Performance Technology for Parallel Component Software

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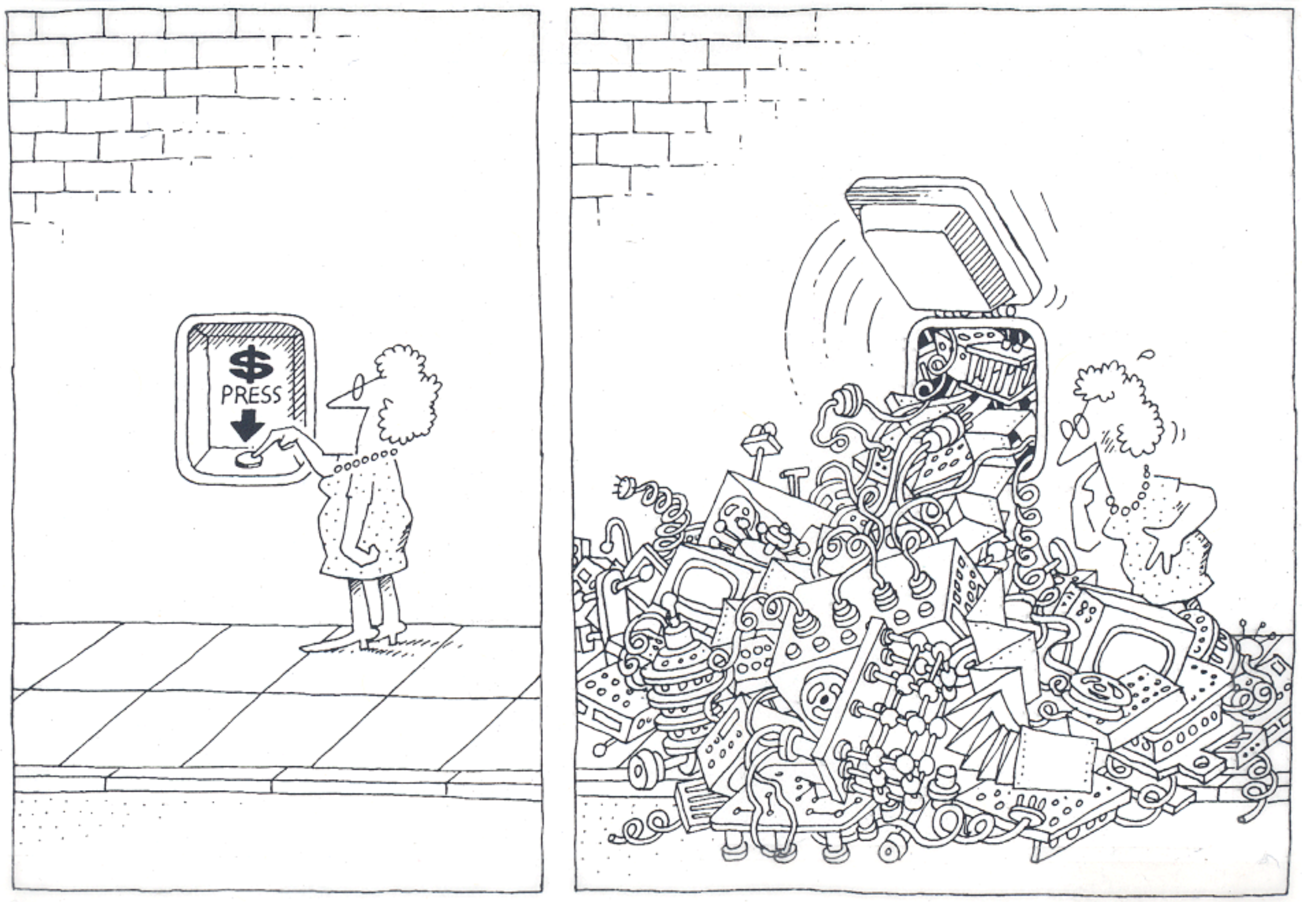
Outline

- What is Component Software? [www.cca-forum.org]
- Performance Engineered Component Software
- CCA Performance Observation Component
  - CCAFFEINE (Classic C++)
  - SIDL
- Applications :
  - Optimizer Component
  - Combustion Component
- Concluding remarks

Why Components?



The task of the software development team is to engineer the illusion of simplicity *[Booch]*.

The Good the Bad and the Ugly

- An example of what can lead to a crisis in software:
- At least 41 different Fast Fourier Transform (FFT) libraries:
  - see, http://www.fftw.org/benchfft/doc/ffts.html
- Many (if not all) have different interfaces
  - different procedure names and different input and output parameters
- SUBROUTINE FOUR1(DATA, NN, ISIGN)
  - Replaces DATA by its discrete Fourier transform (if ISIGN is input as 1) or replaces DATA by NN times its inverse discrete Fourier transform (if ISIGN is input as -1). DATA is a complex array of length NN or, equivalently, a real array of length 2*NN. NN MUST be an integer power of 2 (this is not checked for!).

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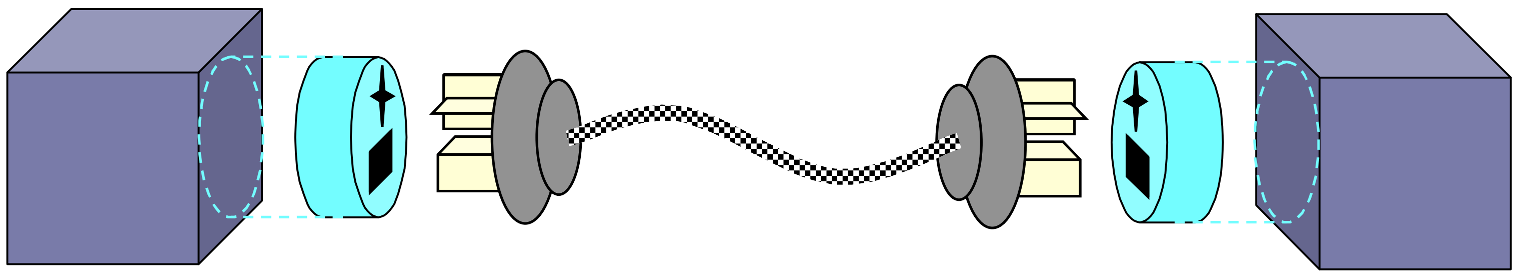
What Are Components [Szyperski]

- A component is a binary unit of independent deployment
  - well separated from other components
    - fences make good neighbors
  - can be deployed independently
- A component is a unit of third-party composition
  - is composable (even by physicists)
  - comes with clear specifications of what it requires and provides
  - interacts with its environment through well-defined interfaces
- A component has no persistent state
  - temporary state set only through well-defined interfaces
  - throw away that dependence on global data (common blocks)
- Similar to Java packages and Fortran 90 modules (with a little help)

Component Technology

- What is a component?

