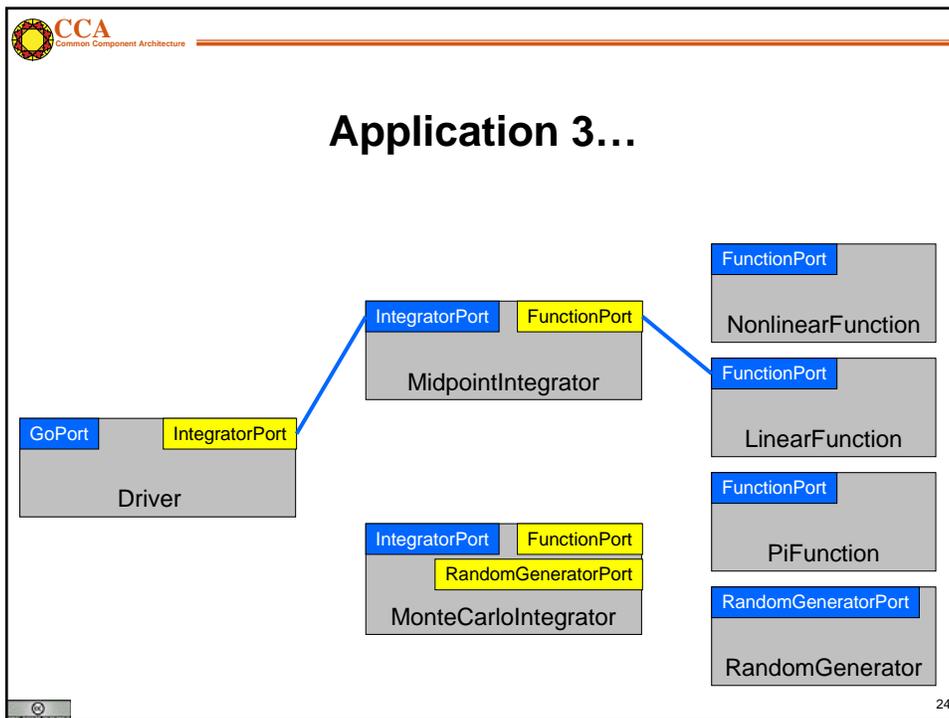
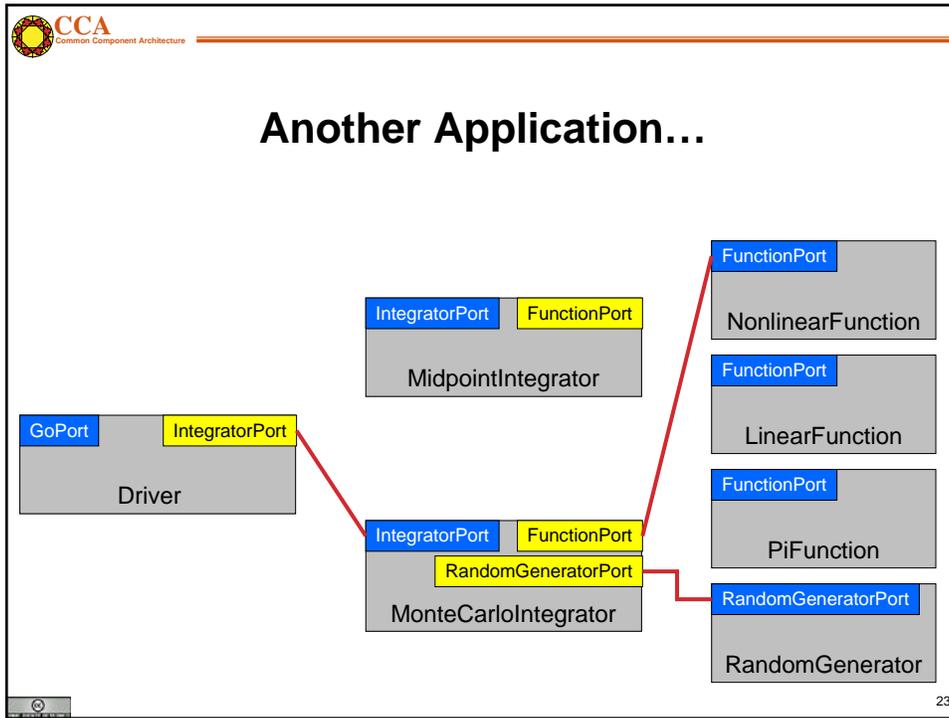
## What is a Component Architecture?

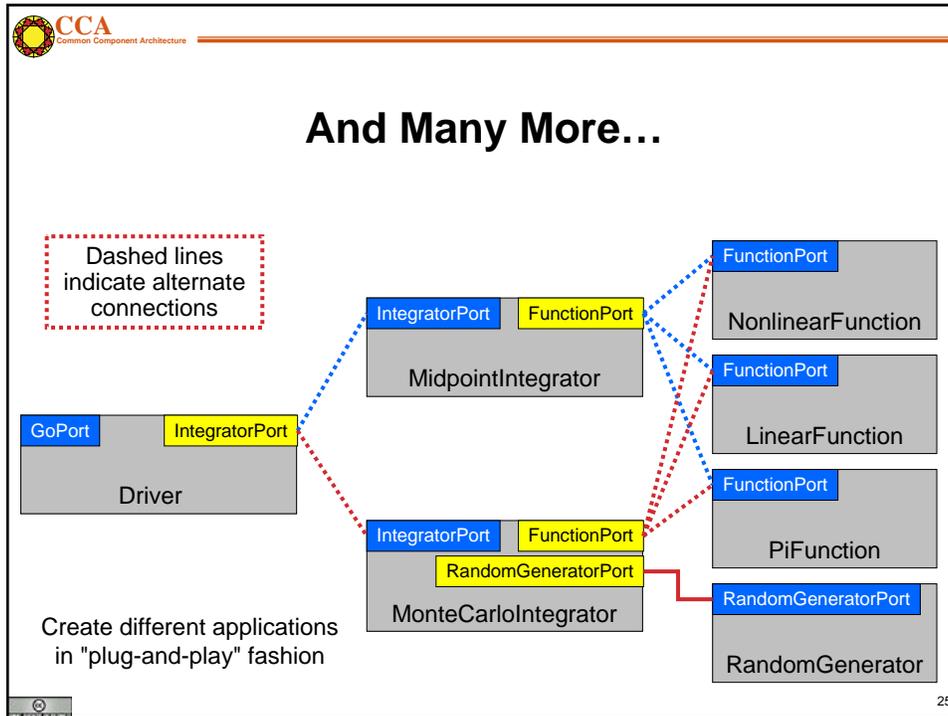
- A set of **standards** that allows:
  - Multiple groups to write units of software (**components**)...
  - And have confidence that their components will **work with other components** written in the same architecture
- These standards **define**...
  - The rights and responsibilities of a **component**
  - How components express their **interfaces**
  - The environment in which components are composed to form an application and executed (**framework**)
  - The rights and responsibilities of the framework



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Supplementary material for handouts

### Comparison of Application Development Approaches

Characteristics	Monolithic Simulation Code	Simulation Frameworks	Library -Based	Component -Based
Support for specific workflows and information flows	High	High	Low	Low
Flexibility w.r.t. workflow and information flow	Low	Medium	High	High
User-level extensibility	Low	Medium	High	High
Ease of incorporation of outside code (code reuse)	Low	Low-Medium	Medium	High
Ease of experimentation	Low	Medium	Medium	High
Amount of new code required to create a complete simulation	Low	Medium	High	High (reuse can reduce)
Breadth of current "ecosystem" for "plugins"	Low	Medium	High	Low (but growing)
Ease of coupling simulations	Low	Low	Medium	High

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## Be Aware: “Framework” Describes Many Things

- Currently in scientific computing, this term means different things to different people
- **Basic software composition environment**
  - Examples: CCA, CORBA Component Model, ...
- An environment facilitating development of applications in **a particular scientific domain** (i.e. fusion, computational chemistry, ...)
  - Example: Earth System Modeling Framework, <http://www.esmf.ucar.edu>
  - Example: Computational Facility for Reacting Flow Science, <http://cfrfs.ca.sandia.gov>
- An environment for managing complex **workflows** needed to carry out calculations
  - Example: Kepler: <http://kepler-project.org>
- **Integrated data analysis and visualization environments** (IDAVEs)
- Lines are often fuzzy
  - Example: Cactus, <http://www.cactuscode.org>
- Others types of frameworks *could* be built based on a **basic software composition environment**



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Supplementary material for handouts

## Relationships: Components, Objects, and Libraries

- Components are typically discussed as **objects** or collections of objects
  - **Interfaces** generally designed in **OO** terms, but...
  - Component **internals need not be OO**
  - **OO languages are not required**
- Component environments can **enforce** the use of **published interfaces** (prevent access to internals)
  - Libraries can not
- It is possible to load **several instances** (versions) of a component in a single application
  - Impossible with libraries
- Components *must* include some code to **interface with the framework/component environment**
  - Libraries and objects do not



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## What is the CCA?

- Component-based software engineering has been developed in other areas of computing
  - Especially business and internet
  - Examples: CORBA Component Model, COM, Enterprise JavaBeans
- Many of the needs are similar to those in HPC scientific computing
- But scientific computing imposes special requirements not common elsewhere
- CCA is a component environment specially designed to meet the needs of HPC scientific computing



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## Special Needs of Scientific HPC

- Support for legacy software
  - How much **change** required for component environment?
- Performance is important
  - What **overheads** are imposed by the component environment?
- Both parallel and distributed computing are important
  - What approaches does the component model support?
  - What **constraints** are imposed?
  - What are the **performance costs**?
- Support for **languages, data types, and platforms**
  - Fortran?
  - Complex numbers? Arrays? (as first-class objects)
  - Is it available on my parallel computer?



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## CCA: Concept and Practice

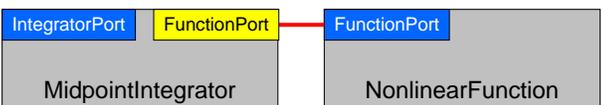
- In the following slides, we explain important **concepts** of component-based software from the CCA perspective
- We also sketch how these concepts are **manifested in code** (full details in the Hands-On)
- The **CCA Specification** is the mapping between concept and code
  - A standard established by the CCA Forum
  - Expressed in the Scientific Interface Definition Language (SIDL) for language neutrality (syntax similar to Java)
  - SIDL can be translated into bindings for specific programming languages using, e.g., the Babel language interoperability tool

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## CCA Concepts: Components



- A component encapsulates some computational functionality
- Components provide/use one or more interfaces
  - A component with no interfaces is formally okay, but isn't very interesting or useful
- In SIDL, a component is a **class** that **implements** (inherits from) ***gov.cca.Component***
  - This means it must implement the **setServices** method to tell framework what ports this component will **provide** and **use**
  - ***gov.cca.Component*** is defined in the CCA specification

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## CCA Concepts: Ports

```

    graph LR
      MI[MidpointIntegrator] --- IP[IntegratorPort]
      MI --- FP1[FunctionPort]
      NF[NonlinearFunction] --- FP2[FunctionPort]
      FP1 --- FP2
  
```

- Components interact through well-defined **interfaces**, or **ports**
  - A port expresses some **computational functionality**
  - In Fortran, a port is a bunch of subroutines or a **module**
  - In OO languages, a port is an **abstract class** or **interface**
- Ports and connections between them are a procedural (caller/callee) relationship, **not dataflow!**
  - e.g., *FunctionPort* could contain a method like `evaluate(in Arg, out Result)` with data flowing both ways

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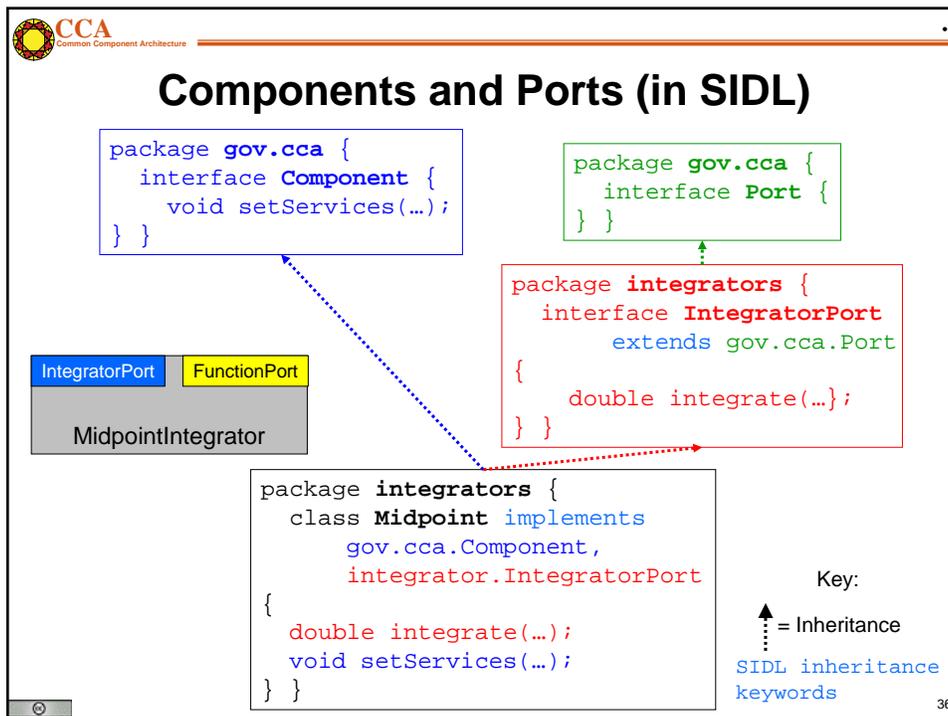
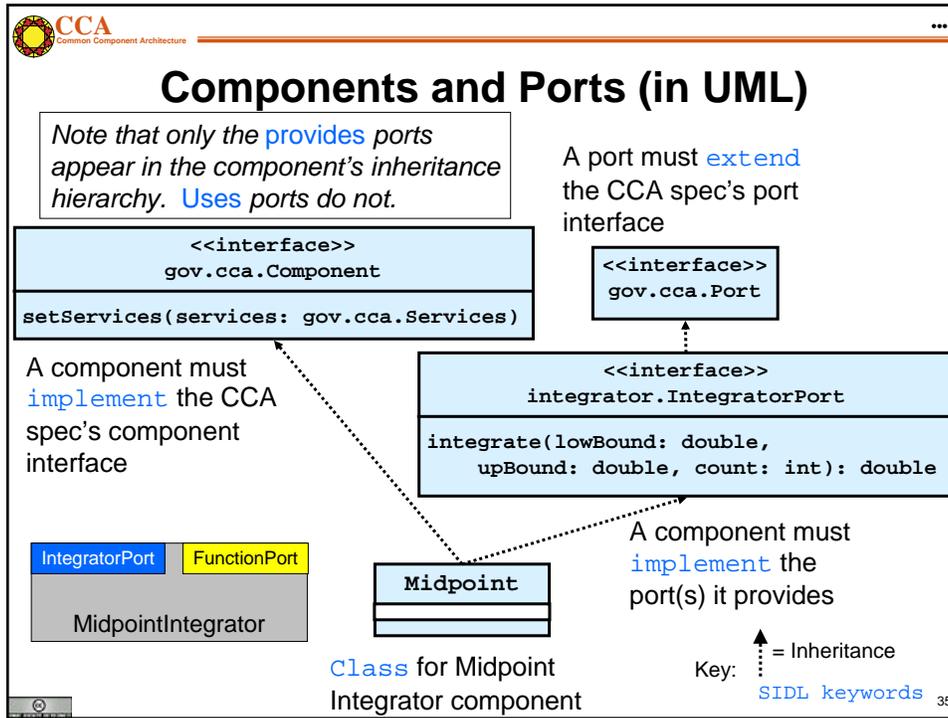
## CCA Concepts: *Provides* and *Uses* Ports

```

    graph LR
      MI[MidpointIntegrator] --- IP[IntegratorPort]
      MI --- FP1[FunctionPort]
      NF[NonlinearFunction] --- FP2[FunctionPort]
      FP1 --- FP2
  
```

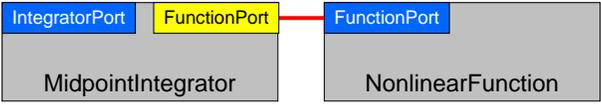
- Components may **provide** ports – **implement** the class or subroutines of the port ( **"Provides" Port** )
  - *Providing* a port implies certain inheritance relationships between the component and the abstract definition of the interface (**more details shortly**)
  - A component can *provide* multiple ports
    - Different "views" of the same functionality, or
    - Related pieces of functionality
- Components may **use** ports – **call** methods or subroutines in the port ( **"Uses" Port** )
  - *Use* of ports is just like calling a method normally except for a little additional work due to the "componentness" (**more details shortly**)
  - No inheritance relationship implied between caller and callee
  - A component can *use* multiple ports

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## Using Ports



- Calling methods on a port you use requires that you first obtain a “handle” for the port
  - Done by invoking `getPort()` on the user’s `gov.cca.Services` object
  - Free up handle by invoking `releasePort()` when done with port
- Best practice is to bracket actual port usage as closely as possible without using `getPort()`, `releasePort()` too frequently
  - Can be expensive operations, especially in distributed computing contexts
  - Performance is in tension with dynamism
    - can’t “re-wire” a ports that is “in use”

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## Where Do Ports Come From?

