Combining computer algebra systems with **S**ymbolic **C**omputation **S**oftware **C**omposability **P**rotocol

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Third RISC/SCIEnce Training School in Symbolic Computation, Linz, 18 July 2008

*Supported by the EU FP6 project "**SCIEnce** – **S**ymbolic **C**omputation **I**nfrastructure for **E**urope"*

Acknowledgements

Thanks to:

- SCIEnce and *SCIEnce*tists, and especially to Temur Kutsia and John McDermott

The subject of the talk

Infrastructure for distributed symbolic computation:

- Underlying protocol: SCSCP
- Encoding for mathematical objects: OpenMath standard
- SCSCP implementation in GAP
- You should expect similar things to appear in any SCSCP-compliant system
- I will speak more about providing SCSCP services (a kind of web services), and small-scale parallelization, while the subsequent talks by Abyd Al Zain will introduce middleware for symbolic grids

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Modern needs of symbolic computation community

- Efficient tools for combining different computational algebra systems to solve complex problems that require capabilities not available in any single system
- Web services client and server interfaces allowing deployment of computer algebra systems as Web services and local/remote calls of facilities of another system in easy and efficient way
- This may be used to combine several copies of the same system in a parallel computing context of various scales from multicore to grids

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Most common restrictions from our GAP experience

- interfaces do not support remote communication
- transmission of large or complex objects may be difficult
- Support of new system requires new I/O convertor. It relies upon the I/O format, may be subject to parsing errors and needs update if I/O format of the linked system changes
- not enough deeply (syntax, cd) and widely (other CAS) supported data encoding format (*OpenMath*)
- not interactive, just database access (Web services)
- not enough robust (*ParGAP*)
- less efficient for irregular parallel computing (*ParGAP*)
- shaped to deal with the particular problem (*dc*)
- may not work in some operating systems
- may be not easy customisable by the end-user

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Our main directions of work

- Software composability:
  - A programme of standards developments and implementations for symbolic computation software to use Web services and OpenMath technologies, allowing them to be efficiently composed to solve complex problems
- Symbolic computing on the Grid:
  - developing common standards and middleware to allow the production of Grid-enabled symbolic computation systems
  - constructing research prototypes supporting appropriate security, scheduling, and resource broking for complex symbolic computing applications on computational Grids

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Common protocol for communication

In the direction of the software composability, on the first step we designed the *Symbolic Computation Software Composibility Protocol* (**SCSCP**) by which a computer algebra system (CAS) may offer services for the following clients:

- Another instance of the same CAS (in a parallel computing context or on different architectures)
- Another CAS running on the same computer or remotely
- A Web server which passes on the same services as Web services using SOAP/HTTP protocols to another clients
- Grid middleware

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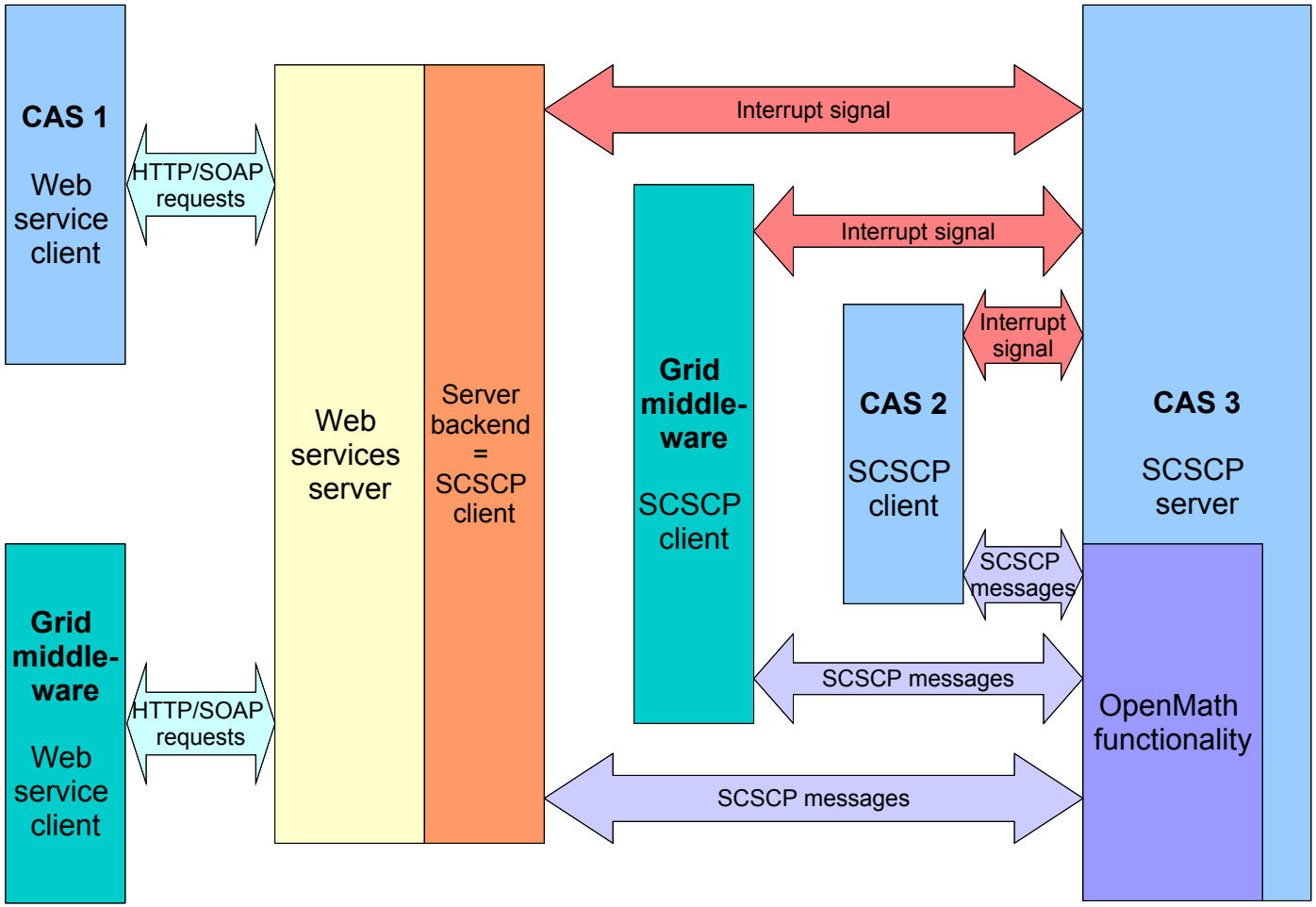
Current vision of SCSCP usage