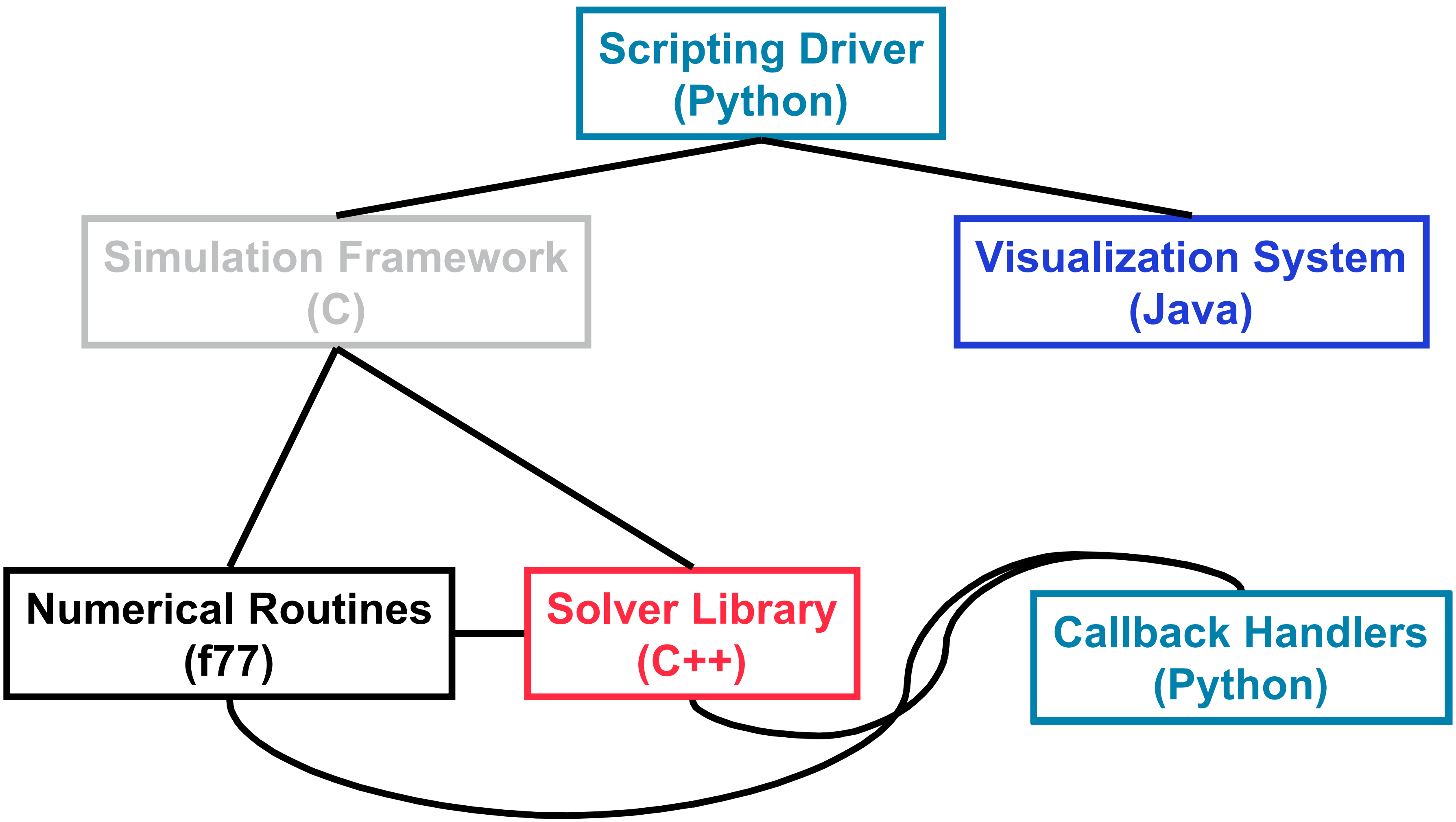


  - Implementation provides functionality buts hides details
    - No direct access is possible
  - Interface provides access to component functionality
    - Access "ports" are well-defined and generated by tools
  - Matching connector links component interfaces
    - Constructed by framework and hidden from users

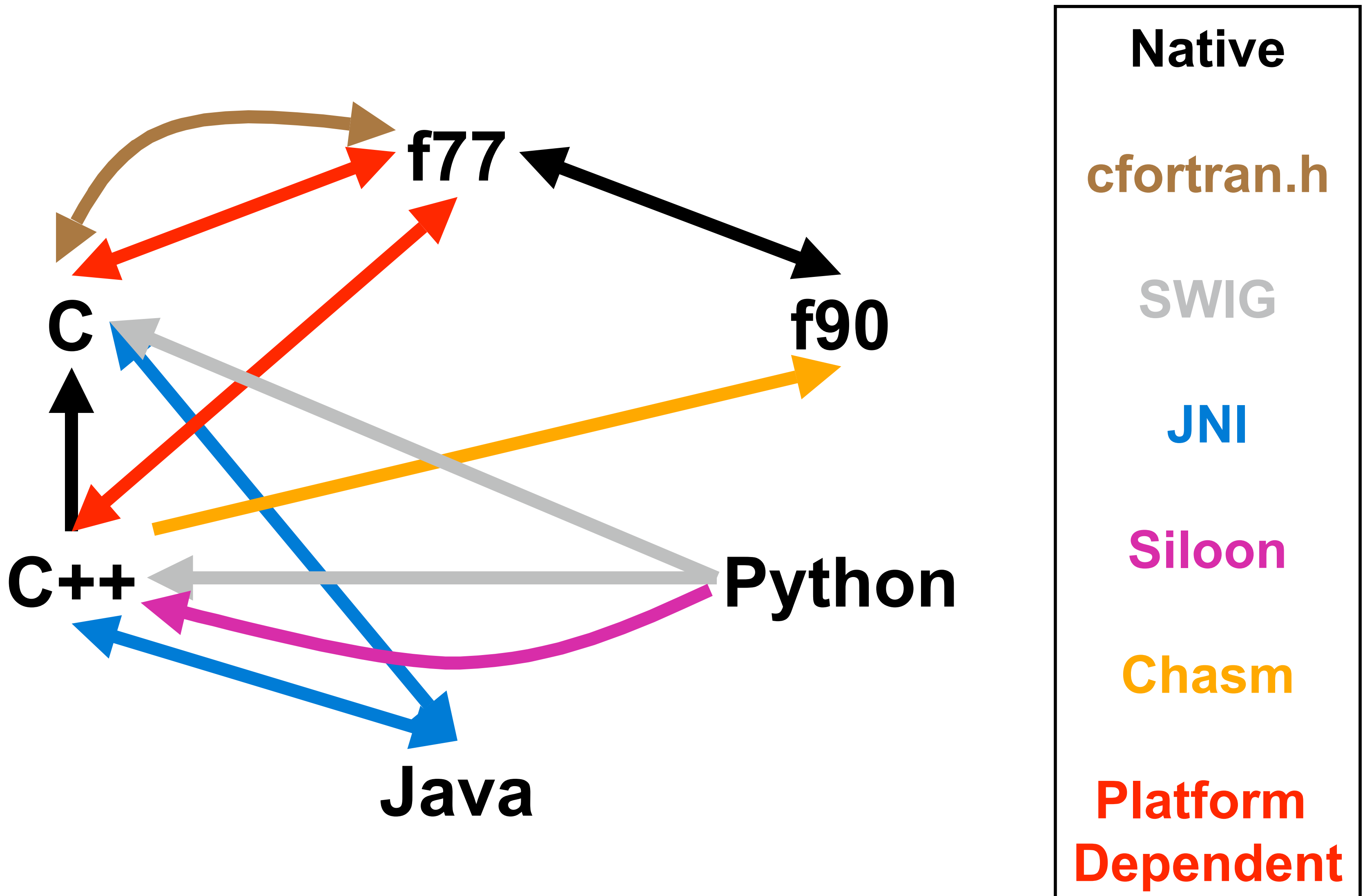
Component Technology Features

- Interoperability across multiple languages
  - Language independent interfaces (C/C++, Fortran, Java,…)
  - Automatically generated bindings to working code
- Interoperability across multiple platforms
  - Computer systems hardware independence
  - Operating systems independence
- Transparent execution model
  - Serial, parallel, and distributed system
- Incremental evolution of application software
- Components promote software reuse
- Components are “plug-and-play”

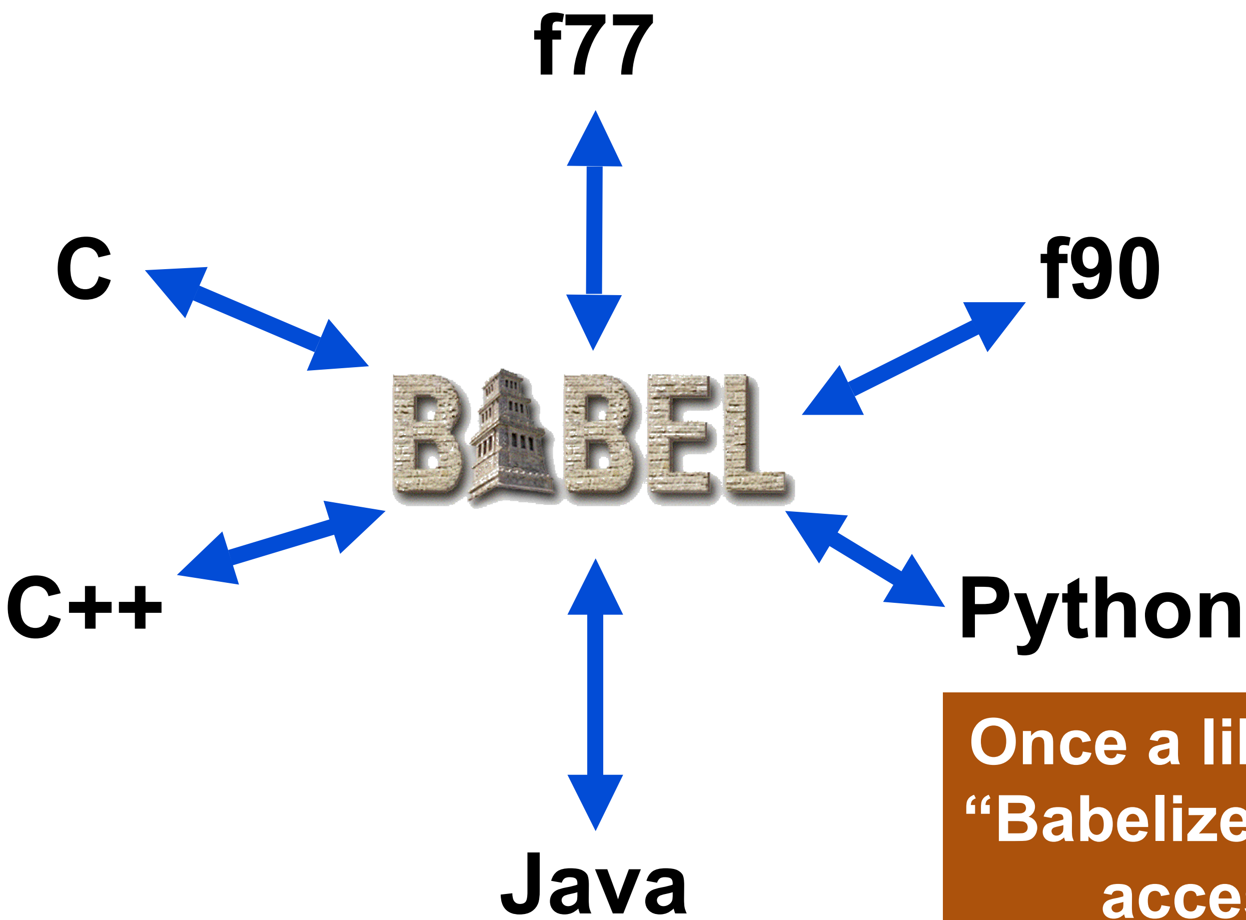
Language Interoperability



Mixing Languages is Hard!