- Most ports are designed and implemented by **users** of CCA
  - May be specific to an application or used more broadly (i.e. community-wide)
- The **CCA specification** defines a *small* number of ports
  - Most are services CCA frameworks must provide for use by components
  - Some are intended for users to implement in their components, and have a special meaning recognized by the framework
    - *E.g. gov.cca.ports.GoPort* provides a very simple protocol to start execution of component-based applications

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## Interfaces are Key to Reuse and Interoperability of Code

- **Interoperability** -- multiple implementations conforming to the same interface
- **Reuse** – ability to use a component in many applications
- The larger the community that agrees to the interface, the greater the opportunity for interoperability and reuse

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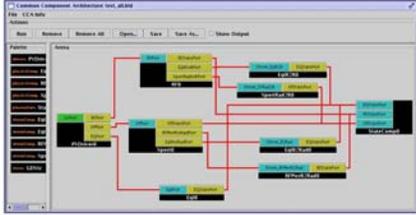
## Interfaces are an Investment

- The larger the community, the greater the time & effort required to obtain agreement
  - Equally true in component and non-component environments
    - MPI 1.0 (well understood at the start) took 8 months, meeting every six weeks
    - MPI 2.0 (not well understood at the start) took 1.5 years, meeting every six weeks
  - Convenient communities are often “project” and “scientific domain”
- Formality of “standards” process varies
- Biggerstaff's Rule of Threes
  - Must look at at least **three systems** to understand what is common (reusable)
  - Reusable software requires **three times the effort** of usable software
  - Payback only after **third release**

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## CCA Concepts: Frameworks

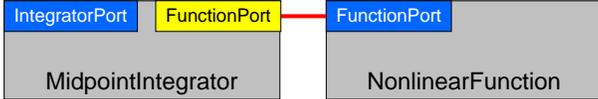


- The framework provides the means to “hold” components and **compose** them into applications
- Frameworks allow **connection of ports** without exposing component implementation details
- Frameworks provide a small set of **standard services** to components
  - Framework services are CCA ports, just like on components
  - Additional (non-standard) services can also be offered
  - Components can register ports as services using the `ServiceProvider` port
- *Currently:* specific frameworks are specialized for specific computing models (parallel, distributed, etc.)
- *Future:* better integration and interoperability of frameworks

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## Components Must Keep Frameworks Informed



- Components must tell the framework about the ports they are providing and using
  - Framework will not allow connections to ports it isn't aware of
- Register them using methods on the component's `gov.cca.Services` object
  - `addProvidesPort()` and `removeProvidesPort()`
  - `registerUsesPort()` and `unregisterUsesPort()`
  - All are defined in the CCA specification
- Ports are usually registered in the component's `setServices()` method
  - Can also be added/removed dynamically during execution

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**CCA Concepts: Language Interoperability**

- Scientific software is increasingly diverse in use of programming languages
- In a component environment, users should not care what language a component is implemented in
- “Point-to-point” solutions to language interoperability are not suitable for a component environment
- The **Babel** language interoperability tool provides a common solution for all supported languages
- **Scientific Interface Definition Language** provides language-neutral way of expressing interfaces

More on Babel later!

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**Coding in a CCA Environment**

More details in the CCA Tools module

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**CCA Supports Parallelism -- by "Staying Out of the Way" of it**

- Single component multiple data (SCMD) model is component analog of widely used SPMD model
- Each process loaded with the same set of components wired the same way
- Different components in same process "talk to each" other via ports and the framework
- **Same component in different processes talk to each other through their favorite communications layer (i.e. MPI, PVM, GA)**

Components: Blue, Green, Red  
Framework: Gray

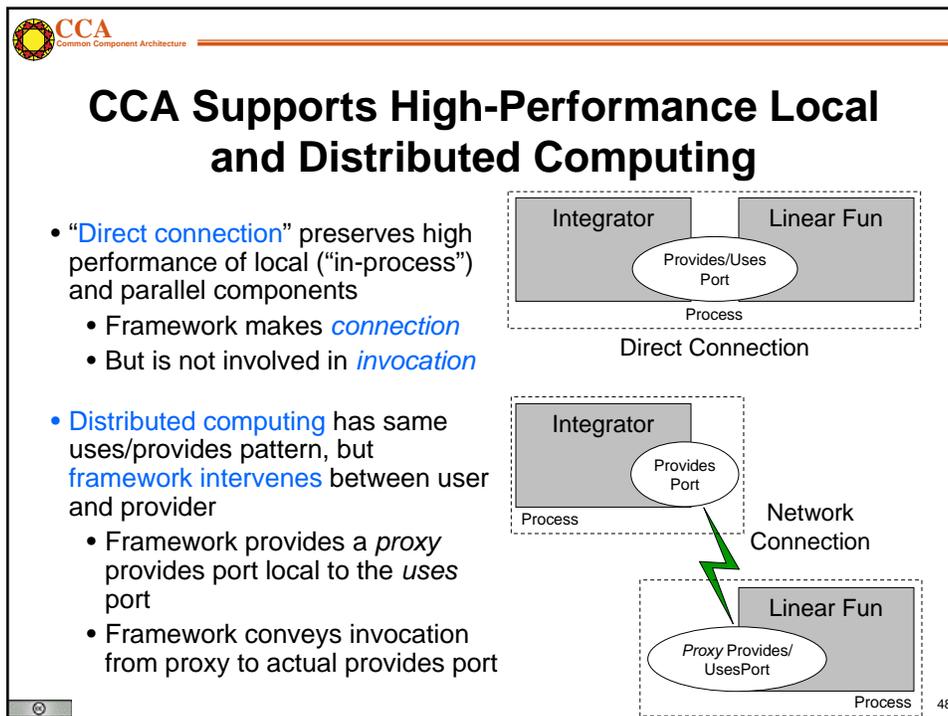
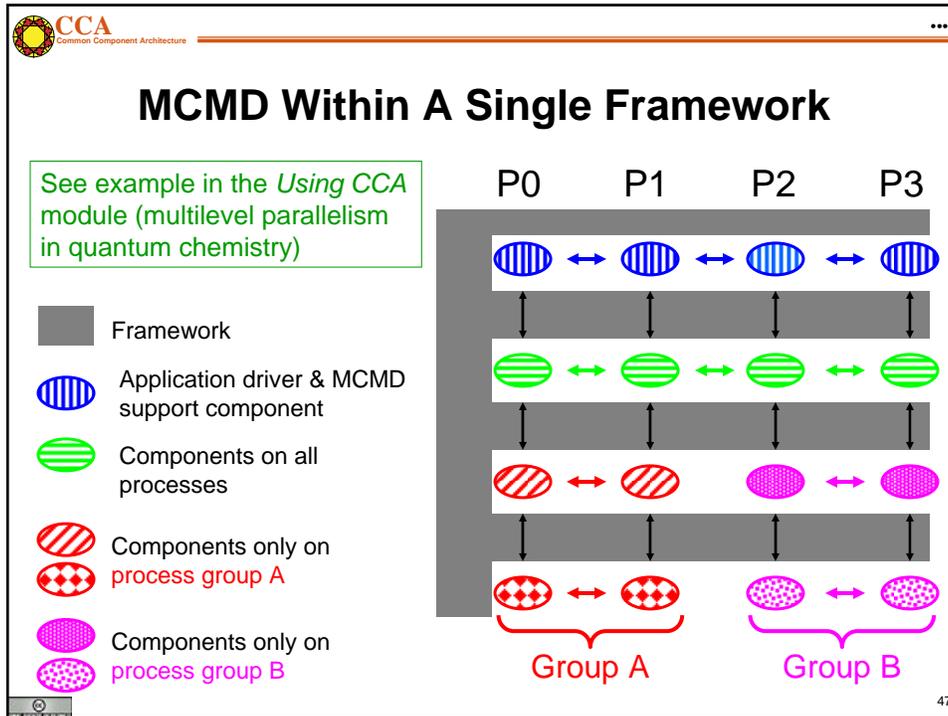
Any parallel programming environments that can be mixed outside of CCA can be mixed inside

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**"Multiple-Component Multiple-Data" Applications in CCA**

- Simulation composed of multiple SCMD sub-tasks
- Usage Scenarios:
  - Model coupling (e.g. Atmosphere/Ocean)
  - General multi-physics applications
  - Software licensing issues
    - i.e. limited number of instances
- Approaches
  - Run single parallel framework
    - Driver component that partitions processes and builds rest of application as appropriate (through BuilderService)
  - Run multiple parallel frameworks
    - Link through specialized communications components
    - Link as components (through AbstractFramework service)

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## “Direct Connection” Details

- Directly connected components are in the **same address space**
  - Data can be passed by reference instead of copying
  - Just like “traditional” programs
  - Framework involved in **connecting** components, but **not invocations** on ports
- Cost of “CCAness” in a direct connect environment is **one level of indirection** on calls **between** components
  - Equivalent to a C++ **virtual function call**: lookup function location, invoke it
  - Overhead is on the **invocation only** (i.e. latency), not the total execution time
  - Cost equivalent of ~2.8 F77 or C function calls
  - ~48 ns vs 17 ns on 500 MHz Pentium III Linux box

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## Performance, the Big Picture

**Direct-Connect, Parallel**

- No CCA overhead on...
  - calls within component
  - parallel communications across components
- Small overheads on invocations on ports
  - Virtual function call (CCAness)
  - Language Interoperability (some data types)

**Distributed**

- No CCA overhead on calls within component
- Overheads on invocations on ports
  - Language interoperability (some data types)
  - Framework
  - (Wide area) network

Parallel Computer

Distributed Environment

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## Maintaining HPC Performance

- The performance of your application is as important to us as it is to you
- The CCA is designed to provide maximum performance
  - But the best we can do is to make your code perform **no worse**
- Facts:
  - Measured overheads per function call are **low**
  - Most overheads **easily amortized** by doing enough work per call
  - Other changes made during componentization may also have performance impacts
  - Awareness** of costs of abstraction and language interoperability facilitates design for high performance

More about performance in notes

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Supplementary material for handouts

## Some Performance Results and References

- Lois Curfman McInnes, et al. **Parallel PDE-Based Simulations Using the Common Component Architecture**. In Are Magnus Bruaset, Petter Bjorstad, and Aslak Tveito, editors, *Numerical Solution of PDEs on Parallel Computers*. Springer-Verlag, 2005. Invited chapter, in press.
- S. Benson, et al. **Using the GA and TAO Toolkits for Solving Large-Scale Optimization Problems on Parallel Computers**. Technical report ANL/MCS-P1084-0903, Argonne National Laboratory, September 2003.
- Boyana Norris, et al. **Parallel Components for PDEs and Optimization: Some Issues and Experiences**. *Parallel Computing*, 28:1811--1831, 2002.
- David E. Bernholdt, et al. **A Component Architecture for High-Performance Computing**. In *Proceedings of the Workshop on Performance Optimization via High-Level Languages and Libraries (POHLL-02)*, 2002.

# of procs	% overhead
1	0.06
4	0.13
16	0.14
32	0.18
64	0.20
128	0.20
170	0.11

**Maximum 0.2% overhead** for CCA vs native C++ code for parallel molecular dynamics up to 170 CPUs

Problem Size	Linear Solver Component (sec)	PETSc SLES (sec)
100x100	~5	~5
150x150	~25	~25
200x200	~55	~55
250x250	~95	~95

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Supplementary material for handouts


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## Overhead from Component Invocation

- Invoke a component with different arguments
  - Array
  - Complex
  - Double Complex
- Compare with f77 method invocation
- Environment
  - 500 MHz Pentium III
  - Linux 2.4.18
  - GCC 2.95.4-15
- Components took 3X longer
- Ensure granularity is appropriate!
- Paper by Bernholdt, Elwasif, Kohl and Epperly

Function arg type	f77	Component
Array	80 ns	224ns
Complex	75ns	209ns
Double complex	86ns	241ns

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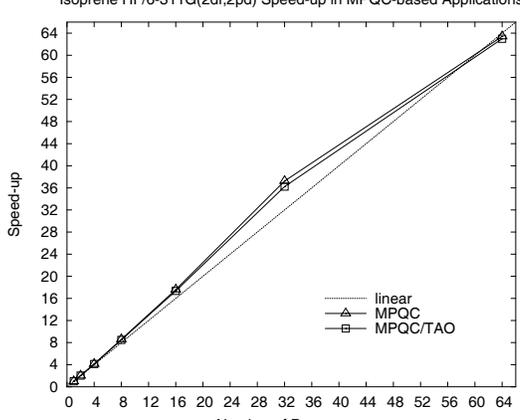
Supplementary material for handouts


CCA  
Common Component Architecture

## Scalability : Component versus Non-component. I

- Quantum chemistry simulation
- Sandia's MPQC code
  - Both componentized and non-componentized versions
- Componentized version used TAO's optimization algorithms
- Problem :Structure of isoprene HF/6-311G(2df,2pd)

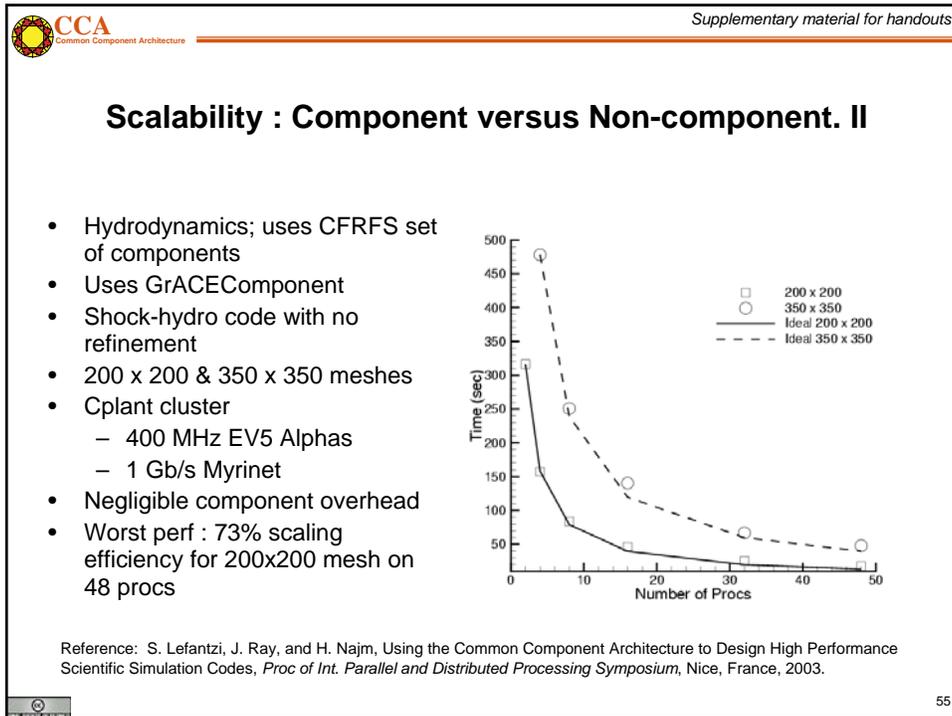
Isoprene HF/6-311G(2df,2pd) Speed-up in MPQC-based Applications



Number of Processors	MPQC Speed-up	MPQC/TAO Speed-up
1	1.0	1.0
2	2.0	2.0
4	4.0	4.0
8	8.0	8.0
16	16.0	16.0
32	32.0	31.0
64	64.0	62.0

Parallel Scaling of MPQC w/ native and TAO optimizers

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**Advanced CCA Concepts**

Brief introductions only, but more info is available – just ask us!