Babel makes all supported languages peers

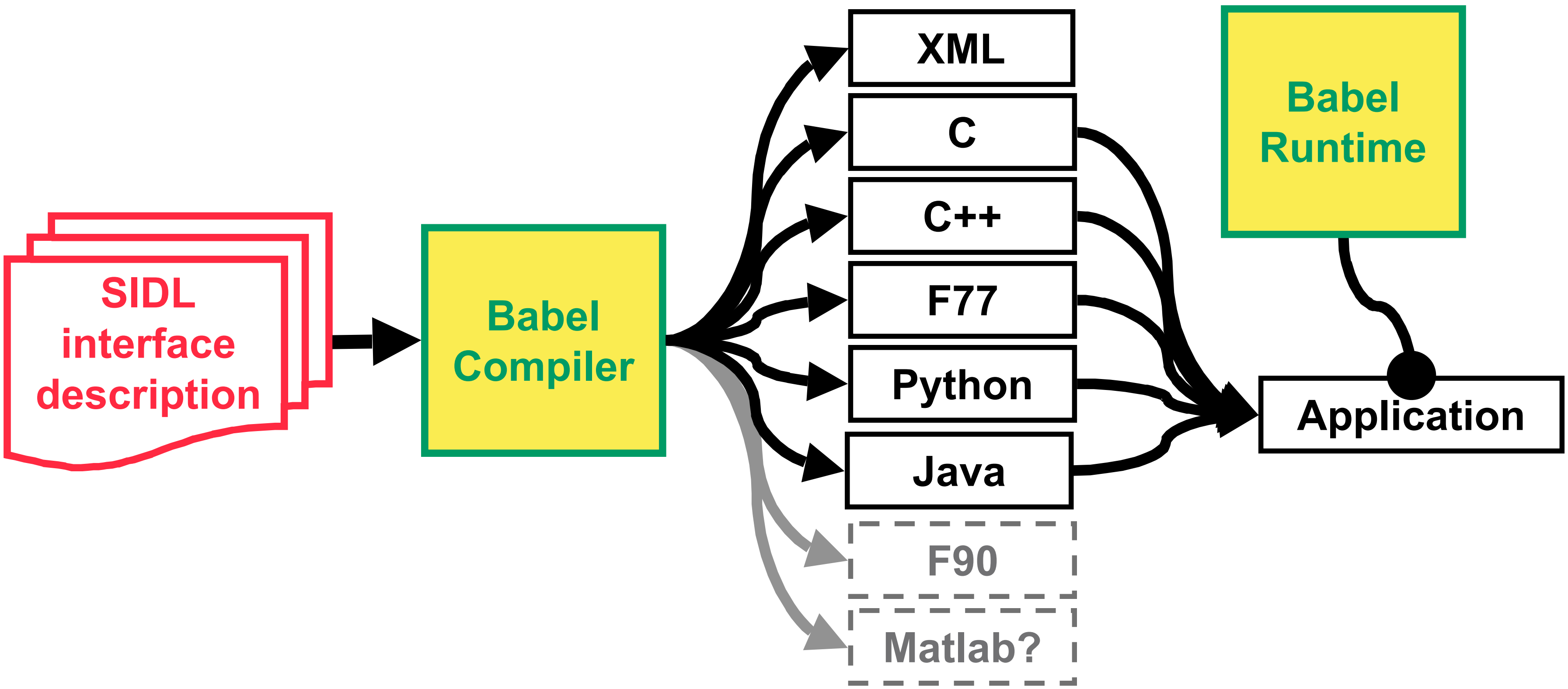


This is not an LCD Solution!

Once a library has been "Babelized" it is equally accessable from all supported languages

Babel's Mechanism for Mixing Languages

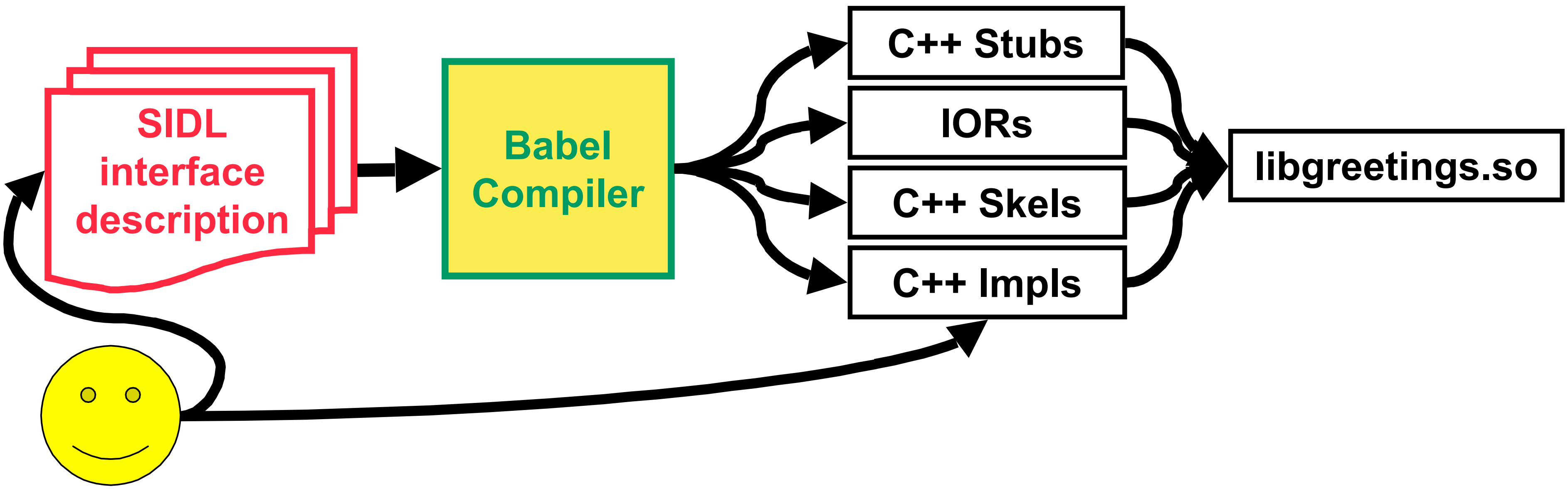
- Code Generator
- Runtime Library



greetings.sidl: A Sample SIDL File

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

Library Developer Does This...



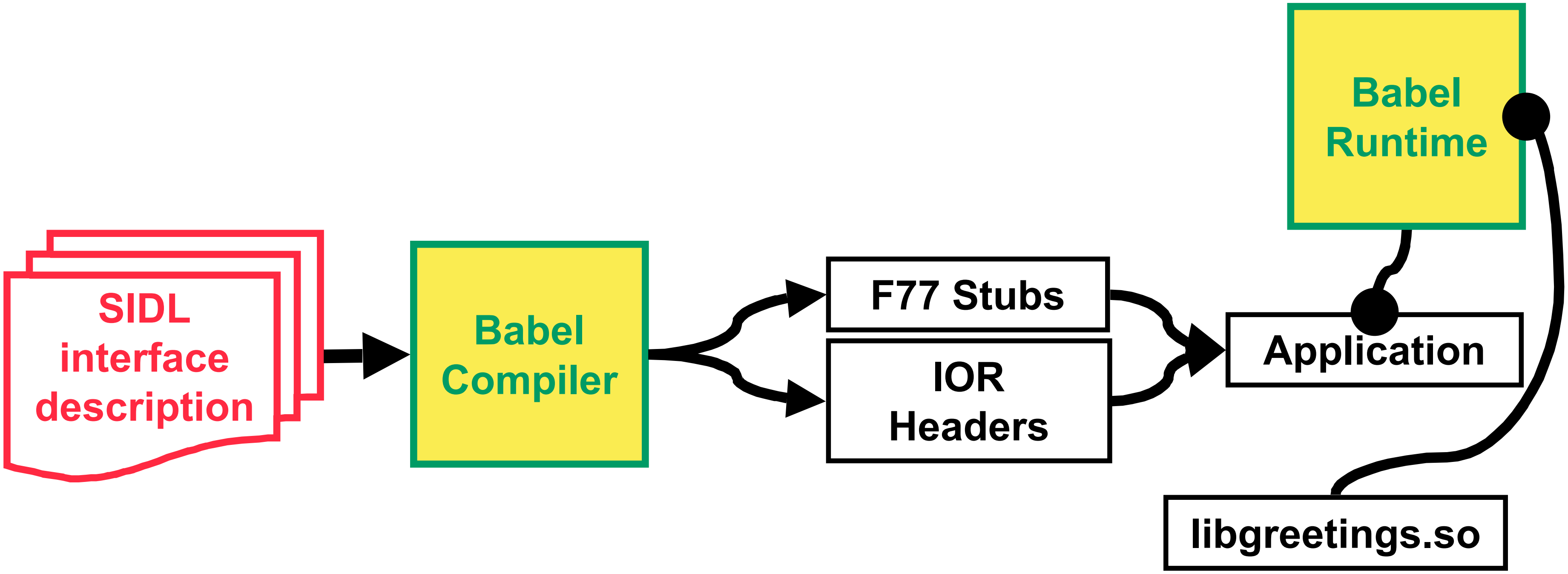
- `babel --server=C++ greetings.sidl`
- Add implementation details
- Compile & Link into Library/DLL