- Leveraging the component environment to provide additional capabilities to software developers
- The Proxy Component pattern (Hands-On, papers)
- Component lifecycle (tutorial notes, Hands-On)
- Components can be dynamic (papers)
- Improving the quality of component software (papers)
- Support for advanced parallel/high-performance computing (papers)

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Common Component Architecture

## The Proxy Component Pattern

- A “proxy” component can be inserted between the user and provider of a port without either being aware of it (non-invasive)
- Proxy can **observe** or **act** on all invocations of the interface
- Similar to **aspect-oriented programming**
- For many purposes, proxies can be **generated automatically** from SIDL definition of the port

Sample uses for proxy components:

- **Performance:** instrumentation of method calls
- **Debugging:** execution tracing, watching data values
- **Testing:** Capture/replay

Performance Monitoring with TAU

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## Component Lifecycle

Additional material in notes

- **Composition Phase (assembling application)**
  - Component is **instantiated** in framework
  - Component interfaces are **connected** appropriately
- **Execution Phase (running application)**
  - Code in components uses functions provided by another component
- **Decomposition Phase (termination of application)**
  - **Connections** between component interfaces may be **broken**
  - Component may be **destroyed**

In an application, individual components may be in different phases at different times

Steps may be under human or software control

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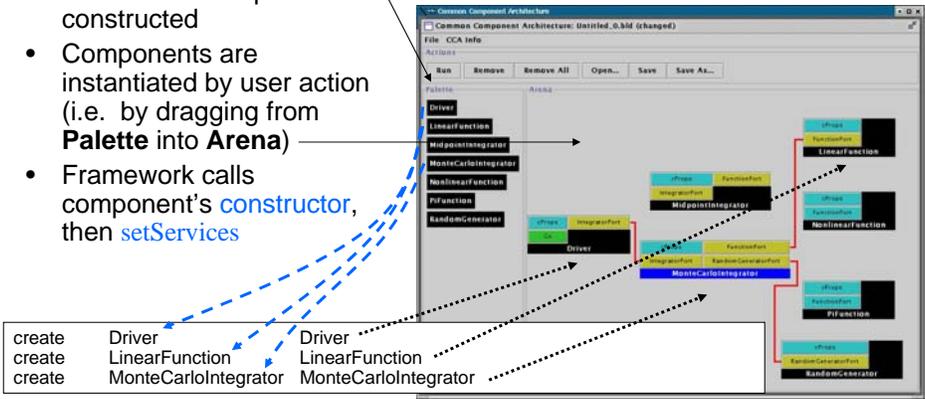
Supplementary material for handouts


Common Component Architecture

## User Viewpoint: Loading and Instantiating Components

- Components are code + metadata
- Using metadata, a **Palette** of available components is constructed
- Components are instantiated by user action (i.e. by dragging from **Palette** into **Arena**)
- Framework calls component's **constructor**, then **setServices**

- Details are **framework-specific!**
- **Ccaffeine** currently provides both command line and GUI approaches



create	Driver	Driver	Driver
create	LinearFunction	LinearFunction	LinearFunction
create	MonteCarloIntegrator	MonteCarloIntegrator	MonteCarloIntegrator

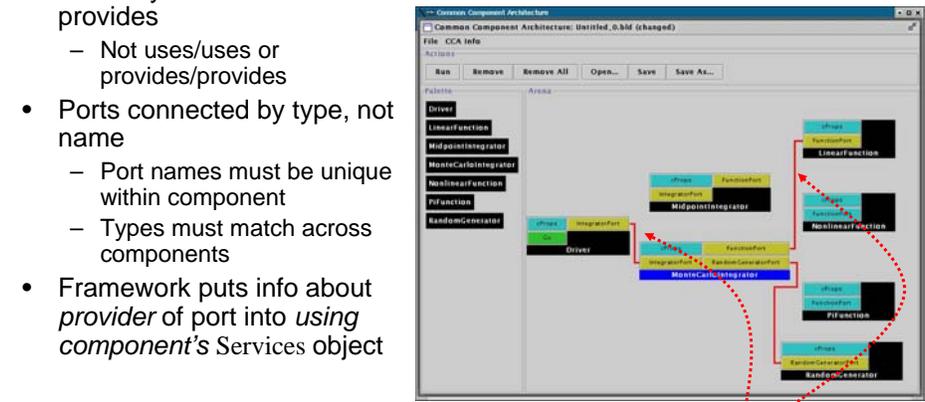
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Supplementary material for handouts


Common Component Architecture

## User Connects Ports

- Can only connect uses & provides
  - Not uses/uses or provides/provides
- Ports connected by type, not name
  - Port names must be unique within component
  - Types must match across components
- Framework puts info about *provider* of port into *using component's* Services object



connect	Driver	IntegratorPort	MonteCarloIntegrator	IntegratorPort
connect	MonteCarloIntegrator	FunctionPort	LinearFunction	FunctionPort
...				

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Supplementary material for handouts



## Component's View of Instantiation

- Framework calls component's **constructor**
- Component initializes internal data, etc.
  - Knows *nothing* outside itself
- Framework calls component's **setServices**
  - Passes setServices an object representing everything "outside"
  - setServices declares ports component *uses* and *provides*
- Component *still* knows nothing outside itself
  - But Services object provides the means of communication w/ framework
- Framework now knows how to "decorate" component and how it might connect with others

Framework interaction code  
**constructor** **setServices** **destructor**

**CCA.Services**  
 provides IntegratorPort  
 uses FunctionPort,  
 RandomGeneratorPort

Integrator code  
  
 MonteCarloIntegrator

➔

IntegratorPort

FunctionPort

RandomGeneratorPort

MonteCarloIntegrator

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Supplementary material for handouts



## Component's View of Connection

Framework interaction code

**CCA.Services**  
 ... uses FunctionPort  
 (connected to NonlinearFunction  
 FunctionPort), ...

Integrator code  
  
 MonteCarloIntegrator

➔

**CCA.Services**  
 provides FunctionPort

Function code  
  
 NonlinearFunction

- Framework puts info about provider into **user component's** Services object
  - *MonteCarloIntegrator's* Services object is aware of connection
  - *NonlinearFunction* is not!
- **MCI's** integrator code cannot yet call functions on FunctionPort

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Supplementary material for handouts



## Component's View of Using a Port

- User calls `getPort` to obtain (handle for) port from `Services`
  - Finally user code can “see” provider
- **Cast** port to expected type
  - OO programming concept
  - Insures type safety
  - Helps enforce declared interface
- **Call** methods on port
  - e.g.  
`sum = sum + function->evaluate(x)`
- Call `releasePort`

Framework interaction code

**CCA.Services**  
 ..., uses `FunctionPort`  
 (connected to `NonlinearFunction`  
`FunctionPort`), ...

Integrator code

MonteCarloIntegrator

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## Dynamic Component Assemblies

- `gov.cca.BuilderService` allows **programmatic composition** of components
  - Components can be instantiated/destroyed, and connected/disconnected under program control

Sample uses of `BuilderService`:

- Python “**driver**” **script** which can assemble and control an application
  - i.e. MCMD climate model
- **Adaptation** to changing conditions
  - Swap components in and out to give better performance, numerical accuracy, convergence rates, etc.
  - **TASCS** project “**Computational Quality of Service**” activity

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## Enhancing Software Quality

- Current component architectures define **syntax** of interfaces
- Extend interface to include **semantics** (behavior) for more complete definition
  - “Design by contract”
  - Help ensure component **performs correctly**
  - Help ensure component **is used correctly**
- Selective enforcement to control impact
- **TASCS project** “Software Quality and Verification” activity

```

package vector version 1.0 {
  class Utils { ...
    static double norm(in array<double> u,
                      in double tol,
                      in int badLevel)
      require /* Preconditions */
        not_null : u != null;
        u_is_1d : dimen(u) == 1;
        non_negative_tolerance : tol >= 0.0;
      ensure /* Postconditions */
        no_side_effects : is pure;
        non_negative_result : result >= 0.0;
        nearEqual(result, 0.0, tol)
        iff isZero(u, tol);
    ... }
  }
}
            
```

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## Supporting Emerging HPC Hardware Environments

- CCA does not dictate a specific approach to parallelism
- **Different approaches and tools can be provided via components and custom frameworks**

**Examples...**

- Uintah Computational Framework (Utah) provides a multi-threaded parallel execution environment based on task graphs
  - Specialized to certain structured adaptive mesh refinement problems
- **TASCS developing services to manage groups of parallel components/tasks (MCMD)**

**Also...**

- **TASCS developing support for heterogeneous processor environments**
  - FPGAs, GP-GPUs, accelerators, and other co-processors
  - Accelerator code encapsulated as components, interacting w/ components on primary processors
- **Integration of fault tolerance capabilities with CCA under development (CIFTS-TASCS collaboration)**

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## Is CCA for You?

- Much of what CCA does can be done without such tools *if* you have sufficient discipline
  - The larger a group, the harder it becomes to impose the necessary discipline
- Projects may use different aspects of the CCA
  - CCA is *not* monolithic – use what *you* need
  - Few projects use all features of the CCA... initially
- Evaluate what *your* project needs against CCA's capabilities
  - Other groups' criteria probably differ from yours
  - CCA continues to evolve, so earlier evaluations may be out of date
- Evaluate CCA against other ways of obtaining the desired capabilities
- Suggested starting point:
  - CCA tutorial "hands-on" exercises



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## Take an Evolutionary Approach

- The CCA is designed to allow selective use and incremental adoption
- "SIDLize" interfaces incrementally
  - Start with essential interfaces
  - Remember, only externally exposed interfaces need to be Babelized
- Componentize at successively finer granularities
  - Start with whole application as one component
    - Basic feel for components without "ripping apart" your app.
  - Subdivide into finer-grain components as appropriate
    - Code reuse opportunities
    - Plans for code evolution



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## View it as an Investment

- CCA is a long-term investment in your software
  - Like most software engineering approaches
- There is a cost to adopt
- The payback is longer term
- Remember Biggerstaff's Rule of Threes
  - Look at three systems, requires three times the effort, payback after third release



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## CCA is Still Under Development

- We've got...
  - A stable component model
  - Working tools
  - Active users
- But...
  - We know its not perfect
  - We're not "done" by any stretch
- Talk to us...
  - If you're evaluating CCA and need help or have questions
  - If you don't think CCA meets your needs
  - If you've got suggestions for things we might do better



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## What Can CCA Do Today?

- Ccaffeine framework for HPC/parallel
  - XCAT and other options for distributed computing
- Language interoperability
  - Fortran 77/90/95, C, C++, Java, Python
  - Support for Fortran/C user-defined data structures under development
- CCA Tools working on a variety of platforms
  - Linux most widely used
  - Mac OS X second
  - Some IBM AIX users
  - Works on Cray XT series, port to IBM BlueGene in progress
  - Porting is driven by user needs, so let us know!



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## CCA Tools – Language Interoperability and Frameworks

**CCA Forum Tutorial Working Group**  
[http://www.cca-forum.org/tutorials/  
tutorial-wg@cca-forum.org](http://www.cca-forum.org/tutorials/tutorial-wg@cca-forum.org)



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## Goal of This Module

The diagram illustrates the goal of the module. It shows two green boxes representing 'Component A' and 'Component B'. Between them are orange arrows pointing in both directions, labeled 'CCA/Frameworks'. Below the components are two blue boxes labeled 'Babel' and 'Chasm'. Arrows point from Babel and Chasm to the components. The entire setup is enclosed in a purple oval labeled 'CCA IDE'.

- Describe **tools** for multi-lingual, scientific component 'plug-and-play'

IDE = Interactive Development Environment 73

**CCA**  
Common Component Architecture

## CCA adds value to component development

The flowchart details the development process. It starts with 'Port Definitions (SIDL)' and 'Component Definition (SIDL)' (grey boxes) which feed into the 'Babel compiler (SIDL → language)' (blue box). The Babel compiler produces 'Generated language code' (dashed box). This code, along with 'Component source code' (grey box), goes into the 'Language compiler & linker' (blue box). This produces 'Compiled Components (object libraries)' (hatched boxes). These are then used in an 'Application (component assembly)' (hatched boxes) within the 'CCA Framework' (orange text). The 'Babel runtime library & Chasm F90 array library' (blue and green text) also feeds into the Language compiler & linker. The 'CCA IDE' (purple text) is shown at the bottom, connected to the Port Definitions, Component Definition, and Component source code. A key at the bottom right identifies the colors: grey for User code, blue for CCA Tools, dashed for Generated code, and hatched for Object libraries. An illustration of a person at a computer is at the bottom center.

**Key:**

- User code (grey)
- CCA Tools (blue)
- Generated code (dashed)
- Object libraries (hatched)

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**CCA**  
Common Component Architecture

## Tools Module Overview

The diagram illustrates the Tools Module Overview. It shows two components, Component A and Component B, connected by CCA/Frameworks. Below the components are two tools, Babel and Chasm, and the CCA IDE. Arrows indicate the flow of data and control between these elements.

- Language interoperability tools
- Frameworks
- CCA Interactive Development Environment

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*Babel*

## Babel Facilitates Scientific Programming Language Interoperability

- Programming language-neutral interface descriptions
- Native support for basic scientific data types
  - Complex numbers
  - Multi-dimensional, multi-strided arrays
- Automatic object-oriented wrapper generation

The diagram compares Babel's approach to language interoperability. On the left, Babel is shown as a central hub (green circle) with bidirectional arrows connecting it to various languages: f77, f90, Python, Java, C, and C++. On the right, labeled 'vs.', a complex web of direct connections is shown between the same languages, representing a less efficient and more complex approach.

Supported on Linux, AIX, works on OSX, catamount;  
C (ANSI C), C++ (GCC), F77 (g77, Sun f77), F90 (Intel, Lahey, GNU, Absoft, PGI), Java (1.4)

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**Babel**

## Babel Generates Object-Oriented Language Interoperability Middleware

```

    graph LR
      User((user creates)) --> Sidl[comp.sidl]
      Sidl --> Compiler[Babel Compiler]
      Compiler --> Stubs
      Compiler --> IORs
      Compiler --> Skeletons
      Compiler --> Implementations
      Stubs --> Lib[libcomp.so]
      IORs --> Lib
      Skeletons --> Lib
      Implementations --> Lib
      Lib --- Runtime[Babel Runtime]
  
```

1. Write your SIDL file to define public methods
2. Generate server side in your native language using Babel
3. Edit Implementations as appropriate
4. Compile and link into library/DLL

IOR = Intermediate Object Representation    SIDL = Scientific Interface Definition Language    77

**Babel**

## Clients in any supported language can access components in any other language

```

    graph TD
      C[C Stubs] --> IORs
      Cplusplus[C++ Stubs] --> IORs
      F77[F77 Stubs] --> IORs
      F90[F90 Stubs] --> IORs
      Java[Java Stubs] --> IORs
      Python[Python Stubs] --> IORs
      IORs <--> Skeletons
      Skeletons <--> Implementations
      Implementations <--> Component[Component  
(any supported language)]
  
```

Babel presentation coming up! 78

IOR = Intermediate Object Representation

CCA Common Component Architecture *Babel*

## Recent and Upcoming Features

- Remote Method Invocation (Babel RMI)  
Kumfert, Leek, & Epperly IPDPS'07  
*ALPHA – Babel 1.0.\* (aka “stable branch”)*  
*BETA – Babel 1.1.\**  
*Final – Future Stable Branch ( Babel 1.2? )*
- Design-by-Contract  
Dahlgren CBSE'07 (to appear)  
*ALPHA – Internal Babel branch*  
*BETA – Babel 1.1.2 (expected)*
- Feature requests are accepted and tracked in the open using Roundup  
<http://www.cca-forum.org/bugs/babel>

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CCA Common Component Architecture

## Tools Module Overview

The diagram illustrates the Tools Module Overview. It shows two components, Component A and Component B, connected by CCA/Frameworks. Below the components, there are two tools, Babel and Chasm, which are connected to the CCA/Frameworks. The CCA IDE is also shown, connected to the CCA/Frameworks. The diagram is enclosed in a grey oval.

- Language interoperability tools
- ➔ • Frameworks
- CCA Interactive Development Environment

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Common Component Architecture

## Frameworks are Specialized to Different Computing Environments

- “**Direct connection**” preserves high performance of local (“in-process”) and parallel components
  - Framework makes *connection*
  - Framework *not* involved in *invocation*
- **Distributed computing** has same uses/provides pattern, but the framework *intervenes* between user and provider
  - Framework provides a *proxy port* local to the user’s *uses* port
  - Framework conveys invocation from *proxy to actual provides* port

Direct Connection

Network Connection

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**CCA**  
Common Component Architecture

## Graphical User Interfaces (GUIs) Deliver Plug-and-Play Experience

- Plug & play for:
  - Application software assembly
  - Visualization pipelines
  - Workflow management
- Assembling “wiring” diagrams is almost universal.
  - Software assembly: Ccaffeine, XCAT, SciRUN
  - Workflow: XCAT, SciRUN
  - Visualization: SciRUN

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*Caffeine Framework*

## **Caffeine** is a *Direct-Connect*, Parallel-Friendly Framework

- Supports SIDL/Babel components
  - Conforms to latest CCA specification (0.8)
  - Also supports legacy CCA specification (0.5)
    - Any C++ allowed with C and Fortran by C++ wrappers
- Provides command-line and GUI for composition
  - Scripting supports batch mode for SPMD
  - MPMD/SPMD custom drivers in any Babel language

Supported on Linux, AIX, OSX and is portable to modern UNIXes.