Adding the Implementation

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

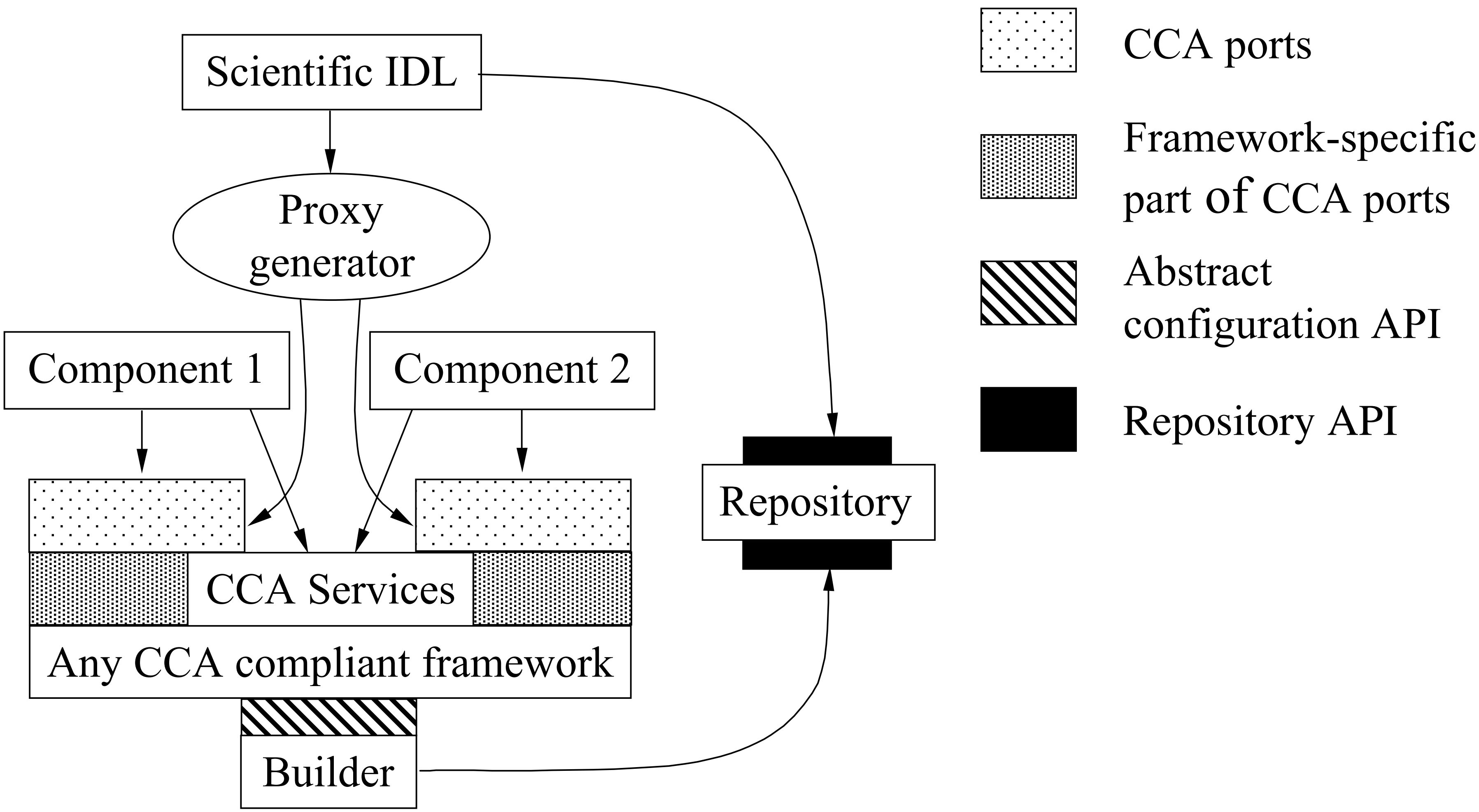
```
string
greetings::English_impl::sayIt()
throw ()
{
  // DO-NOT-DELETE splicer.begin(greetings.English.sayIt)
  string msg("Hello ");
  return msg + d_name + "!";
  // DO-NOT-DELETE splicer.end(greetings.English.sayIt)
}
```

Library User Does This...



- `babel --client=F77 greetings.sidl`
- Compile & Link generated Code & Runtime
- Place DLL in suitable location

Common Component Architecture Specification



CCA Concepts: Ports

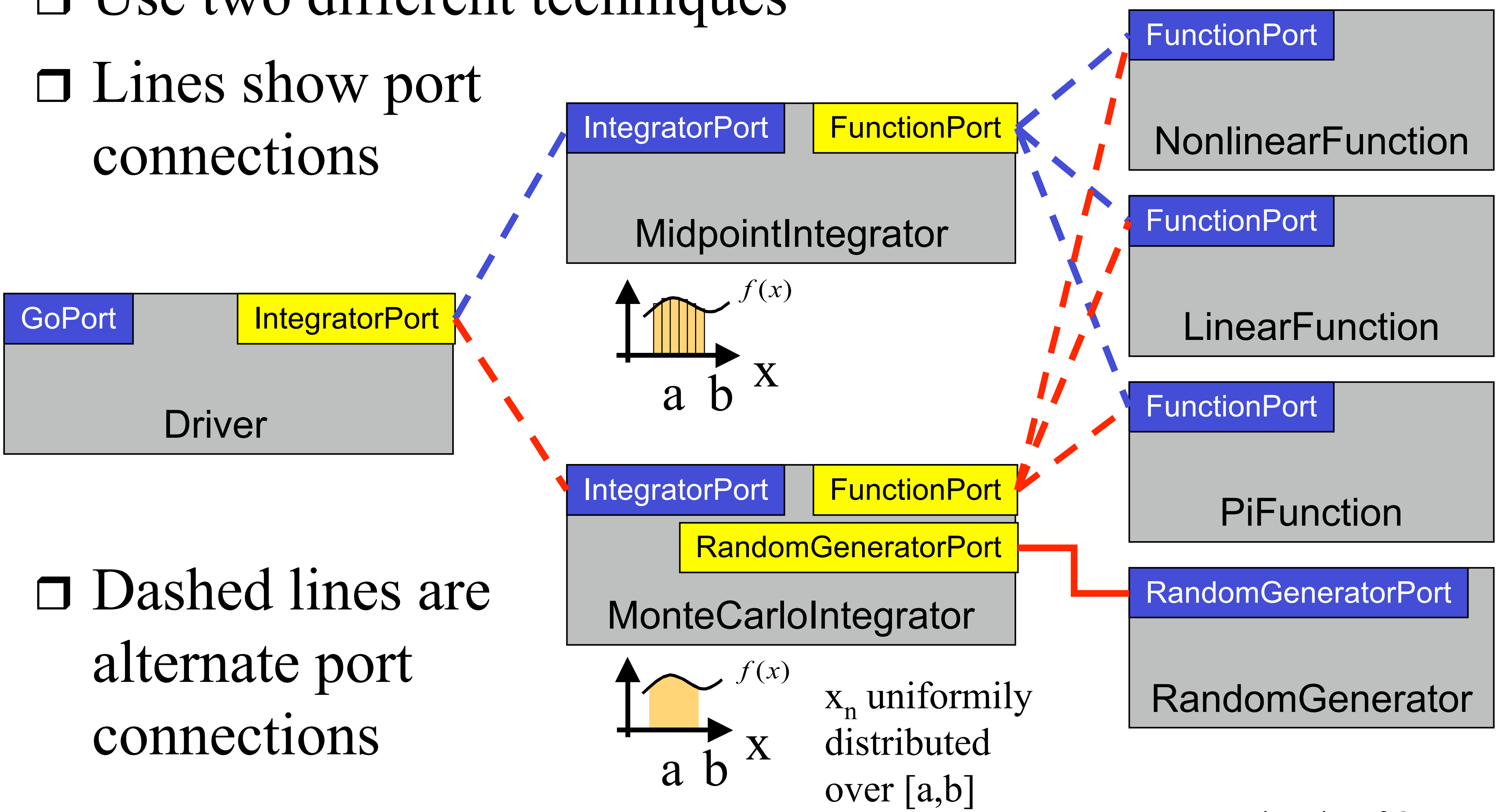
- Designing for interoperability and reuse requires "standard" interfaces
- *Ports* define how components interact
  - Through well-defined interfaces (ports)
  - In OO languages, a port is a class or interface
  - In Fortran, a port is a set of subroutines or a module
- Components may *provide* ports
  - Implement the class or subroutines of the port
- Components may *use* ports
  - Call methods or subroutines in the port
- Links denote a caller/callee relationship