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*Caffeine Framework*

## **Caffeine** Involves a Minimum of Three Steps

- As easy as 1-2-3:
  - Write your component.
  - Describe it with an XML file.
  - Add a line to your Caffeine input file to load the component at runtime.
- Proceed to plug & play...

There are many details and automated tools that help manage components.



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CCA Common Component Architecture *Caffeine Framework (ccafe-gui)*

## Optional Caffeine GUI

- Process
  - User input is broadcast SPMD-wise from Java.
  - Changes occur in GUI *after* the C++ framework replies.
  - If your components are computing, GUI changes are blocked.
- Components interact through *port connections*
  - *provide* ports *implement* class or subroutines "Provides" Port
  - *use* ports *call* methods or subroutines in the port. "Uses" Port
  - Links denote caller/callee relationship *not* data flow

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CCA Common Component Architecture *Caffeine Framework (ccafe-gui)*

## User Connects Ports

- Can only connect *uses* & *provides*
  - *Not* uses/uses
  - *Not* provides/provides
- Ports connected by type not name
  - Port names *must be unique* within a component
  - Types *must match* across components
- Framework puts info about *provider* of port into *using component's* Services object

connect	Driver	IntegratorPort	MonteCarloIntegrator	IntegratorPort
connect	MonteCarloIntegrator	FunctionPort	LinearFunction	FunctionPort
...				

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CCA Common Component Architecture *Caffeine Framework (ccafe-gui)*

## Building an Application (1 of 2)

- Components are code + XML metadata
- Using metadata, a **Palette** of available components is constructed.
- Components are instantiated by user action (i.e. by dragging from **Palette** into **Arena**).
- Framework calls component's **constructor**, then **setServices**

create	Driver	Driver
create	LinearFunction	LinearFunction
create	MonteCarloIntegrator	MonteCarloIntegrator

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CCA Common Component Architecture *Caffeine Framework (ccafe-gui)*

## Building an Application (2 of 2)

1. Click **Configure** port to start parameter input dialogue.
2. For each connection: click a **uses** port then click a **provides** port to establish a connection.
3. Click **Go** port to start the application.

Right-clicking a connection line breaks the connection -- enabling component substitution.

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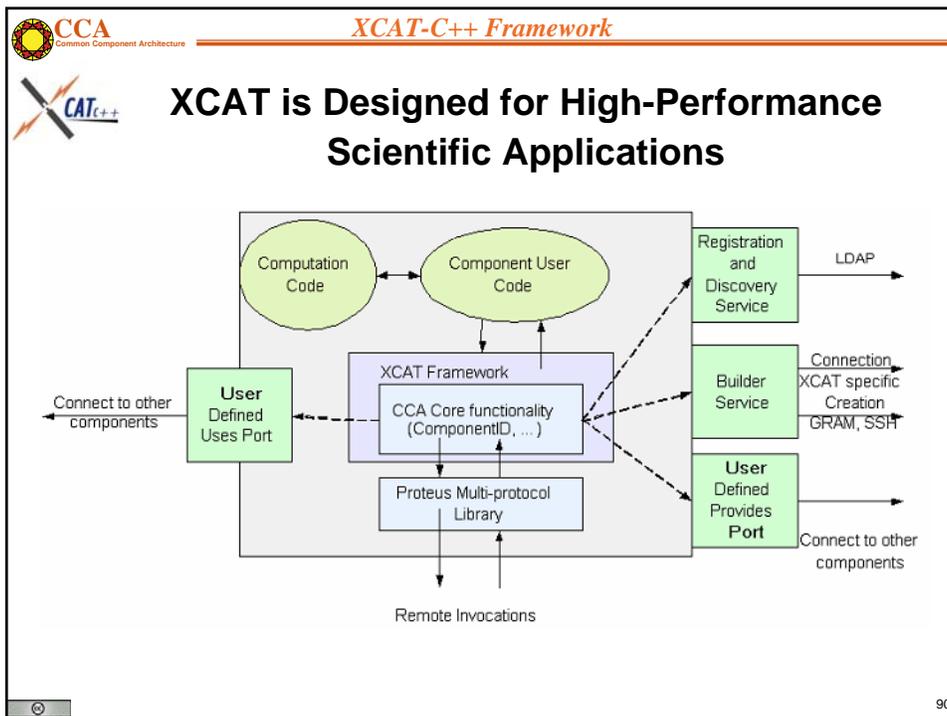
CCA Common Component Architecture **XCAT-C++ Framework**

**XCAT is a Web-services based Distributed Component Framework**

- Remote references
  - Port types described in C++ header files or in WSDL documents
- User Interface
  - C++ and Python interface to CCA *BuilderService*
  - Uses SWIG for Python-C++ translations
- Component creation
  - Remote creation via SSH
- Component communication
  - Proteus multi-protocol library
  - Communication libraries can be loaded at run-time

Tested on Linux.

WSDL = Web Service Definition Language 89



CCA  
Common Component Architecture

*XCAT-C++ Framework*

---

## Basic How-To

1. Define port interfaces as C++ header files or WSDL docs
2. Indicate ports used by each component in a config file
3. Run scripts to generate code for stub-skeletons (for ports)
  - Can also generate component-templates for new components
  - Use component-templates to convert a scientific library into a CCA component
4. Build components using XCAT-C++ make scripts
5. Deploy component executables on the target remote hosts
  - Also set up SSH access to remote hosts
6. Write python scripts (edit examples) to use CCA API to connect components and invoke a Go port
  - Alternatively, can use a C++ front-end
7. Execute the python script (or C++ front-end)

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Common Component Architecture

*XCAT-C++ Framework*

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## Recent and Upcoming Features

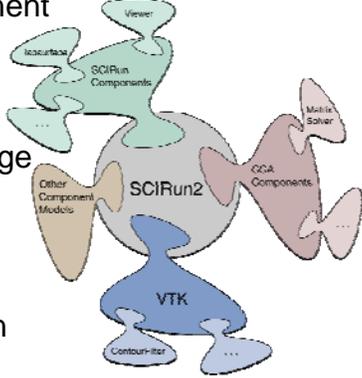
- Incorporate Babel's Remote Method Invocation
  - Allows access to Babel objects through remote Babel stubs
  - Provides direct support for SIDL in distributed applications
- Incorporate Web-services based protocols in BabelRMI
- Performance analysis of Babel-RMI based distributed communication
- Design Distributed Framework Interoperability Specification

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CCA Common Component Architecture **SCIRun2 Framework**

## SCIRun2 is a Cross-Component Model, Distributed Component Framework

- Semi-automatically bridges component *models*
  - Templated components connected at run-time generate bridges
- Parallel Interface Definition Language (PIDL) – a SIDL variant
- User interface – GUI and textual
  - Dynamic composition
- Component and framework creation
  - Remote via SSH
- Component communication
  - C++ RMI with co-location optimization
  - MPI/ Parallel Remote Method Invocation (PRMI)

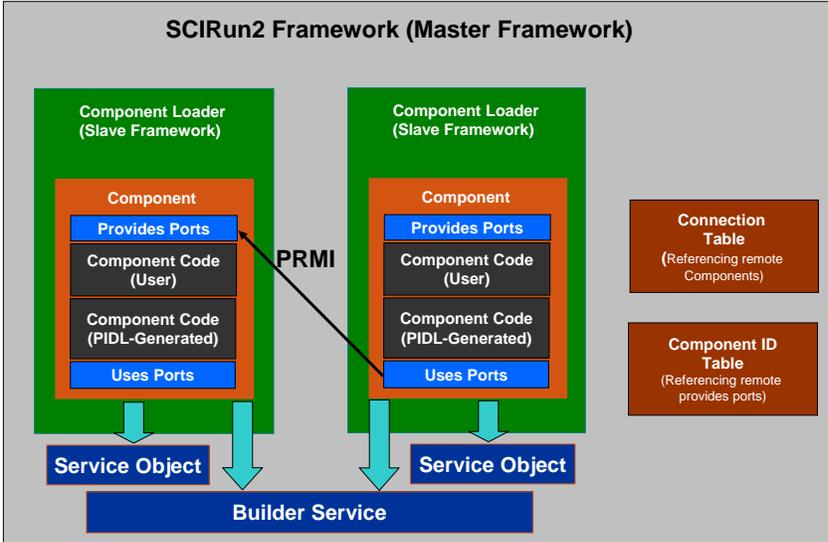


Supported on Linux.

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CCA Common Component Architecture **SCIRun2 Framework**

## Master Framework Coordinates Slave Frameworks in Each Remote Address Space



SCIRun2 Framework (Master Framework)

Component Loader (Slave Framework)

Component

Provides Ports

Component Code (User)

Component Code (PIDL-Generated)

Uses Ports

Service Object

Builder Service

PRMI

Component Loader (Slave Framework)

Component

Provides Ports

Component Code (User)

Component Code (PIDL-Generated)

Uses Ports

Service Object

Builder Service

Connection Table (Referencing remote Components)

Component ID Table (Referencing remote provides ports)

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**SCIRun2 Framework**


---

## Basic How-To

1. Add component source files and makefile to SCIRun2 sources
  - May need to define ports in SIDL
2. Add component information to the component model xml file
3. Build component using SCIRun2 make scripts
  - Alternatively, build component using Babel
4. Start the framework and graphical (default) or text builder
5. Graphically connect component to other CCA-based or non CCA-based components
  - May need to create bridge components to go between models
6. Press the “Go” button on the driver component


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**Experimental Frameworks**

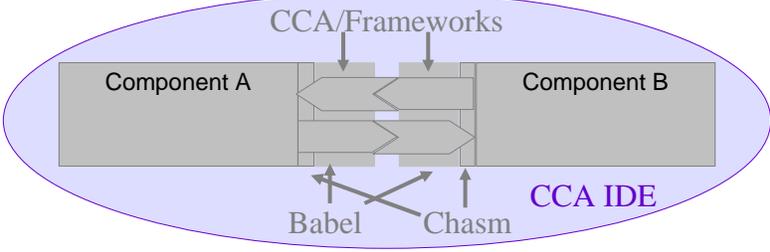

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Framework	Purpose	Summary
<b>Distributed CCA Framework (DCA)</b>	MxN research	<ul style="list-style-type: none"> <li>• <b>Goal:</b> explore MxN Parallel-Remote Method Invocation (PRMI) using MPI</li> <li>• Parallel data transfer and redistribution integrated into port invocation mechanism</li> </ul>
<b>LegionCCA</b>	Grid-based research	<ul style="list-style-type: none"> <li>• <b>Goal:</b> allow component-based CCA applications to run in Grid-scale environments using Legion</li> <li>• Supports creation, scheduling, persistence, migration, and fault notification; relies on Legion's built-in RPC mechanism (~Unix sockets)</li> </ul>
<b>XCAT-Java</b>	Globus-based Grid research	<ul style="list-style-type: none"> <li>• <b>Goal:</b> explore web interface for launching distributed applications</li> <li>• This (alpha) version compatible with latest CCA specification and provides built-in seamless compatibility with OGSi.</li> </ul>


OGSI = Open Grid Services Infrastructure
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 **CCA**  
Common Component Architecture

## Tools Module Overview



The diagram illustrates the Tools Module Overview. It shows two components, Component A and Component B, connected by CCA/Frameworks. Below the components are two tools, Babel and Chasm, which are connected to the CCA/Frameworks. To the right of the components is the CCA IDE. A purple arrow points to the CCA Development Environment bullet point.

- Language interoperability tools
- Frameworks
- CCA Development Environment

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 **CCA**  
Common Component Architecture

*CCA IDE* *Supplementary material for notes*

## Component Development Environment

- Bocca
  - Provides a light-weight, portable environment

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CCA  
Common Component Architecture

CCA IDE

Supplementary material for notes

## Eclipse Environment Provided via Eclipse Plug-ins

- Provides a high-level graphical environment
  - Creating new SIDL-based components
  - Componentizing legacy codes
    - C, C++, Java and Fortran
- Automatic code generation

Supported on Linux, Windows, MacOS.

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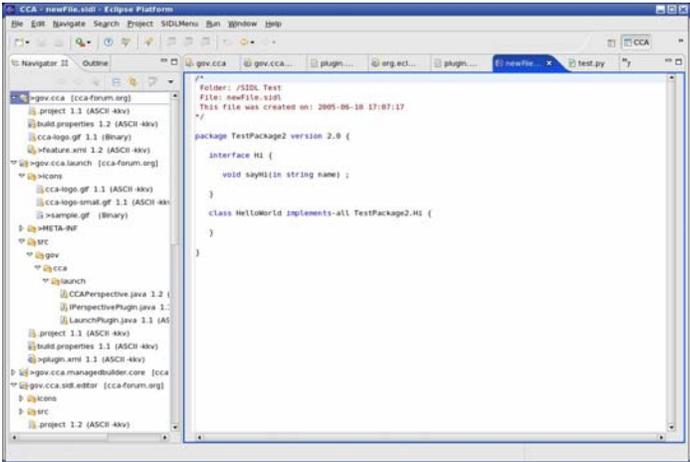
CCA IDE

Supplementary material for notes

## Component Development Environment Starts at the Eclipse Platform Level

- Plug-ins for:
- SIDL Editor
- Wizards
- Preliminary automated build support



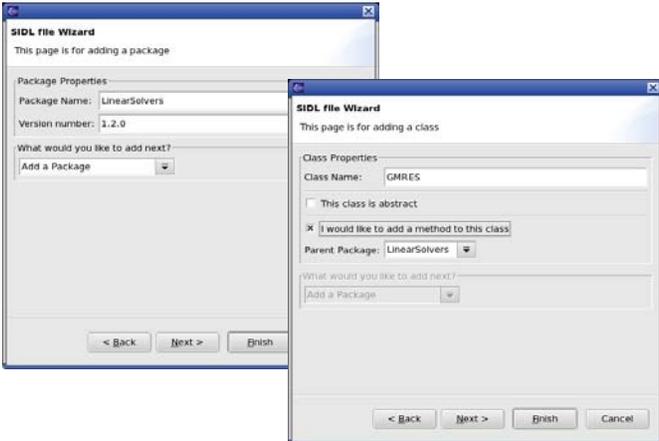
Imperative that you start by creating a new project!

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CCA Common Component Architecture **CCA IDE** Supplementary material for notes

## Wizards are Available for Adding Packages and Classes or Generating SIDL from Legacy Codes

- Intuitive interfaces to port and component definition
- Helper wizards for setting port, component and (in the future) application properties



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CCA Common Component Architecture **CCA IDE**

## Bocca Development Environment

- Provides a text-based, portable environment
  - Create or import SIDL and CCA based codes.
  - Automatic build system maintenance.
  - Easy to adopt or abandon while preserving code, build.
- No GUI required.
- Still in the early beta stage of development
  - Being tested by managing the tutorial source and a regression test suite.
  - Basis for common CCA toolkit installation.
  - Manages components in all Babel-supported languages (C, C++, Fortran 77, Fortran 90, Java, Python).

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## Bocca is an Application Generator

- Purely command-line driven
  - Generates the glue code that enables components and language interoperability.
  - Enables rapid generation of an entire application skeleton and build system in minutes.
  - Good for full project life-cycle
    - But is also meant to support very rapid prototyping.
- Complementary to a normal IDE
  - Does not provide an integrated editor for creating code.
  - Invoke your own editor with bocca assistance (no need to remember paths to files, build system optionally automatically updated).