CCA Concepts: Frameworks

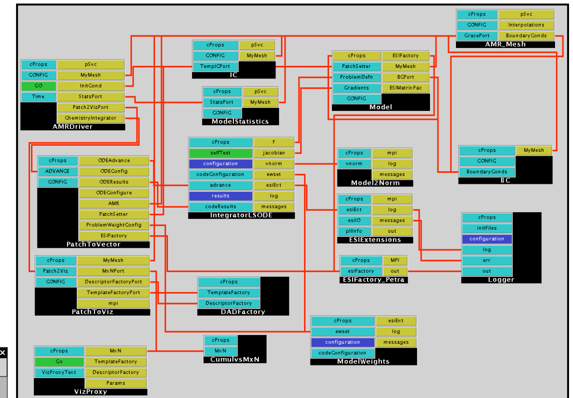
- Provides the means to "hold" components and compose them into applications
- Allow exchange of ports among components without exposing implementation details
- Provide a small set of standard *services* to components
  - Builder services allow programs to compose CCA apps
- Frameworks may make themselves appear as components in order to connect to components in other frameworks
- Specific frameworks support specific computing models

CCA Example

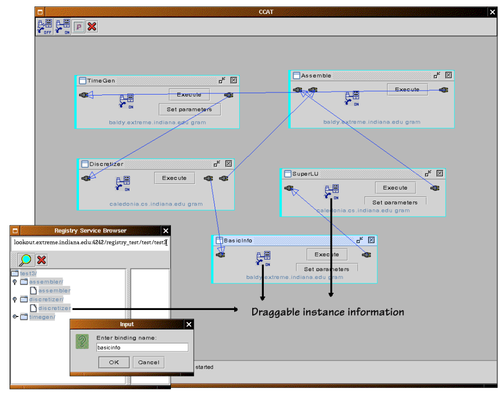
- Numerically integrate a continuous function
- Use two different techniques
- Lines show port connections
- Dashed lines are alternate port connections



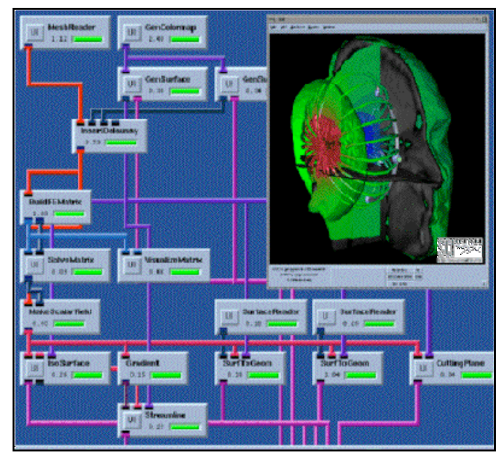
CCA Framework Prototypes



- CCAFFEINE
  - SPMD/SCMD parallel, direct connect
  - Direct connection
- CCAT / XCAT



  - Distributed network
  - Grid Web services
- SCIRun

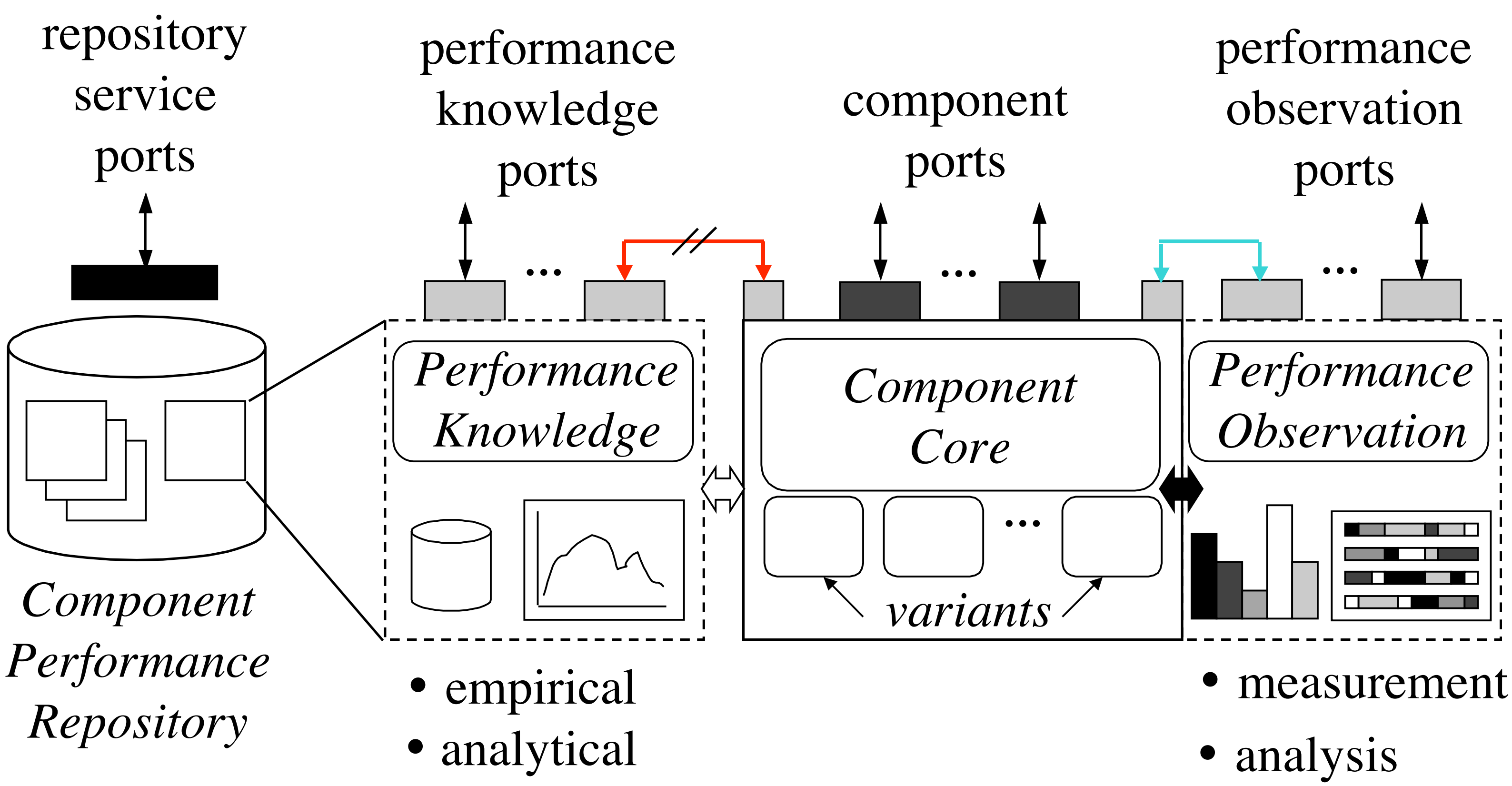


  - Parallel, multithreaded, direct connect
- Decaf
  - Language interoperability via Babel
- Legion (under development)

Performance-Engineered Component Software

- Intra- and Inter-component performance engineering
- Four general parts:
  - Performance observation
    - integrated measurement and analysis
  - Performance query and monitoring
    - runtime access to performance information
  - Performance control
    - mechanisms to alter performance observation
  - Performance knowledge
    - characterization and modeling
- Consistent with component architecture / implementation

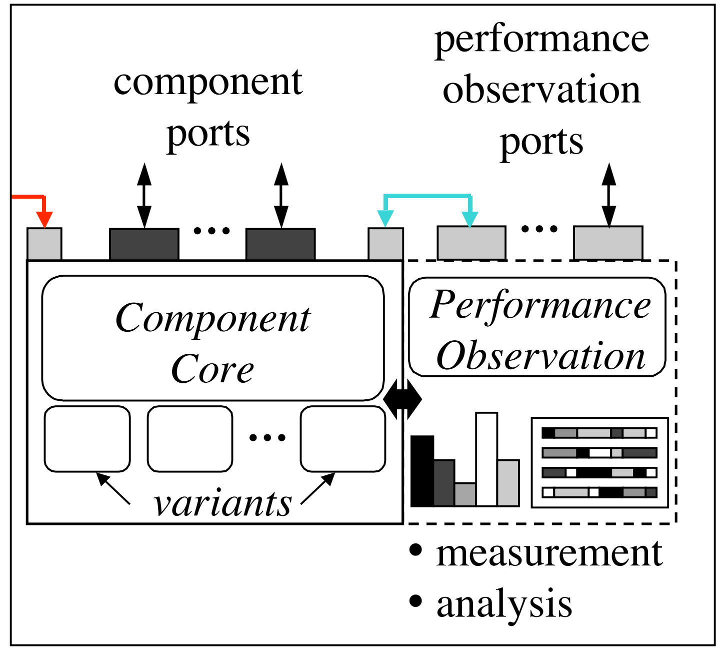
Main Idea: Extend Component Design



- Extend the programming and execution environment to be *performance observable* and *performance aware*