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## Bocca Creates Skeletons for CCA

- Including **ports** and **interfaces**
  - Give the SIDL name and an empty port or interface is created.
- Including **components** and **classes**
  - Give the name and an empty component or class is created.
  - Some extra options: the component uses/provides ports, implemented interfaces or extended classes
- Including **build system**
  - For all ports/components in the project
  - Implemented in any CCA supported language
- Create applications with Ccaffeine GUI (today)
- Including **application** composition (coming soon)



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## Bocca Example

```

# create an empty but buildable CCA skeleton
bocca create project myproj
cd myproj
./configure

bocca create port myJob
bocca create component myWorker --provides=myJob:job1

# fill in public functionality
bocca edit port myJob

# fill in implementation
bocca edit component -i myWorker

# compile application
make
    
```

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## CCA Tools Contacts (1 of 2)

Tool	Purpose	More information
Babel	Scientific language interoperability tool kit	URL: <a href="http://www.llnl.gov/CASC/components">www.llnl.gov/CASC/components</a> Email: <a href="mailto:components@llnl.gov">components@llnl.gov</a> or <a href="mailto:babel-users@lists.llnl.gov">babel-users@lists.llnl.gov</a>
Caffeine	Direct-connect, parallel-friendly framework	URL: <a href="http://www.cca-forum.org/software/">www.cca-forum.org/software/</a> Email: Ben Allan, <a href="mailto:ccafe-help@cca-forum.org">ccafe-help@cca-forum.org</a> Wiki: <a href="https://www.cca-forum.org/wiki">https://www.cca-forum.org/wiki</a>
Bocca	CCA development environment	Email: <a href="mailto:bocca-dev@cca-forum.org">bocca-dev@cca-forum.org</a> bocca FAQ: <a href="https://www.cca-forum.org/wiki">https://www.cca-forum.org/wiki</a>

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## CCA Tools Contacts (2 of 2)

Tool	Purpose	More information
SCIRun2	Cross-component model framework	URL: <a href="http://www.sci.utah.edu/">www.sci.utah.edu/</a> Email: Steve Parker, <a href="mailto:sparker@cs.utah.edu">sparker@cs.utah.edu</a>
XCAT-C++	Globus-based GRID framework	URL: <a href="http://grid.cs.binghamton.edu/projects/xcat/">grid.cs.binghamton.edu/projects/xcat/</a> Email: Madhu Govindaraju, <a href="mailto:mgovinda@cs.binghamton.edu">mgovinda@cs.binghamton.edu</a>

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## Module Summary

- Described **tools** for multi-lingual, scientific component 'plug-and-play'
  - Language interoperability through Babel and Chasm
  - CCA Frameworks provide mechanisms for composition
  - CCA Interactive Development Environments

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# BABEL

**CCA Forum Tutorial Working Group**  
[http://www.cca-forum.org/tutorials/  
tutorial-wg@cca-forum.org](http://www.cca-forum.org/tutorials/tutorial-wg@cca-forum.org)

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## Goal of This Module

**Expose Attendees to How Existing Code is**

- **Wrapped into Babel objects, and then**
- **Promoted to CCA components**

**In the process, will also cover**

- **Babel Basics**
- **Scientific Interface Definition Language (SIDL)**
- **Code sample (“Hello World!”)**

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# BABEL is Middleware for HPC

**R&D 100**  
2006

“The world’s most rapid communication among many programming languages in a single application.”

**Performance (in process)**

	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

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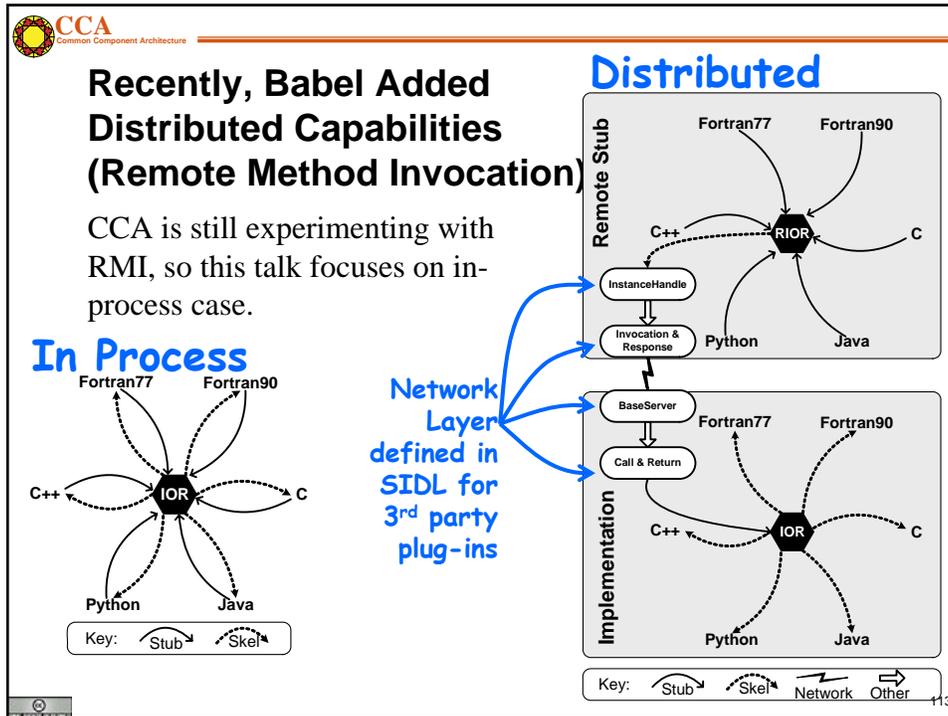
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## Babel Supports a Unified Object-Oriented Type System Spanning Many Languages

**Uses:**

- Stop hand-writing language wrappers!
- Basis for component frameworks
- Add polymorphism in single languages
- Generate language-neutral API specifications
- Turn Python to an interactive debugger

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## Working Code: “Hello World” in F90 Using a Babel Type

```

program helloclient
  ① use greetings_english
  ② use sidl_baseinterface
  implicit none
  ③ type(greetings_english_t) :: obj
  ④ type(sidl_baseinterface_t) :: exc
  character (len=80) :: msg
  character (len=20) :: name
  ⑤ name='World'
  ⑥ call new(obj, exc)
  ⑦ call setName(obj, name, exc)
  ⑧ call sayIt(obj, msg, exc)
  ⑨ call deleteRef(obj, exc)
  print *, msg
end program helloclient
    
```

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CCA Common Component Architecture Supplementary material for handouts

## Handout Material: Code Notes

- ① Use statement for the greetings.English type
- ② Use statement for the sidl.BaseInterface type
- ③ Obj is a F90 derived type we get from the using statement, note the “\_t” extension that prevents it from colliding with the using statement.
- ④ Exc is used to hold exceptions thrown by methods
- ⑤ In C/C++ examples, this variable would be initialized by a the command-line variable “argv[1]”, but its trickier to do portably in F90 and too long, so I just initialize the name to “World”.
- ⑥ Obj is not yet initialized. The Babel idiom in F90 is to call new() to initialize the Babel type. In other languages its \_create(). NOTE: good code would add error checking.
- ⑦ setName() puts data into the obj. It sets its state.
- ⑧ sayIt() returns the entire greeting including the aforementioned name.
- ⑨ deleteRef() is a subroutine that all Babel types inherit from a parent class. All Babel objects are reference counted. When there are no more outstanding references, the object is told to clean up after itself.

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CCA Common Component Architecture ..

## Working Code: “Hello World” in F90 Using a Babel Type

```

program helloclient
  use greetings_English
  use sidl_BaseInterface
  implicit none
  type(greetings_English_t) :: obj
  type(sidl_BaseInterface_t) :: exc
  character (len=80) :: msg
  character (len=20) :: name
  name='World'
  call new( obj, exc )
  call setName( obj, name, exc )
  call sayIt( obj, msg, exc )
  call deleteRef( obj, exc )
  print *, msg
end program helloclient

```

**Looks like a native F90 derived type**

**These subroutines were specified in the SIDL.**

**Other basic subroutines are “built in” to all Babel types.**

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## Question: What language is “obj” really implemented in?

```

program helIoclient
  use greetings_English
  use si dl_Basel nterface
  implicit none
  type(greetings_English_t) :: obj
  type(si dl_Basel nterface_t):: exc
  character (len=80)          : msg
  character (len=20)         :
  name=' World'
  call new( obj, exc )
  call setName( obj, name, exc )
  call sayI t( obj, msg, exc )
  call deleteRef( obj, exc )
  print *, msg
end program helIoclient
    
```

Answer: Can't Know!  
 With Babel, it could be C, C++, Python, Java, Fortran77, or Fortran90/95  
 In fact, it could change on different runs without recompiling this code!

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## CCA uses Babel for high-performance n-way language interoperability

Each one of these red lines, is potentially a bridge between two languages. No telling which language your component will be connected to when you write it.

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## The SIDL File that defines the “greetings.English” type

```

①② package greetings version 1.0 {
③④     interface Hello {
⑤         void setName( in string name );
           string sayIt ( );
           }
⑥     class English implements-all Hello { }
    }

```

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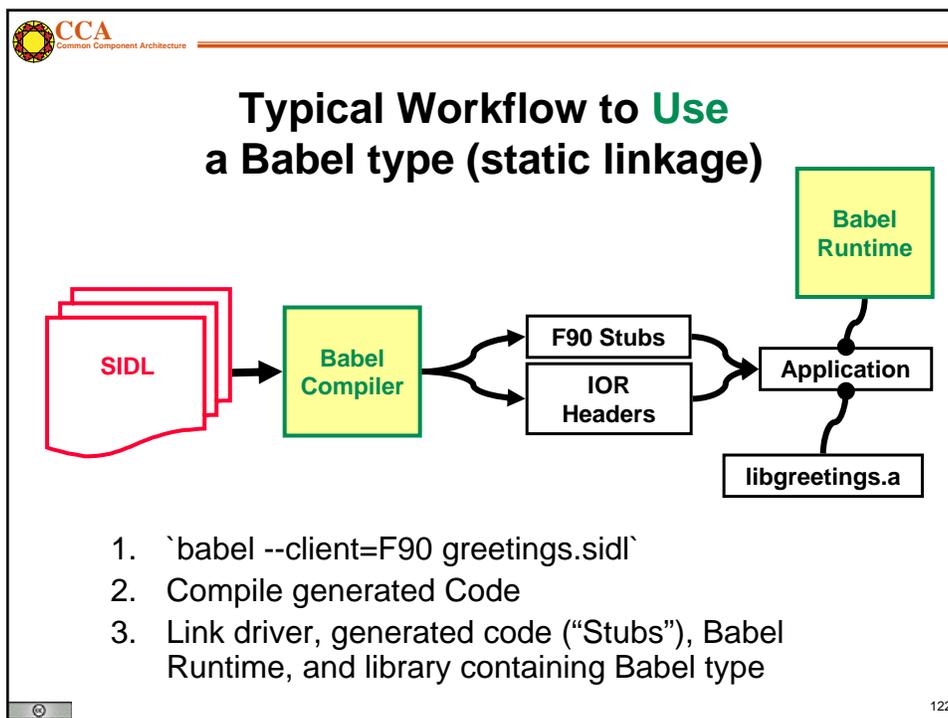
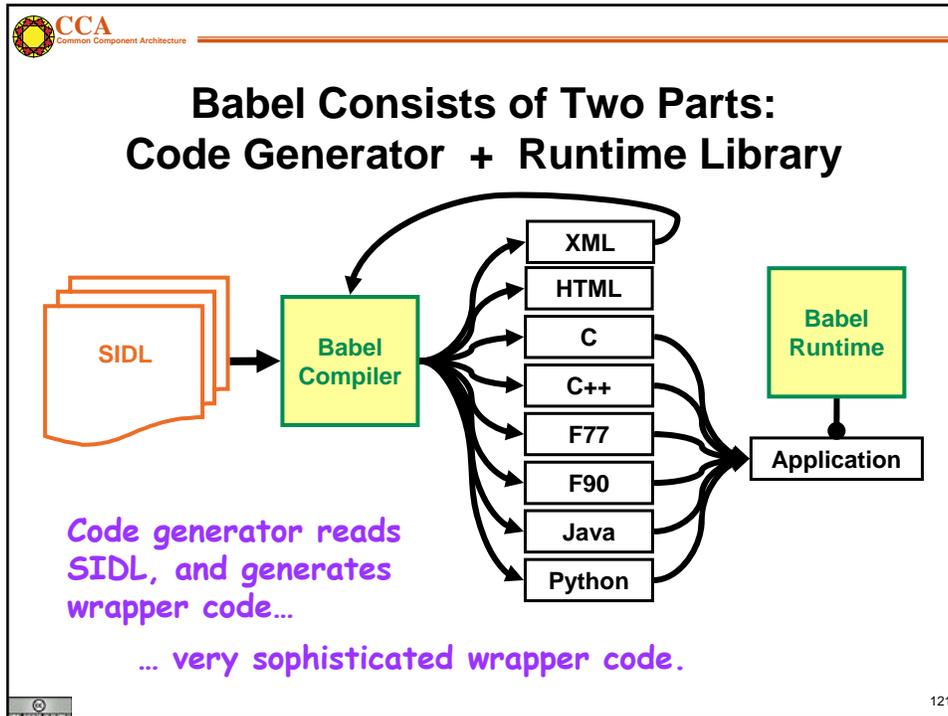
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Supplementary material for handouts

## Handout Material: Code Notes

- ① Packages contain user-defined types and are used to reduce naming collisions. Packages can be nested.
- ② Packages can be versioned. User defined types must be nested inside a versioned package and gain the same version number as the innermost versioned package
- ③ SIDL has a inheritance model similar to Java and Objective C. Classes can inherit multiple interfaces, but at most one implementation (other class).
- ④ An interface describes an API, but doesn't name the implementation.
- ⑤ Note that arguments have mode, type, and name. Mode can be one of “in”, “out”, and “inout”. These SIDL modes have slightly different semantics than Fortran90 “intents”.
- ⑥ This class generates English greetings. One could imagine a strategy for internationalization that uses the Hello interface everywhere, but loads in English, French, or whatever classes based on user's preference.

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## Typical Workflow to Use a Babel type (dynamic linkage)

```

    graph LR
      SIDL[SIDL] --> Babel[Babel Compiler]
      Babel --> F90[F90 Stubs]
      Babel --> IOR[IOR Headers]
      F90 --> App[Application]
      IOR --> App
      App --- Lib[libgreetings.so]
      BabelRuntime[Babel Runtime] -.-> App
  
```

1. ``babel --client=F90 greetings.sidl``
2. Compile same generated code with different flags
3. Link driver, and stubs only (both generated code and F90 stubs to Babel Runtime library)
4. Set `SIDL_DLL_PATH` environment variable to include relevant `*.scl` (or `*.cca`) files.
5. Actual implementations are linked in at runtime

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## Static vs. Dynamic Linkage

- Static
  - Least runtime overhead
  - Easiest to get right, debug, etc.
- Dynamic
  - Allows new types to “plug-in” without relinking driver
  - Necessary for Java or Python calling to other languages (unless you relink their virtual machine)
  - Induces very nondeterministic behavior if done incorrectly

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## Workflow for a Developer Wrapping Their Code into Babel Objects

```

    graph LR
      A[greetings.sidl] --> B[Babel Compiler]
      B --> C[C++ Stubs]
      B --> D[IORs]
      B --> E[C++ Skeletons]
      F((Smiley Face)) --> G[C++ Implementations]
      G -.-> E
      C --> H[libgreetings.a]
      D --> H
      E --> H
      I[legacy_library.a] -.-> H
  
```

1. `babel --server=C++ greetings.sidl`
2. Fill in the implementation details (see next slide)
3. Compile and link into a library/DLL

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## Implementation Details Must be Filled in Between Splicer Blocks

```

namespace greetings {
class EnglishImpl {
private:
    // DO-NOT-DELETE splicer. begin(greetings.EnglishImpl)
    string d_name;
    // DO-NOT-DELETE splicer. end(greetings.EnglishImpl)

string
greetings::EnglishImpl::sayIt()
throw ()
{
    // DO-NOT-DELETE splicer. begin(greetings.EnglishImpl::sayIt)
    string msg("Hello ");
    return msg + d_name + "!";
    // DO-NOT-DELETE splicer. end(greetings.EnglishImpl::sayIt)
}
}
  
```

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## Quick Review of Babel in general before proceeding to CCA specifics

- Babel can be used as a standalone tool
- Each language binding strikes a balance
  - support the SIDL type system (OO, exceptions, etc.)
  - provide it in a manner “natural” to experienced programmers in the target language
- For more details about Babel and SIDL
  - SC|07 tutorial slides for Babel  
<http://www.llnl.gov/CASC/components/docs/sc07.html>
  - Babel User’s Guide (aka. the BUG)  
[http://www.llnl.gov/CASC/components/docs/users\\_guide/](http://www.llnl.gov/CASC/components/docs/users_guide/)



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## CCA uses SIDL to specify APIs and Type Hierarchy for Frameworks, Services, Components, & Ports

- **A CCA framework must**
  - implement gov. cca. AbstractFramework,
  - provide a gov. cca. ports. BuilderService,
  - etc.
- **A CCA port must**
  - be a SIDL interface extending gov. cca. Port
- **A CCA component must**
  - be a SIDL class implementing gov. cca. Component

**The CCA Specification is a SIDL file.**



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## How to write a Babelized CCA Component (1/3)

### 1. Define “Ports” in SIDL

- CCA Port =
  - a SIDL Interface
  - extends gov.cca.Port

```
package functions version 1.0 {
  interface Function extends gov.cca.Port {
    double evaluate( in double x );
  }
}
```



## How to write a Babelized CCA Component (2/3)

### 2. Define “Components” that implement those Ports

- CCA Component =
  - SIDL Class
  - implements gov.cca.Component (and any provided ports)

```
class LinearFunction implements functions.Function,
                               gov.cca.Component {
  double evaluate( in double x );
  void setServices( in cca.Services svcs );
}
```

```
class LinearFunction implements-all
  functions.Function, gov.cca.Component { }
```



Supplementary material for notes

**Tip: Use Babel's XML output like precompiled headers in C++**

The diagram illustrates a two-step process. In the first step, a stack of files labeled 'cca.sidl' is processed by the 'Babel Compiler' to produce 'XML' output, which is then stored in a 'Type Repository' (represented as a purple cylinder). In the second step, a stack of files labeled 'functions.sidl' is processed by the 'Babel Compiler' again. This time, it uses the 'Type Repository' as input. The output consists of four categories: 'Stubs', 'IORs', 'Skeletons', and 'Implementations'.