Performance Observation and Component

- Performance measurement integration in component form
- Functional extension of original component design (⬌)
  - Include new component methods and ports (↕) for other components to access measured performance data
  - Allow original component to access performance data
    - Encapsulate as tightly-coupled and co-resident performance observation object
    - POC "provides" port allow use of optimized interfaces (⮣) to access ``internal" performance observations

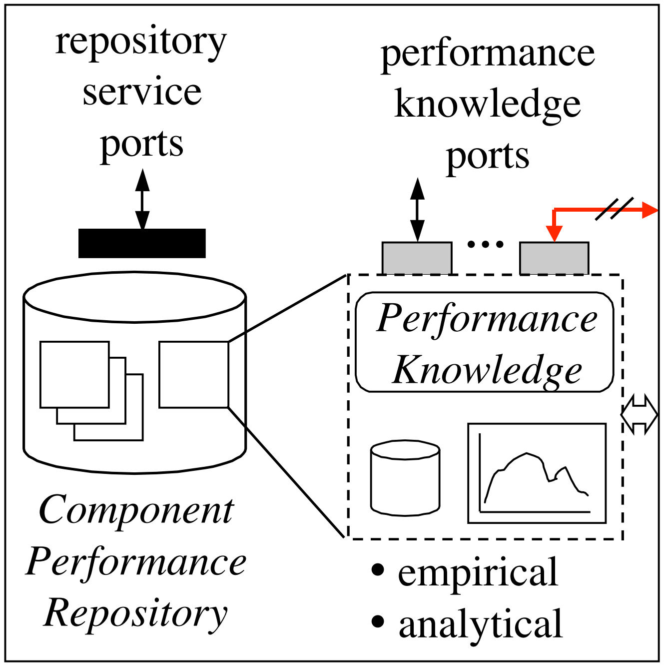


Performance Knowledge

- Describe and store "known" component performance
  - Benchmark characterizations in performance database
  - Empirical or analytical performance models
- Saved information about component performance
  - Use for performance-guided selection and deployment
  - Use for runtime adaptation
- Representation must be in common forms with standard means for accessing the performance information
  - Compatible with component architecture

Component Performance Repository

- Performance knowledge storage
  - Implement in component architecture framework
  - Similar to CCA component repository
  - Access by component infrastructure



- View performance knowledge as component (PKC)
  - PKC ports give access to performance knowledge
  - ↕ to other components, ↱ back to original component
  - Static/dynamic component control and composition
  - Component composition performance knowledge

Performance Engineering Support in CCA

- Define a standard observation component interface for:
  - Performance measurement
  - Performance data query
  - Performance control (enable/disable)
- Implement performance interfaces for use in CCA
  - TAU performance system
  - CCA component frameworks (CCAFFEINE, SIDL/Babel)
- Demonstrations
  - Optimizing component
    - picks from a set of equivalent CCA port implementations
  - Flame reaction-diffusion application

CCA Performance Observation Component

- Design measurement port and measurement interfaces
  - Timer
    - start/stop
    - set name/type/group
  - Control
    - enable/disable groups
  - Query
    - get timer names
    - metrics, counters, dump to disk
  - Event
    - user-defined events

CCA C++ (CCAFFEINE) Performance Interface

```
namespace performance {
 namespace ccaports {
  class Measurement: public virtual classic::gov::cca::Port {
   public:
    virtual ~ Measurement (){}

    /* Create a Timer interface */
    virtual performance::Timer* createTimer(void) = 0;
    virtual performance::Timer* createTimer(string name) = 0;
    virtual performance::Timer* createTimer(string name, string type) = 0;
    virtual performance::Timer* createTimer(string name, string type,
         string group) = 0;

    /* Create a Query interface */
    virtual performance::Query* createQuery(void) = 0;

    /* Create a user-defined Event interface */
    virtual performance::Event* createEvent(void) = 0;
    virtual performance::Event* createEvent(string name) = 0;

    /* Create a Control interface for selectively enabling and disabling
     * the instrumentation based on groups */
    virtual performance::Control* createControl(void) = 0;
  };
 }
}
```

Measurement port

Measurement interfaces

CCA Timer Interface Declaration

```
namespace performance {
 class Timer {
  public:
   virtual ~Timer() {}

   /* Implement methods in a derived class to provide functionality */

   /* Start and stop the Timer */
   virtual void start(void) = 0;
   virtual void stop(void) = 0;

   /* Set name and type for Timer */
   virtual void setName(string name) = 0;
   virtual string getName(void) = 0;
   virtual void setType(string name) = 0;
   virtual string getType(void) = 0;

   /* Set the group name and group type associated with the Timer */
   virtual void setGroupName(string name) = 0;
   virtual string getGroupName(void) = 0;
   virtual void setGroupId(unsigned long group ) = 0;
   virtual unsigned long getGroupId(void) = 0;
 };
}
```

Timer interface methods

Use of Observation Component in CCA Example

```
#include "ports/Measurement_CCA.h"
...
double MonteCarloIntegrator::integrate(double lowBound, double upBound,
                                        int count) {
  classic::gov::cca::Port * port;
  double sum = 0.0;
  // Get Measurement port
  port = frameworkServices->getPort ("MeasurementPort");
  if (port)
    measurement_m = dynamic_cast < performance::ccaports::Measurement * >(port);
  if (measurement_m == 0){
    cerr << "Connected to something other than a Measurement port";
    return -1;
  }
  static performance::Timer* t = measurement_m->createTimer(
                                      string("IntegrateTimer"));
  t->start();
  for (int i = 0; i < count; i++) {
     double x = random_m->getRandomNumber ();
     sum = sum + function_m->evaluate (x);
  }
  t->stop();
}
```

Using TAU Component in CCAFEINE

```
repository get TauTimer
repository get Driver
repository get MidpointIntegrator
repository get MonteCarloIntegrator
repository get RandomGenerator
repository get LinearFunction
repository get NonlinearFunction
repository get PiFunction

create LinearFunction lin_func
create NonlinearFunction nonlin_func
create PiFunction pi_func
create MonteCarloIntegrator mc_integrator
create RandomGenerator rand

create TauTimer tau
connect mc_integrator RandomGeneratorPort rand RandomGeneratorPort
connect mc_integrator FunctionPort nonlin_func FunctionPort
connect mc_integrator TimerPort tau TimerPort
create Driver driver
connect driver IntegratorPort mc_integrator IntegratorPort
go driver Go
quit
```

SIDL Interface for Performance Component

```
version performance 1.0;
package performance
{
  interface Timer
  { /* Start/stop the Timer */
    void start();
    void stop();

    /* Set/get the Timer name */
    void setName(in string name);
    string getName();

    /* Set/get Timer type information (e.g., signature of the routine) */
    void setType(in string name);
    string getType();

    /* Set/get the group name associated with the Timer */
    void setGroupName(in string name);
    string getGroupName();

    /* Set/get the group id associated with the Timer */
    void setGroupId(in long group);
    long getGroupId();
  }   …
```

SIDL Interface : Control

```
interface Control
  { /* Enable/disable group id */
    void enableGroupId(in long id);
    void disableGroupId(in long id);

    /* Enable/disable group name */
    void enableGroupName(in string name);
    void disableGroupName(in string name);

    /* Enable/disable all groups */
    void enableAllGroups();
    void disableAllGroups();
  }
/* Implementation of performance component Control interface*/
  class TauControl implements-all Control
  {
  }

  /* Implementation of performance component Measurement interface*/
  class TauMeasurement implements-all Measurement, gov.cca.Component
  {
  }
```

SIDL Interface : Query

```
/* Query interface to obtain timing information */
  interface Query
  { /* Get the list of Timer and Counter names */
    array<string> getTimerNames();
    array<string> getCounterNames();
    void getTimerData(in array<string> timerList,
      out array<double, 2> counterExclusive,
      out array<double, 2> counterInclusive, out array<int> numCalls,
      out array<int> numChildCalls, out array<string> counterNames,
      out int numCounters);
 /* Writes instantaneous profile to disk in a dump file. */
    void dumpProfileData();
 /* Writes the instantaneous profile to disk in a dump file whose name
     * contains the current timestamp. */
    void dumpProfileDataIncremental();

    /* Writes the list of timer names to a dump file on the disk */
    void dumpTimerNames();
    /* Writes the profile of the given set of timers to the disk. */
    void dumpTimerData(in array<string> timerList);

    /* Writes the profile of the given set of timers to the disk. The dump
     * file name contains the current timestamp when the data was dumped. */
    void dumpTimerDataIncremental(in array<string> timerList); }
```