1. Precompile SIDL into XML using '--text=xml'
2. Store XML in a directory
3. Use Babel's -R option to specify search directories

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**How to write a Babelized CCA Component (3/3)**

The diagram shows the final step of creating a CCA component. It starts with a 'Repo (XML)' (purple cylinder) and a stack of 'functions.sidl' files. Both are processed by the 'Babel Compiler'. The compiler generates four categories: 'C Stubs', 'IORs', 'C Skeletons', and 'C Implementations'. The 'C Implementations' category is shown with a dashed border, indicating it is a placeholder for user-defined code. A yellow smiley face icon is positioned below the 'C Implementations' box, with a green arrow pointing from it to the 'C Implementations' box, suggesting the user's role in filling this section. The final output is a 'libfunctions.so' file.

3. Use Babel to generate the interoperability glue
  - Execute ``babel --server=C -RRepo functions.sidl``
4. Fill in Implementations as needed

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## Review: Goal of This Module

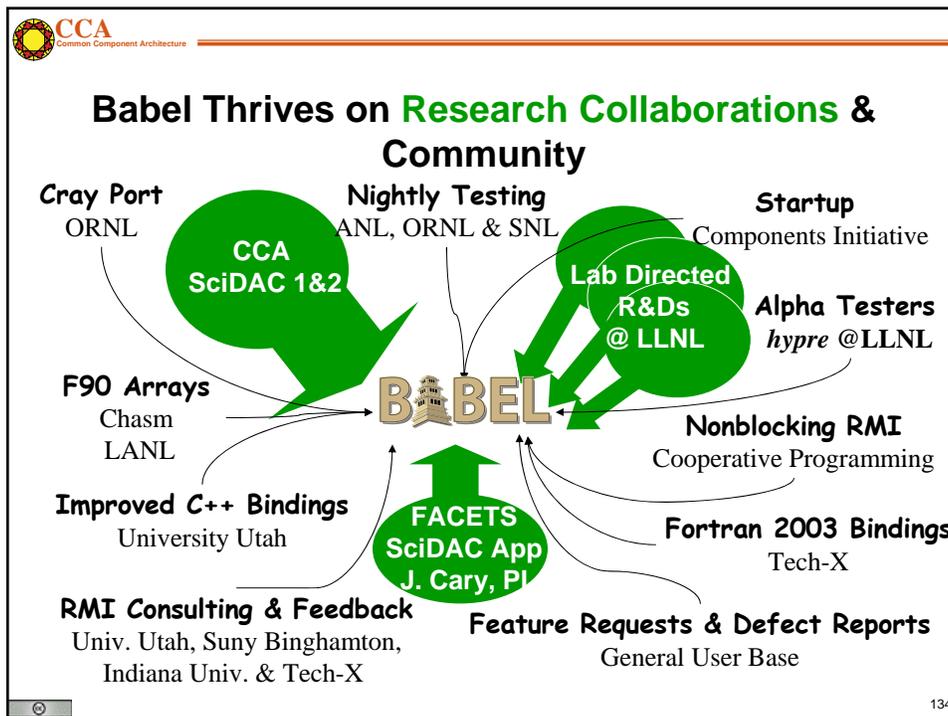
**Learn how existing code is**

- Wrapped into Babel objects, and
- Promoted to CCA components

**In the process, will also covered**

- **Babel Basics**
- **Scientific Interface Definition Language (SIDL)**
- **Code sample (“Hello World!”)**

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## Contact Information

- Project: <http://www.llnl.gov/CASC/components>
- Project Team Email: [components@llnl.gov](mailto:components@llnl.gov)
- Mailing Lists: [majordomo@lists.llnl.gov](mailto:majordomo@lists.llnl.gov)  
subscribe [babel-users](#) [email address]  
subscribe [babel-announce](#) [email address]
- Bug Tracking: <https://www.cca-forum.org/bugs/babel/>  
or email to [babel-bugs@cca-forum.org](mailto:babel-bugs@cca-forum.org)



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---

## Using CCA: Approaches & Experience

**CCA Forum Tutorial Working Group**  
[http://www.cca-forum.org/tutorials/  
tutorial-wg@cca-forum.org](http://www.cca-forum.org/tutorials/tutorial-wg@cca-forum.org)



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## Modern Scientific Software Development

- Complex codes, often **coupling** multiple types of physics, time or length scales, involving a broad range of computational and numerical techniques
- Different parts of the code require significantly **different expertise** to write (well)
- Generally written by **teams** rather than individuals

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*Supplementary material for handouts*

## Using CCA to Help Manage Complexity

- Application areas participating in the CCA:  
astronomy, astrophysics, biological and medical simulations, chemically reacting flow, climate and weather modelling, combustion, computational chemistry, data management, fusion and plasma physics modelling, linear algebra, materials science, molecular electronics, nanoscience, nuclear power plant simulations, structured adaptive meshes, unstructured meshes, and visualization
- Research agencies sponsoring software development using the CCA:  
DOE (SciDAC, Office of Science, NNSA/ASC), NASA, NIH, NSF, DoD, European Union

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Supplementary material for handouts

## Outline

- Developing Components
  - Strategies for both developing new codes and wrapping existing codes
- Case Studies
  - Chemistry project
    - Moderate-sized multi-disciplinary, multi-institutional team
    - Using Ccaffeine framework, SIDL components
  - Combustion toolkit
    - Small team, both new and wrapped codes
    - Using Ccaffeine framework, C++ components

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Supplementary material for handouts

## Developing Components (Both New Codes and Wrappers to Existing Codes)

- Productivity Benefits
- Application Decomposition Strategies
- Interface Design Issues
  - Social factors
  - Technical factors
- Implementation Issues and Patterns

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## CCA Productivity Benefits

- Fast algorithmic **experiments** and benchmarks by substituting components
- Once ports are defined, domain-expert component implementers can **work separately** in their own **favorite languages**
- Work of **transient contributors** remains as well-defined, lasting components
- Wrapped legacy portions **need not be reimplemented or reverified**



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## Components in the Small: Impacts within a Project

**Benefits include:**

- Rapid testing, debugging, and benchmarking
- Support for implementation-hiding discipline
- Coordination of independent workers
- Interface change effects across components are clear and usually automatically found by compilers if overlooked
- Object-orientation made simpler for C and Fortran



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## Components in the Large: Connecting Multiple Projects

**Benefits include:**

- SIDL can be used to facilitate the interface consensus processes
- Different sub-projects do not have to agree on one implementation language
- Developers who never meet in person have an excellent chance of code integration working on the first try

**Costs include:**

- Consensus can be expensive to obtain
- Writing code for others to use is more difficult than writing it just for yourself



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## Application Decomposition Strategies

- Conceptually decompose the application into
  - cutting-edge areas (*less stable*)
  - and
  - areas that can employ existing component-based libraries (*more stable*)
- Decompose each area into components for
  - physics
  - mathematics
  - data managementas dictated by the application; sketch a typical component layout
- Many components will encapsulate *algorithmic logic only*, with little or no private data
- Most HPC applications will have a *central data abstraction* that provides data memory management and parallel communication
- In a multilanguage application, all *I/O may need to be isolated* into components written in a single common language (file based I/O should not be affected)
- Component boundaries (and port interfaces) may be set to *isolate proprietary code or difficult contributors*



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Supplementary material for handouts

## Interface Design: Social Factors (Defining Ports to Wrap Existing Code)

- Will the port hide just one implementation, or will there need to be plug compatibility with other implementations? From other teams?
- Who defines the interface and maintains it?
  1. Project dictator? (*Fast...*)
  2. The owner of the legacy functionality? (*Slow, if not you...*)
  3. A standards committee? (*Really slow...*)
- How many iterations of redefining the ports will the customers tolerate?

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Supplementary material for handouts

## Interface Design: Technical Factors

- Do we make a single large port look like the underlying library or divide functions into groups on separate ports?
- Should a function with many optional arguments be split into several alternative functions with simpler usage?
- Do we make the ports more general than the existing code?
- Do we require the ports to work across languages?  
Across networks?
  - If not, gains in efficiency or coding ease might be had
  - If so, memory management and I/O challenges may arise

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Supplementary material for handouts

## Implementation Issues in Wrapping

- Do we split large libraries into several components?
  - Splitting is difficult to do if global variables or common blocks are widely used.
- Do we expect more than one implementation instance of a port in a single run-time?
  - If not, interface contracts may include global side effects
- Do we integrate the wrapper code in the existing code's development and build processes?
  - If not, how do we ensure build consistency and on-going wrapper support?
- Code bases with large interfaces need automated wrapping tools
  - E.g., see [Chasm info in the Tools module](#) of the tutorial

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Supplementary material for handouts

## Benefits of Wrapping Code Using CCA

- Setting a language-neutral interface definition (SIDL) can greatly clarify design discussions
- Provides a chance to reorganize the interface and hide globals
- Allows testing of alternate versions if doing performance studies
- Allows easy “experimentation” with new algorithms
- Software discipline is enforced, not optional
- Implementation decisions (to split libraries, etc) can be easily revised over time if interfaces remain constant (possibly with the addition of new interfaces)

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Supplementary material for handouts

## Interface Design for *New Code*

- Write SIDL for each connection (port) in the sketched component layout
- If two ports must always be used together, consider merging them
- Review SIDL drafts for near-duplication of ports
- Avoid creating interface contracts that require using hidden global data
- Consider exporting tuning and/or configuration parameter inputs as a port
- All the design issues from wrapping existing code apply, also
- ***Interfaces will change.***



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Supplementary material for handouts

## Recommended Implementation Patterns

- Expect to decompose initial components further as work progresses and requirements expand
- Build systems (i.e. `make`) should be kept as simple as possible
  - Keep a subdirectory for port definitions and any implementation-independent glue code derived from the ports
  - Keep each component (and any wrapped code) in its own subdirectory
  - Keep application-wide flags in a configure script or an include file common to all components and ports
  - Consistency is key. Extract build flags from `cca-spec-babel-config` and if possible compile & link with `babel-libtool`



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Supplementary material for handouts

## Outline

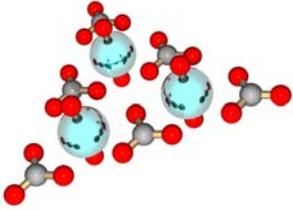
- Developing Components
  - Strategies for both developing new codes and wrapping existing codes
- Case Studies
  - Chemistry project
    - Moderate-sized multi-disciplinary, multi-institutional team
    - Using Ccaffeine framework, SIDL components
  - Combustion toolkit
    - Small team, both new and wrapped codes
    - Using Ccaffeine framework, C++ components

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## Case Study 1: Chemistry Project

- Funded via SciDAC initiative
- Initial focus: Full-featured components for structure optimization
  - **Chemistry models** provided by MPQC (SNL) & NWChem (PNNL)
  - **Numerical optimization** provided by TAO (ANL) solvers
  - **Linear algebra** provided by GA (PNNL) and PETSc (ANL)
- Recent work:
  - Multi-level parallelism
  - Low-level chemistry model integration (e.g., molecular integrals)



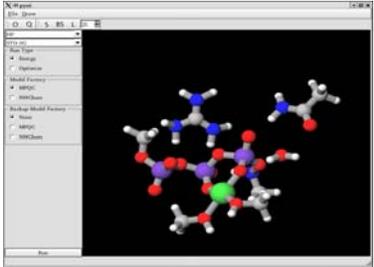
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## CCA-Chemistry Project Participants

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Curtis L. Janssen  
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 **Pacific Northwest National Laboratory**  
Operated by Battelle for the U.S. Department of Energy

 **ARGONNE NATIONAL LABORATORY**  
UNIVERSITY OF CHICAGO

 **Sandia National Laboratories**

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## CCA Impacts in Computational Chemistry

Through 4 chemistry applications we consider different facets of CCA functionality:

- **Molecular Geometry Optimization**
  - Combining diverse expertise of 5 different research groups
- **Lennard-Jones Molecular Dynamics**
  - Achieving good scalability and low CCA overhead
- **Multi-level Parallelism in Computational Chemistry**
  - Combining SPMD and MPMD parallelism
- **Molecular Integral Evaluation**
  - Component interoperability at deeper levels within chemistry libraries



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## App 1: Molecular Geometry Optimization: Combining Diverse Expertise

**CCA quantum chemistry application using components based on:**

- MPQC, NWChem (chemistry – energy evaluation)
- GA, PETSc (parallel data management and linear algebra)
- TAO (numerical optimization)

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## Molecular Geometry Optimization

Compute the molecular geometry with minimum energy, i.e. solve  $\min f(u)$ , where  $f: R^n \Rightarrow R$ .

**Builder**  
Construct application using framework builder services

**GUI**

**Optimization**  
 $u_{i+1} = u_i + \alpha S \dots$

**Coordinate Model**  
(perform transformations)

**Model Factory** (instantiate model)

**MPQC**

**NWChem**

**Linear Algebra** (PETSc, GA)

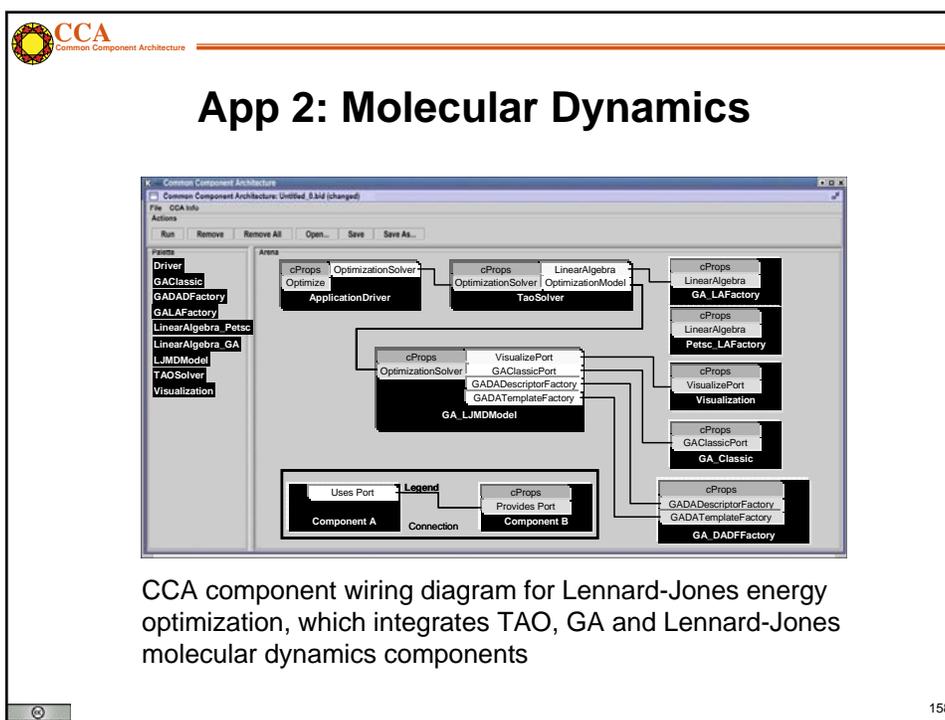
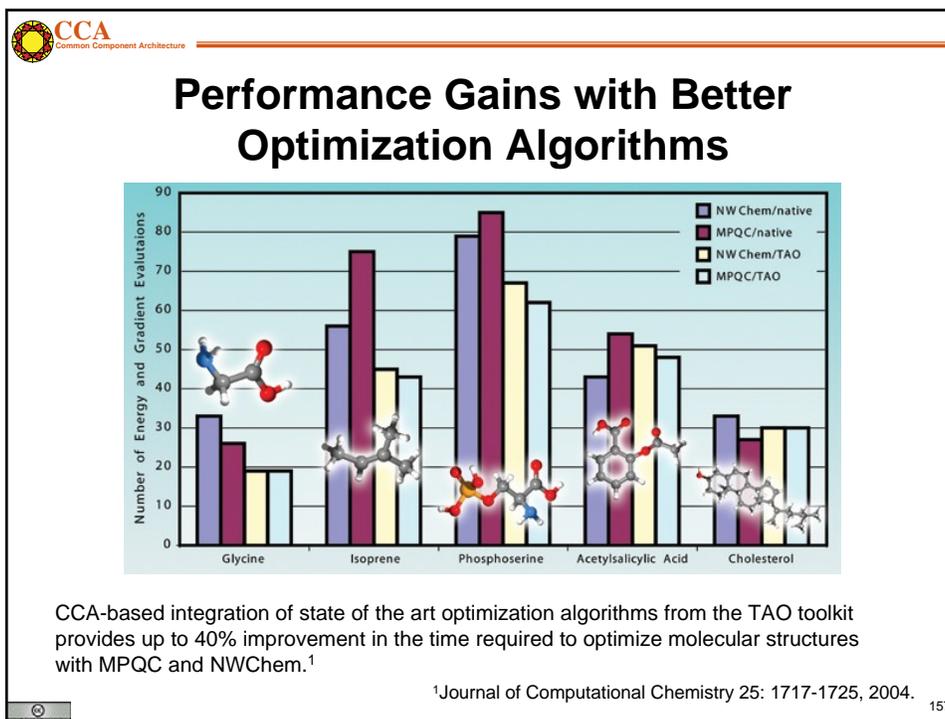
**User Input**