SIDL Interface :Event

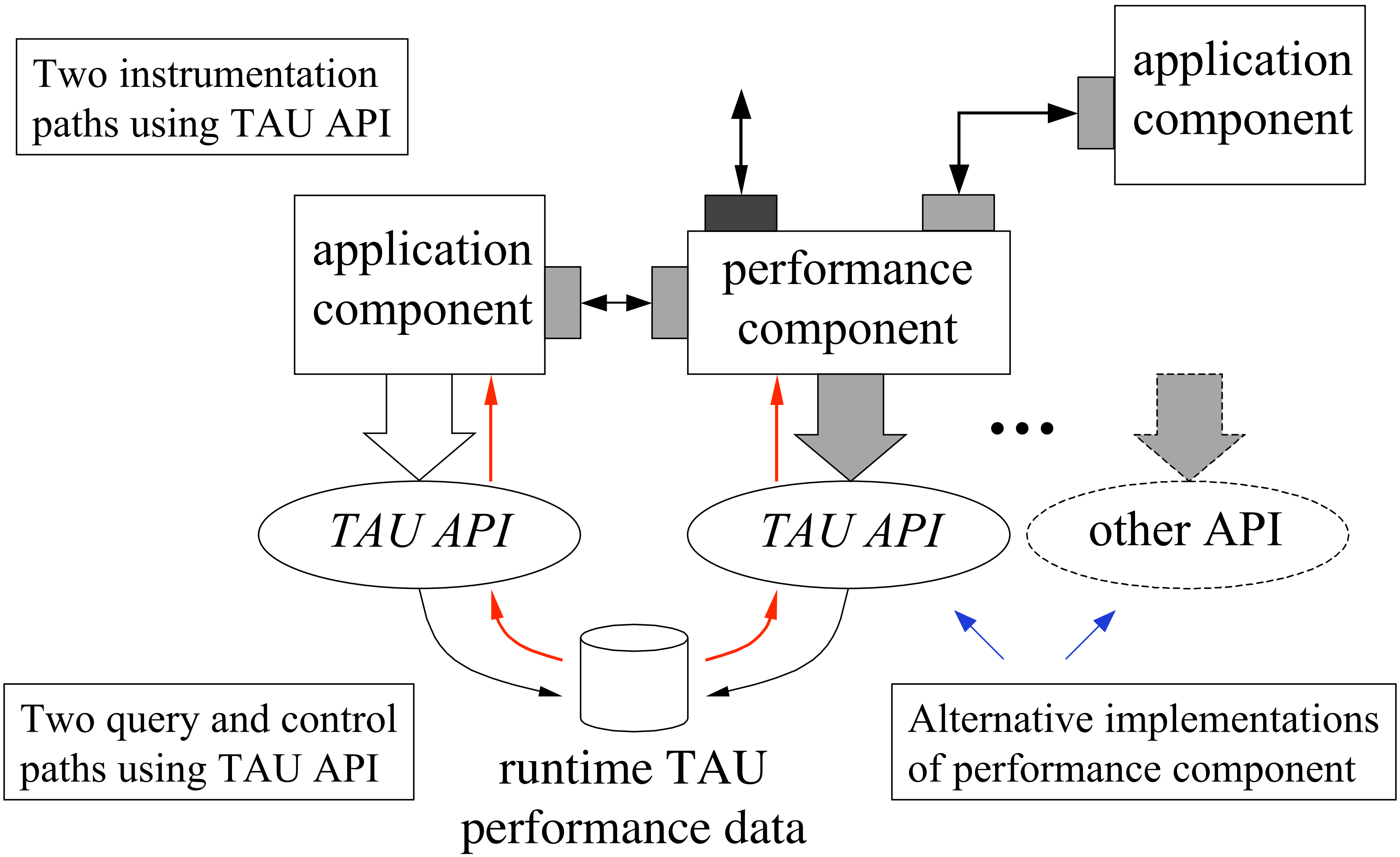
```
/* User defined event profiles for application specific events */
 interface Event
 { /* Set the name of the event */
   void setName(in string name);

   /* Trigger the event */
   void trigger(in double data);
 }
```

Measurement Port Implementation

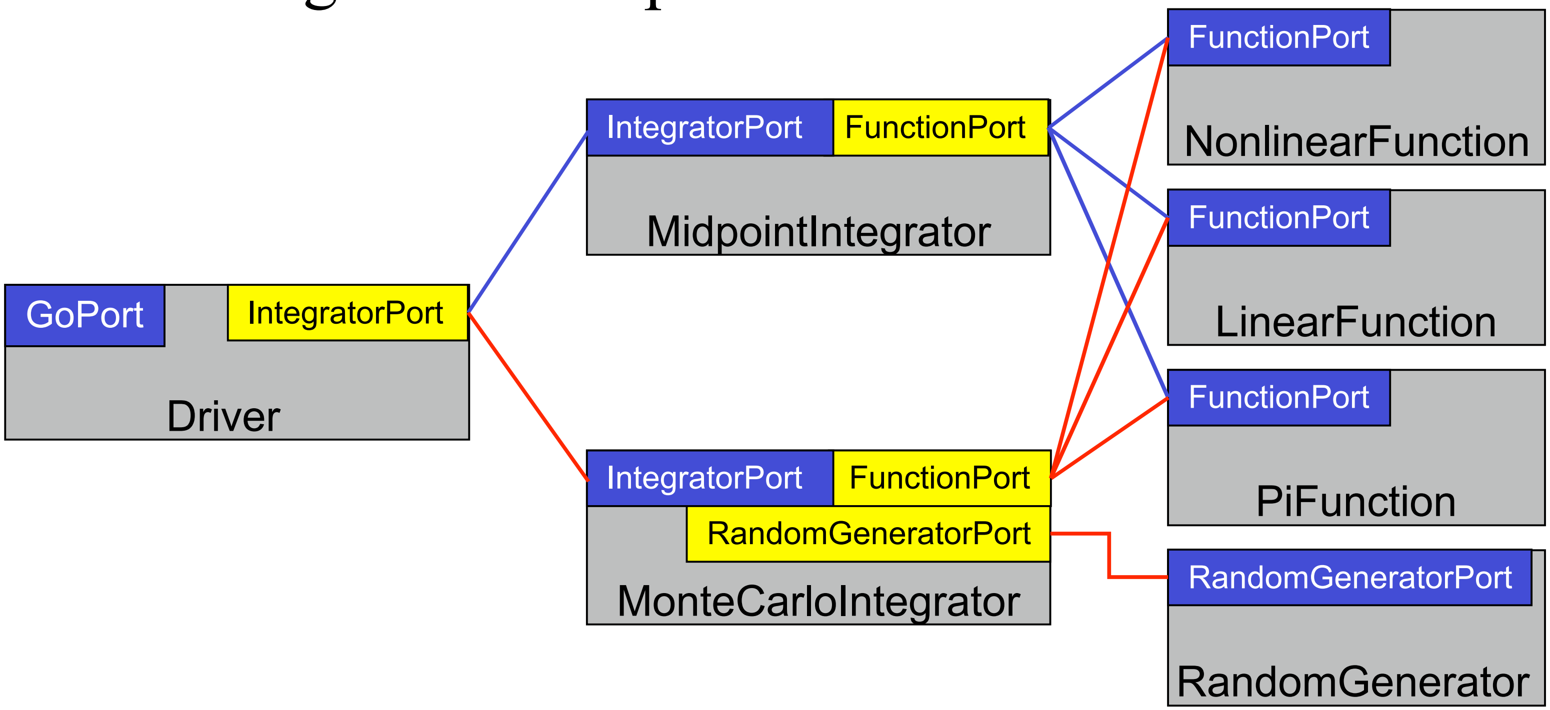
- Use of `Measurement` port (i.e., instrumentation)
  - independent of choice of measurement tool
  - independent of choice of measurement type
- TAU performance observability component
  - Implements the `Measurement` port
  - Implements `Timer`, `Control`, `Query`, `Control`
  - Port can be registered with the CCAFEINE framework
- Components instrument to generic `Measurement` port
  - Runtime selection of TAU component during execution
  - `TauMeasurement_CCA` port implementation uses a specific TAU library for choice of measurement type

What's Going On Here?

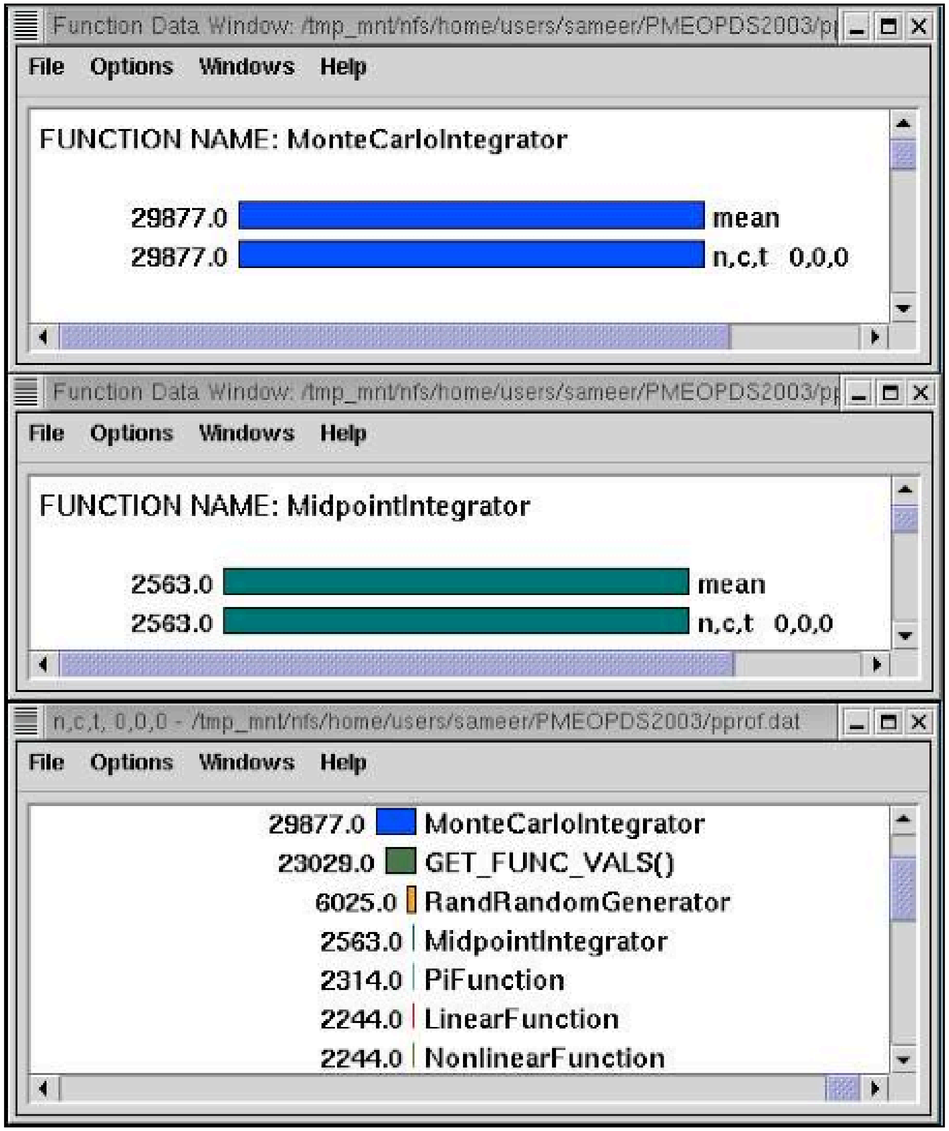


Simple Runtime Performance Optimization

- Components are "plug-and-play"
  - One can choose from a set of equivalent port implementations based on performance measurements
  - An outside agent can monitor and select an optimal working set of components



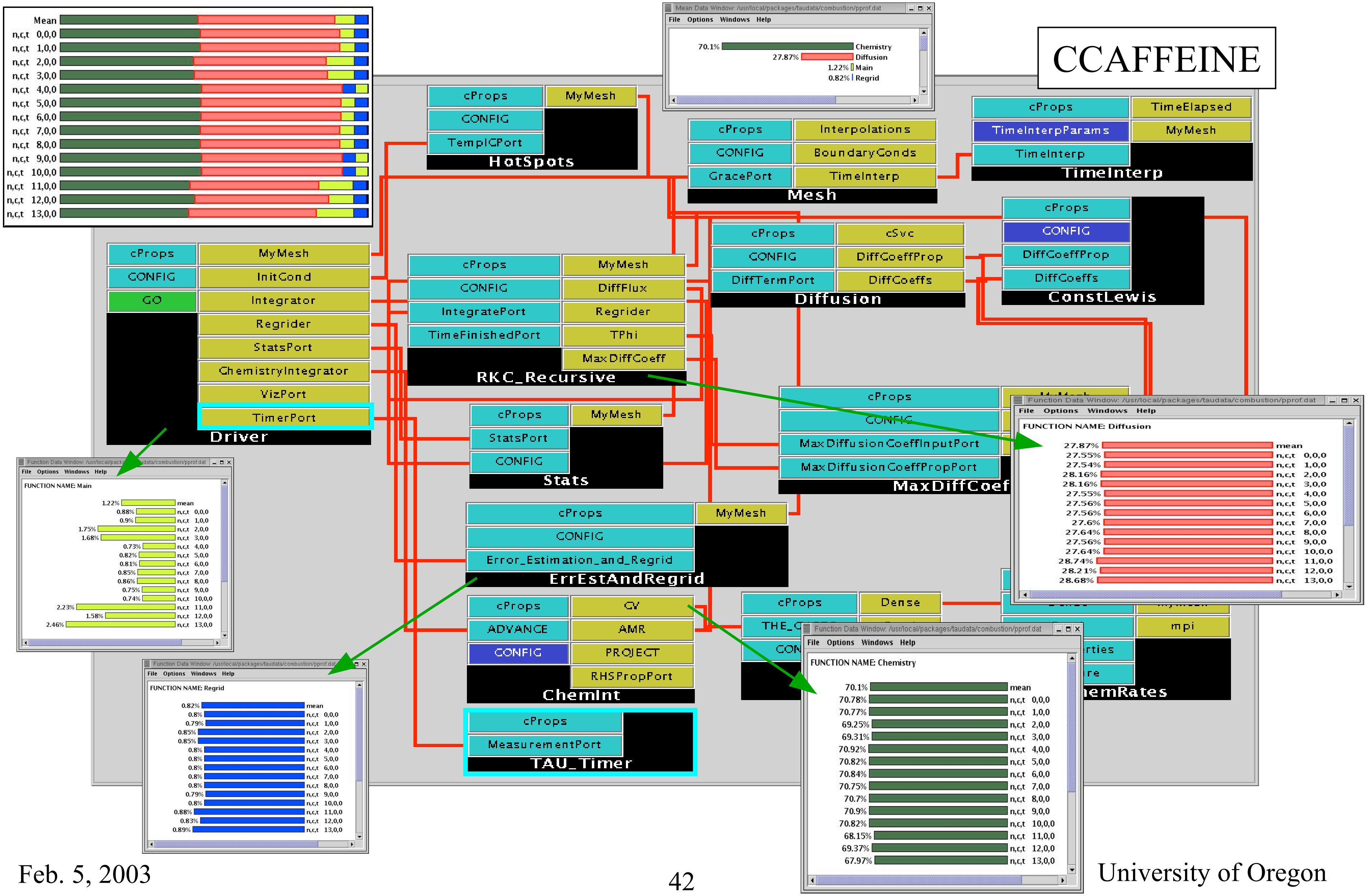
Component Optimizing Performance Results



Computational Facility for Reacting Flow Science

- Sandia National Laboratory
  - DOE SciDAC project (http://cfrfs.ca.sandia.gov)
  - Jaideep Ray
- Component-based simulation and analysis
  - Sandia's CCAFFEINE framework
  - Toolkit components for assembling flame simulation
    - integrator, spatial discretizations, chemical/transport models
    - structured adaptive mesh, load-balancers, error-estimators
    - in-core, off-machine, data transfers for post-processing
  - Components are C++ and wrapped F77 and C code
- Kernel for 3D, adaptive mesh low Mach flame simulation

Flame Reaction-Diffusion Demonstration



Meeting CCA Performance Engineering Goals?

- Language interoperability?
  - SIDL and Babel give access to all supported languages
  - TAU supports multi-language instrumentation
  - Component interface instrumentation automated with PDT
- Platform interoperability?
  - Implement observability component across platforms
  - TAU runs wherever CCA runs
- Execution model transparent?
  - TAU measurement support for multiple execution models
- Reuse with any CCA-compliant framework?
  - Demonstrated with SIDL/Babel, CCAFEINE, SCIRun

Importance to Grid Computing and Performance

- Component software is a natural model for developing applications for the Grid
  - ICENI (Imperial College), CCAT / XCAT (U. Indiana)
- Our work leverages abstraction power of CCA as well as the infrastructure of CCA frameworks
  - Similarly leverage Grid infrastructure and services
  - Mostly riding back of CCA framework development
- Application-level performance view coupled with Grid resource assessment and monitoring
  - More responsive to performance dynamics
  - Beginning work with NWS forecaster in applications

Meeting CCA Performance Engineering Goals?

- Component performance knowledge?
  - Representation and performance repository work to do
  - Utilize effectively for deployment and steering
  - Build repository with TAU performance database
- Performance of component compositions?
  - Component-to-component performance
    - Per connection instrumentation and measurement
    - Utilize performance mapping support
  - Ensemble-wide performance monitoring
    - connect performance “producers” to “consumers”
    - component-style implementation

Concluding Remarks

- Parallel component systems pose challenging performance analysis problems that require robust methodologies and tools
- New performance problems will arise
  - Instrumentation and measurement
  - Data analysis and presentation
  - Diagnosis and tuning
  - Performance modeling
- Performance engineered components
  - Performance knowledge, observation, query and control
- Available from:

http://www.cs.uoregon.edu/research/paracomp/tau/tauprofile/dist/taucomponent.tar.gz

Support Acknowledgement

- TAU and PDT support:
  - Department of Energy (DOE)
    - DOE 2000 ACTS contract
    - DOE MICS contract
    - DOE ASCI Level 3 (LANL, LLNL)
    - U. of Utah DOE ASCI Level 1 subcontract
  - DARPA
  - NSF National Young Investigator (NYI) award