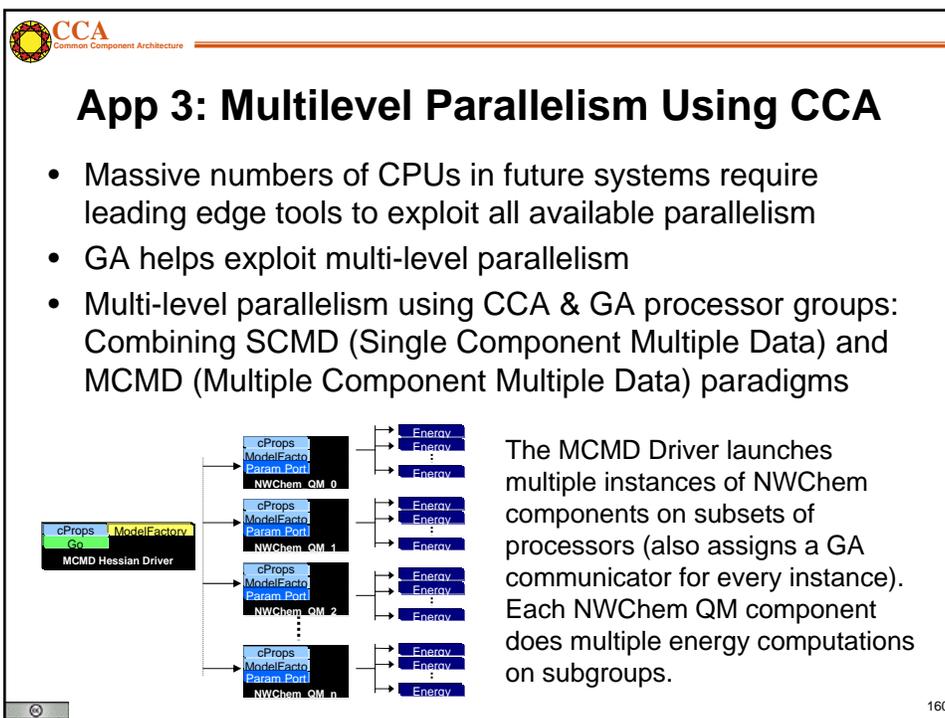
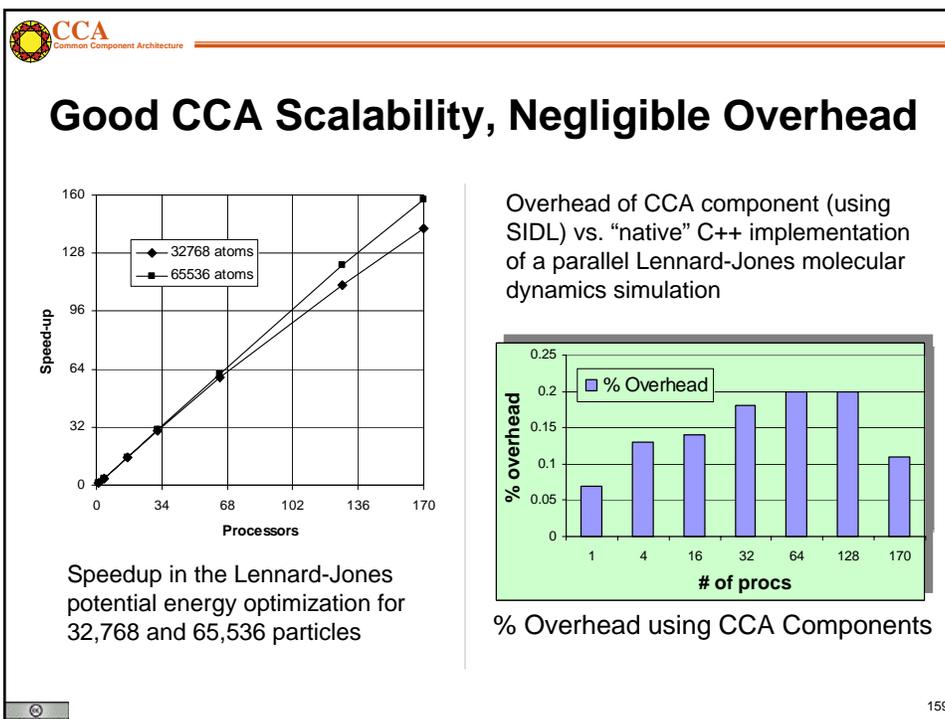
**Legend:**

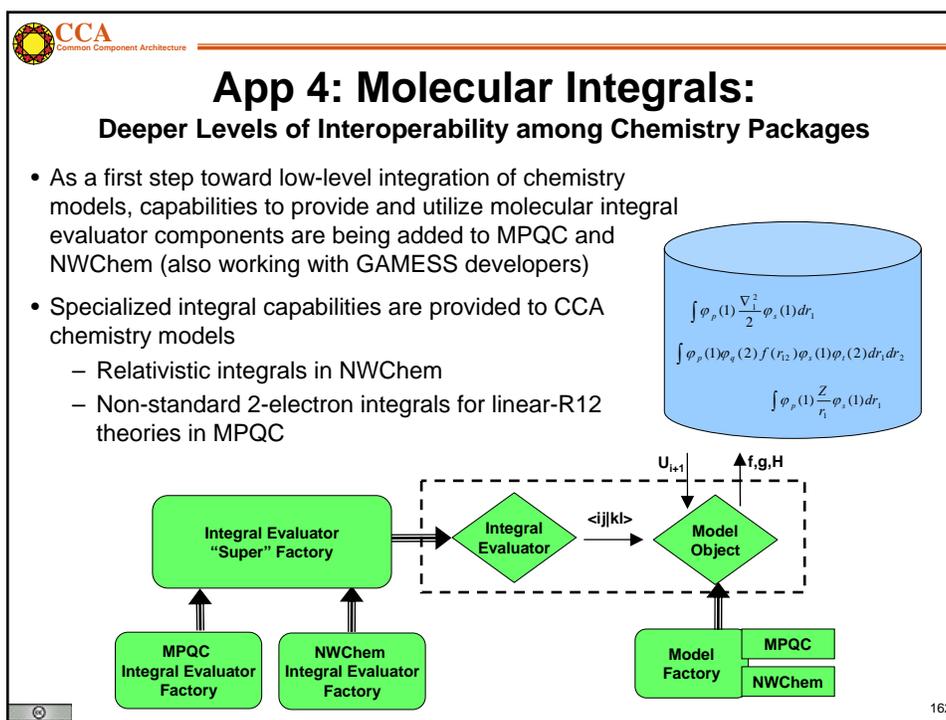
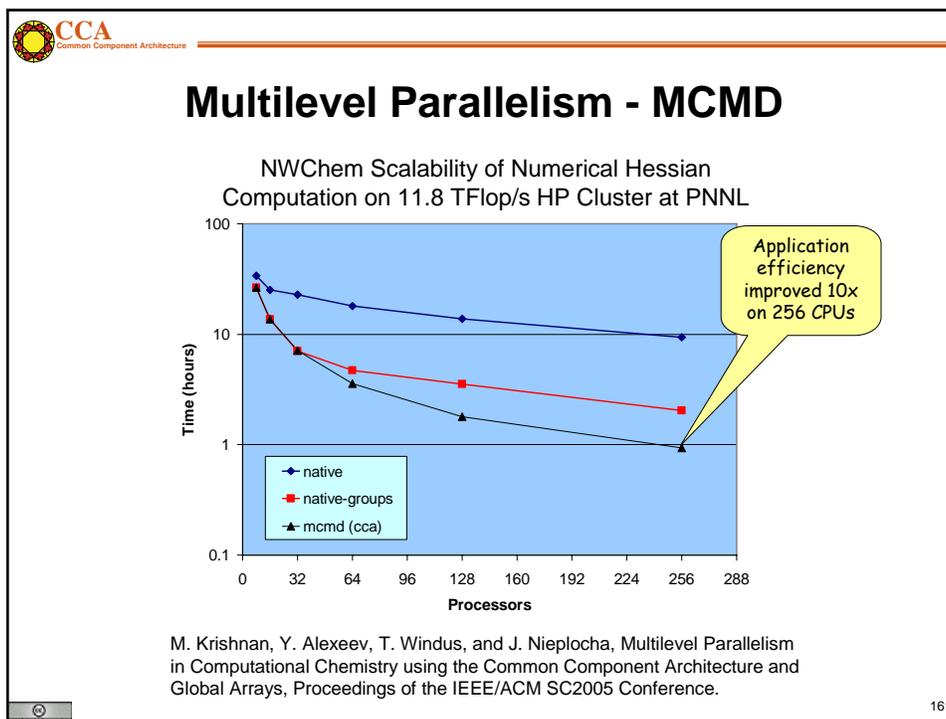
- $f(u)$  energy
- $u$  Cartesian coordinates
- $u$  internal coordinates
- $g$  gradient (in Cartesians)
- $g$  gradient (in internals)
- $H$  Hessian (in Cartesians)
- $H$  Hessian (in internals)
- $s$  update (in internals)

Relatively high-level interfaces

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Supplementary material for handouts

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## CCA Impacts in Computational Chemistry: Review

Through 4 chemistry applications we considered different facets of CCA functionality:

- Combining diverse expertise of 5 different research groups
- Achieving good scalability and low CCA overhead
- Implementing multi-level parallelism by combining SPMD and MPMD paradigms
- Addressing component interoperability at deeper levels within chemistry libraries

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## Case Study 2: Combustion Project

- Computational Facility for Reacting Flow Science (CFRFS)
  - <http://cfrfs.ca.sandia.gov>
  - Funded via SciDAC initiative (PI: H. Najm)
- Focus: A toolkit to perform simulations of lab-sized unsteady flames
  - Solve the Navier-Stokes w/detailed chemistry
  - Various mechanisms up to ~50 species, 300 reactions
- Consequently:
  - Disparity of **length scales** :
    - use structured adaptively refined meshes
  - Disparity of **time scales** (transport versus chemistry) :
    - use an operator-split construction and solve chemistry implicitly
    - adaptive chemistry: use **computational singular perturbation** to find and follow low dimensional chemical manifolds

J. Ray, S. Lefantzi, J. Lee, C. Kennedy, W. Ashurst, K. Smith, M. Liu, N. Trebon

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## Why Use CCA in the CFRFS Toolkit?

- Separate clearly the physics models, numerical algorithms, and the “CS” parts of the toolkit
  - Strictly functional!
- Realize the separation in software
- Tame *software* complexity
- Separate contributions by transient contributors
  - Form the bulk of the developers
- Create “chunks” of well-defined functionality that can be developed by experts (usually numerical analysts and combustion researchers)



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## Design Principles of the Toolkit / 1

- **Principal Aim: Reduce software complexity**
  - We can deal with the rest
- Functional decomposition into components
  - “Data Object” and Mesh components
  - (Large) set of numerical algorithmic components (integrators, linear/nonlinear solvers, etc.)
  - (Large) set of physical models components (gas-phase combustion chemistry, thermodynamics, fluid dynamic quantities, e.g. viscous stress tensor)
  - Handful of adaptors



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## Design Principles of the Toolkit / 2

- Decomposition reflected in the port design and implementation
  - Most re-implemented port is the one that exchanges a rectangular sub-domain's data for processing by components
- Sparse connectivity between components
  - i.e., components communicate with a few others
  - Large apps (component assemblies) are composed by assembling smaller, largely independent sub-assemblies
    - Sub-assemblies usually deal with a certain physics
  - Intuitive way to assemble a *multiphysics* code

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## The Code

Transport subassembly

Diffusion coefficients

Chemistry reaction subassembly

Separate component subsystems for transport (black) and for reaction (orange) in a reaction-diffusion code. They two are coupled at a relatively high level.

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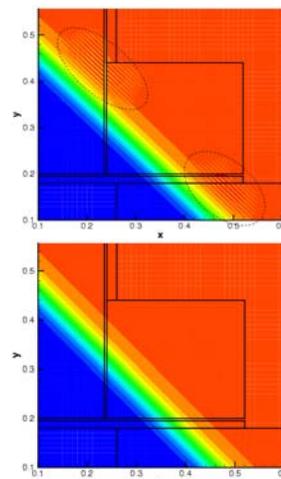
## Has the Toolkit Approach Helped Tame Software Complexity?

- How has the code evolved?
  - How often have new ports been added?
  - How many rewrites have been done?
- How large are the components?
- How many ports do they have?
  - How large are the ports?
- How many ports exist?
  - i.e., Is the design general enough to support many implementations?
- What is the connectivity of components in application codes?



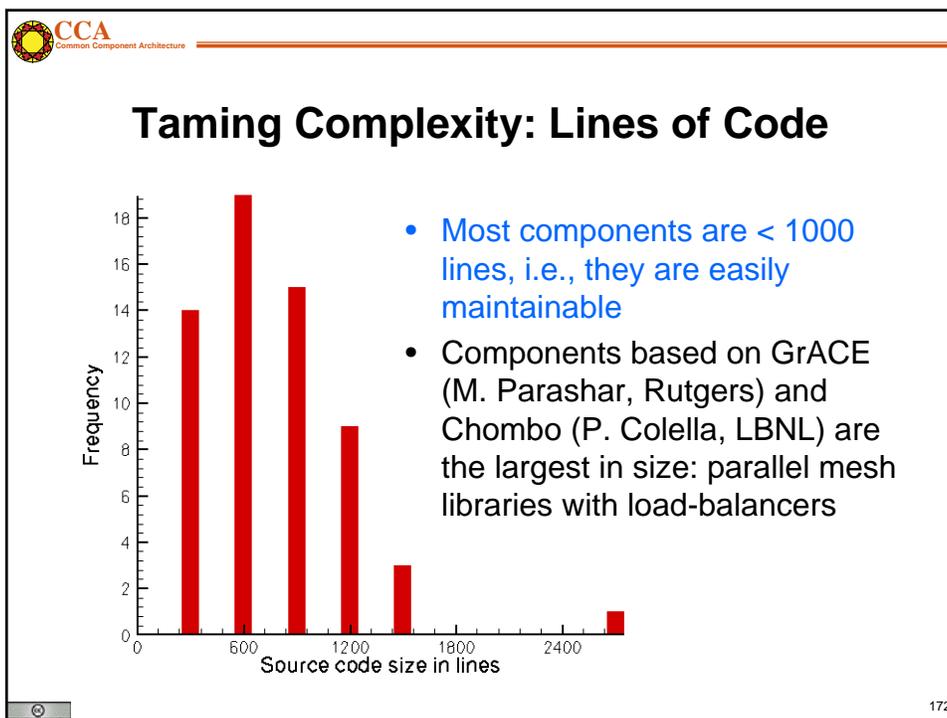
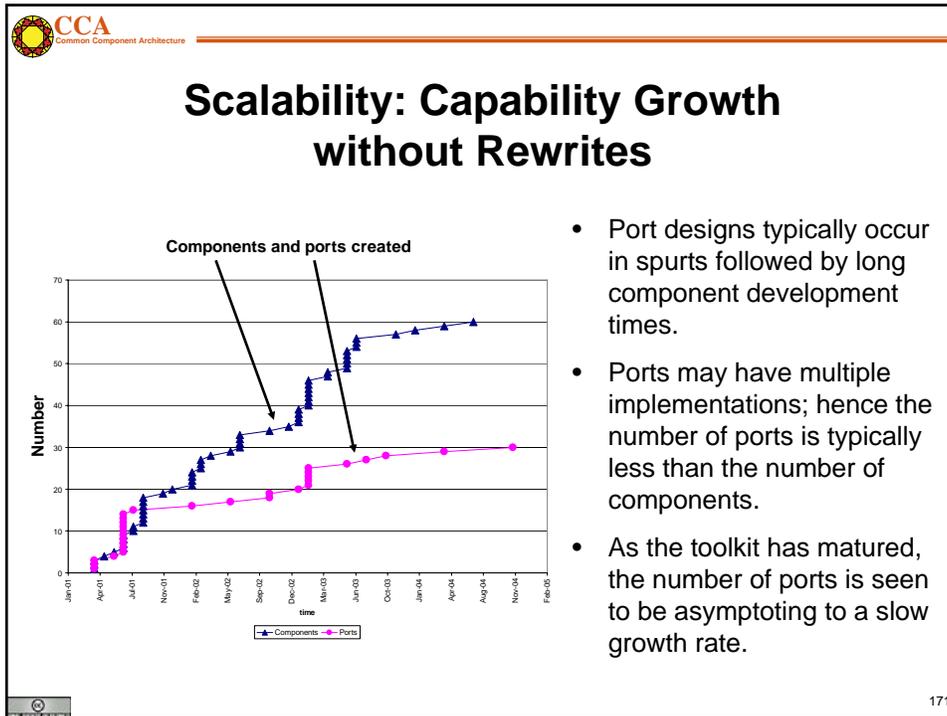
## CFRFS Toolkit Status

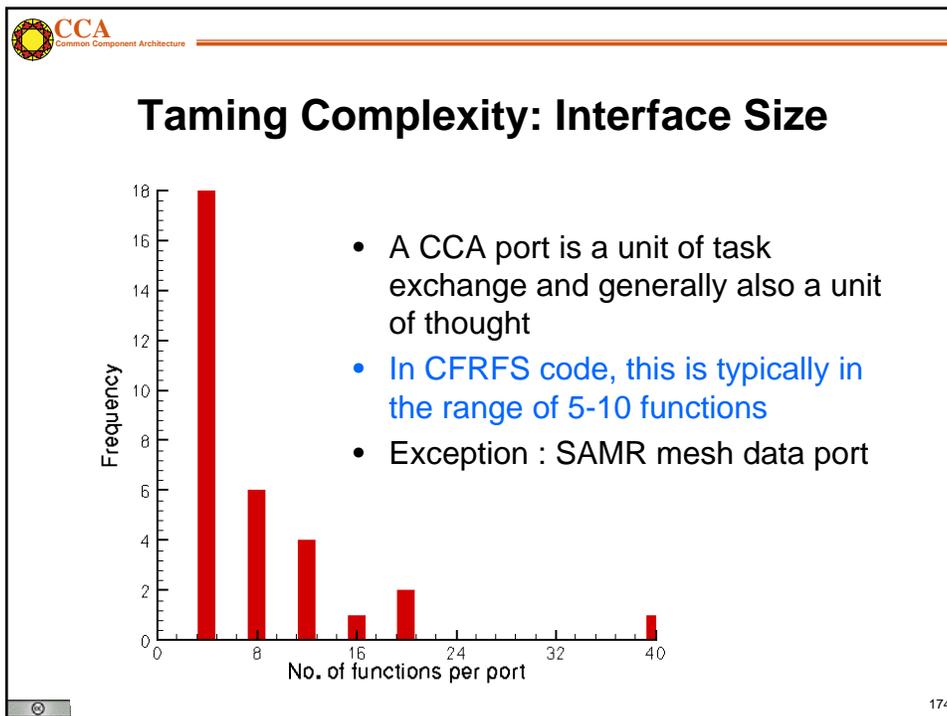
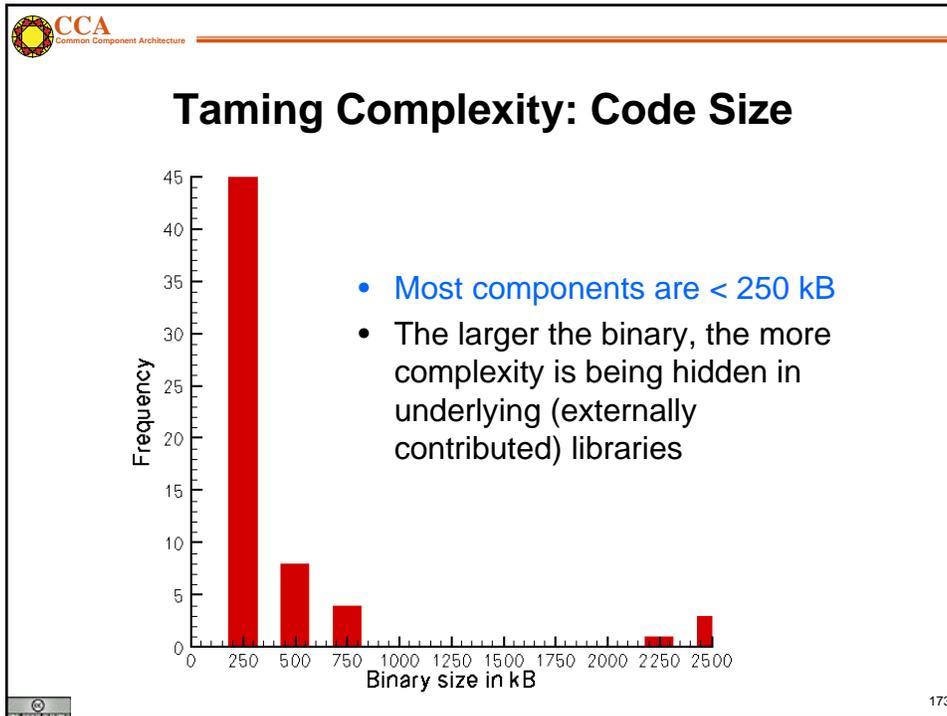
- Started in 2001
- **61 components** today, all peers, independent, mixed and matched for combustion and shock hydrodynamics
- **7 external libraries**
- Contributors: 9 in all, including 3 summer students
- Only 2 of the 9 contributors are at SNL today

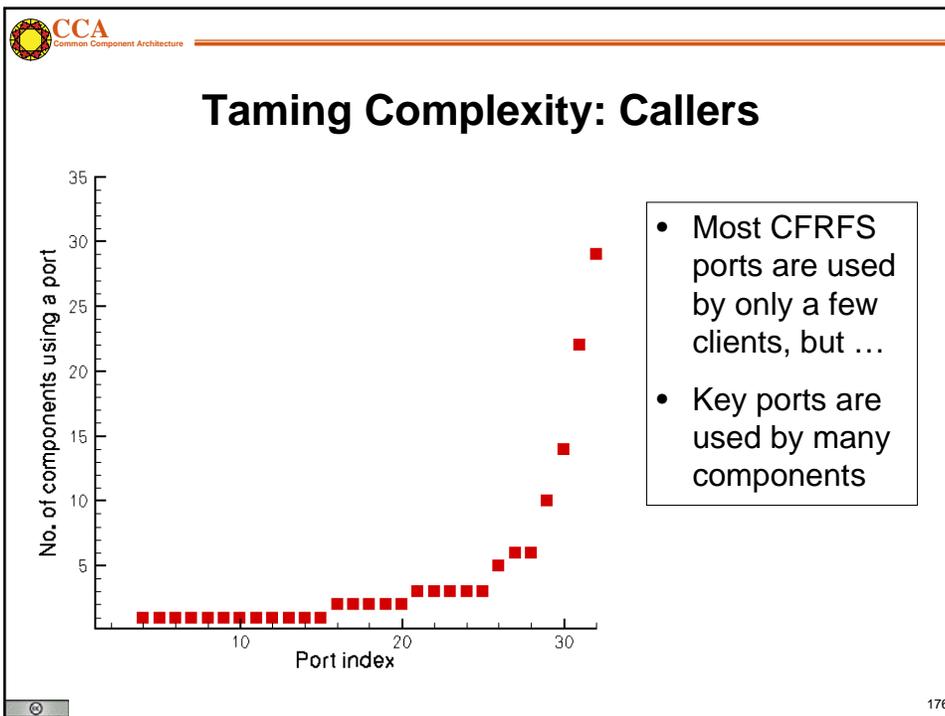
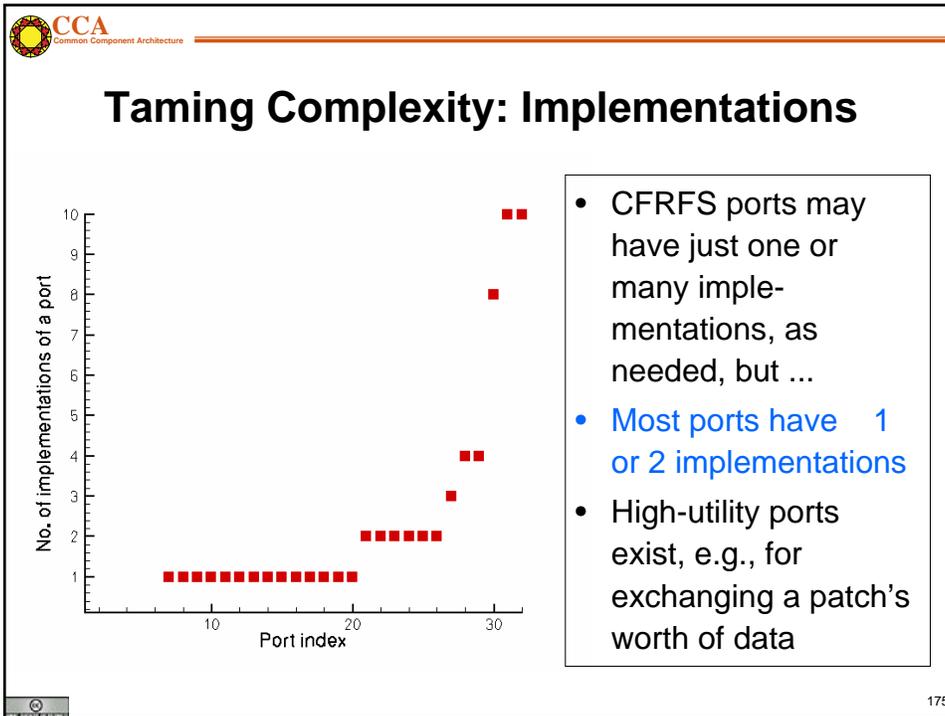


*A Fitzhugh-Nagumo equation being solved on a block-structured adaptively refined mesh. The top image illustrates Runge phenomena at coarse-fine interfaces (dashed ovals) when using high-order schemes (6<sup>th</sup> order interpolations with 4<sup>th</sup> order discretizations). Filtering them with an 8<sup>th</sup> order filter removes them (bottom).*





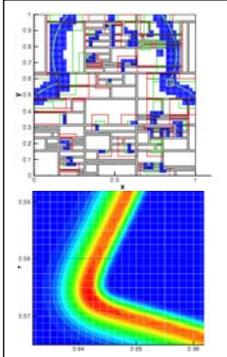




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## Scientific Productivity

- Conventional Measures
  - 4 journal papers in CFD/Numerics
  - 4 software-oriented journal papers, 1 book chapter
  - ~11 conference papers, including best paper award
  - Over 60 presentations
  - 1 MS and 1 PhD theses
  - 6 test applications
  - See papers at: <http://cfrfs.ca.sandia.gov>
- Unconventional Measures
  - Did the toolkit spawn new research in app-focused CS (e.g., performance evaluation/enhancement/modeling?)
  - Can the design accommodate software which were themselves designed to be *frameworks* and *not components* ?



*H<sub>2</sub>O<sub>2</sub> chemical subspecies profile and associated AMR mesh*

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## Adaptive Codes / Computational Quality of Service

- Can codes be optimized during runtime ?
  - CCA code is an assembly of components
  - Component applications can be non-optimal because
    - The mathematical characteristics of the simulation are different from those of the component
    - The component is badly implemented
- So, can one dynamically “re-arrange” an assembly to improve performance?
- Simplistically, 2 approaches:
  - Create performance model per component, use best one
  - Create expert system that analyzes problem and picks good solution strategy

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## Requirements for CQoS codes

- A software framework within which ordinary components can be “CQoS-ified”
  - By “decorating” a given component-network with extra CQoS components
- The ‘extra’ components form a control system which monitors, tweaks and/or replaces components commensurate with the problem and the computer at hand.
  - Requires continuous performance monitoring
    - How do you monitor a component non-invasively?
  - Requires continuous querying of a performance database to analyze current situation and make predictions
- The control infrastructure/framework/software is generic, the control law is domain specific.



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## Who’s working on CQoS ?

- Control law work:
  - Computational chemistry: evaluation of integrals
  - Partitioning of block-structured adaptive meshes
  - Iterative sparse linear algebra: mix-and-match accelerators and preconditioners
- Infrastructure work
  - Performance measurement: Automatic performance data (statistical) analysis
  - Design of a CQoS API (to enable extraction & storage of performance data)
  - Quick-and-dirty experimentation in a CQoS world (SciPY based)
  - Infrastructural components – databases, regression-ers etc



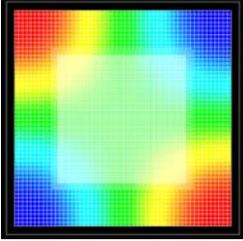
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## Incorporating Other Frameworks

- Chombo (by P. Colella, LBNL) has solvers (AMRGodunov, AMRElliptic, etc.) that:
  - Work on block structured adaptive meshes
  - Accept Chombo-specific data structures
  - But fundamentally require:
    - A double pointer, an array, where variables on a patch (box) are stored in blocked format
    - Bunch of integer arrays that describe the array
- Challenge: Can Chombo be used within CCA?
- Need a standardized way of getting data into Chombo
  - Pointer aliasing, not data copy
- Implementation of this “standard” interface



*Using Chombo to solve the Poisson equation (needed for CFRFS flame simulations).*

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## Using CCA: Summary

- Review of guidelines for developing high-performance scientific components (both new code and wrappers for existing code)
- CCA is an enabling technology for scientific applications
  - Has enabled mathematicians, chemists, combustion scientists, and computer scientists to contribute new strategies that are shrink-wrapped for easy re-use
  - Apart from **science research**, also spawned **new research directions in CS**
  - Has enabled research scientists to investigate unconventional approaches, for example multilevel parallelism and dynamic adaptivity
- For more info on the CCA applications/case studies, see:
  - Chemistry: <http://www.cca-forum.org/~cca-chem>
  - Combustion: <http://cfrfs.ca.sandia.gov>
- **Different facets of CCA components may be useful within different projects ... What are **your** needs and priorities?**

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## ***A Few Notes in Closing***

**CCA Forum Tutorial Working Group**  
[http://www.cca-forum.org/tutorials/  
tutorial-wg@cca-forum.org](http://www.cca-forum.org/tutorials/tutorial-wg@cca-forum.org)

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## **Resources: Its All Online**

- Information about all CCA tutorials, past, present, and future:  
<http://www.cca-forum.org/tutorials/>
- Specifically...
  - Latest versions of hands-on materials and code:  
<http://www.cca-forum.org/tutorials/#sources>
    - Hands-On designed for self-study as well as use in an organized tutorial
    - Should work on most Linux distributions, less tested on other unixen
    - Still evolving, so please contact us if you have questions or problems
  - Archives of all tutorial presentations:  
<http://www.cca-forum.org/tutorials/archives/>
- Questions...  
[help@cca-forum.org](mailto:help@cca-forum.org) or [cca-tutorial@cca-forum.org](mailto:cca-tutorial@cca-forum.org)



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## Getting Help

- We want to help insure you have a good experience with CCA, so let us know if you're having problems!
- Tutorial or "start-up" questions
  - [help@cca-forum.org](mailto:help@cca-forum.org) or [cca-tutorial@cca-forum.org](mailto:cca-tutorial@cca-forum.org)
- Problems with specific tools
  - *check documentation for updated contact info*
  - cca-tools bundle (includes Chasm, Babel, Ccaffeine): [Rob Armstrong](mailto:Rob.Armstrong@lanl.gov), [cca-tools@cca-forum.org](mailto:cca-tools@cca-forum.org)
  - Bocca: [Rob Armstrong](mailto:Rob.Armstrong@lanl.gov), [bocca@cca-forum.org](mailto:bocca@cca-forum.org)
  - Chasm: [Craig Rasmussen](mailto:Craig.Rasmussen@lanl.gov), [crasmussen@lanl.gov](mailto:crasmussen@lanl.gov)
  - Babel: [babel-users@llnl.gov](mailto:babel-users@llnl.gov)
  - Ccaffeine: [ccafe-users@cca-forum.org](mailto:ccafe-users@cca-forum.org)
- General questions, or not sure who to ask?
  - [help@cca-forum.org](mailto:help@cca-forum.org)



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## CCA is Interactive

- Collectively, CCA developers and users span a broad range of scientific interests.
  - There's a good chance we can put you in touch with others with relevant experience with CCA
- CCA Forum Quarterly Meetings
  - Meet many CCA developers and users
  - <http://www.cca-forum.org/meetings/>
- "Coding Camps"
  - Bring together CCA users & developers for a concentrated session of coding
  - Held as needed, typically 3-5 days
  - May focus on a particular theme, but generally open to all interested participants
  - If you're interested in having one, *speak up* (to individuals or [cca-forum@cca-forum.org](mailto:cca-forum@cca-forum.org))
- Visits, Internships, etc.



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## Thank You!

Thanks for attending this tutorial

We welcome feedback and questions