What is OpenMath?

- standard for representing mathematical objects with their semantics
- the current OpenMath Standard 2.0 is dated June 2004
- the worldwide OpenMath activities are coordinated within the OpenMath Society, based in Helsinki
- the idea is to allow their exchange between various programs, storing in databases, publishing on web . . .
- two encodings: XML and binary format

What is OpenMath?

- basic objects: integers, floats, strings, byte arrays, variables, symbols
- symbols consist of a name and a reference to a definition in an external document called *content dictionary* (**CD)**
- OpenMath objects can be combined recursively in a number of ways: application, attribution, binding, error
- support of various symbols may be different in various CASs, it may be complete (encoding and decoding) or only in one of these ways
- let us look at some examples in GAP
- see `http://www.openmath.org` for further details
- if you need support of existing symbols or interested in creating new CD - please contact us!

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SCSCP: OpenMath inside

- Protocol messages represented as OpenMath objects
- Content Dictionaries **scscp1**, **scscp2** developed for this purpose
- **SCSCP** specification defines semantical and technical descriptions and allowed sequences of OpenMath-encoded messages to and from CAS:
  - remote procedure call
  - returning result of successfully completed procedure
  - returning a signal about procedure termination
- Both transmission of actual mathematical objects and references to them are supported
- Flexibility: service designer can choose the data to be `OMSTR`, `OMB`, `OMFOREIGN`, containing information in some other format, even including MathML encoding

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scscp1 CD defines:

- three main kinds of messages: `procedure_call`, `procedure_completed`, `procedure_terminated`
- options that may be added to the `procedure_call` message: `option_runtime`, `option_debuglevel`, `option_min_memory`, `option_max_memory`, `option_return_object`, `option_return_cookie`
- information that may be supplied with the result: `info_runtime`, `info_memory`
- standard errors: `error_runtime`, `error_memory`, `error_system_specific`

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scscp2 CD defines:

- procedures for remote objects: `store`, `retrieve`, `unbind`
- special procedures: `get_allowed_heads`, `get_transient_cd`, `get_signature`, `get_service_description`,
- special symbols: `signature`, `service_description`, `symbol_set`, `symbol_set_all`, `no_such_transient_cd`

GAP implementation of the SCSCP

- GAP Package SCSCP (in development):
  `http://www.cs.st-andrews.ac.uk/~alexk/scscp.htm`
- Allows GAP to work as an SCSCP server and client
- Uses GAP packages IO, GAPDoc and OpenMath.dev
- Needs functionality for the exception and error handling in GAP.dev added by Steve Linton (will appear in GAP 4.5)
- We may provide on demand a client's version for GAP 4.4.10, which works in Linux, Windows and Mac OS
- Communication goes via TCP/IP protocol
- Handling OpenMath encoding, including:
  - new symbols from scscp1 and scscp2 OM CDs
  - support of OM attributes (OMATTR, OMATP)
  - support of OM references (OMR)

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User-level functionality:

- Installing procedures available as SCSCP services
- Running the SCSCP server
- Sending request to the server and getting result
- Store/Retrieve procedures allowing to work with remote objects
- InputOutputTCPStreams, compatible with other kinds of streams in GAP
- The underlying technology is well-hidden: we allow the end user to know nothing about OpenMath and SCSCP !!!

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Configuring SCSCP GAP server

1. Specify in `gap4r4/pkg/scscp/config.g`:
   - default InfoLevel, host name and port number
2. Put all what you need in the configuration file (see example in `gap4r4/pkg/scscp/tst/myserver.g`), including:
   - loading all necessary packages
   - other required GAP code or its reading from other file(s)
   - installation of SCSCP procedures using
     ```
     InstallSCSCPprocedure("NameForClient",
     InternalName );
     ```
   - starting the server with the command
     ```
     RunSCSCPserver( SCSCPserverAddress,
     SCSCPserverPort );
     ```
3. Start GAP with `gap myserver.g`

Examples of simple calls

myserver.g

```
...
FactorialAsString := x -> String(Factorial( x ) );
...
InstallSCSCPprocedure( "Factorial", Factorial );
InstallSCSCPprocedure( "WS_factorial", FactorialAsString );
...
```

GAP session

```
gap> EvaluateBySCSCP( "Factorial", [ 10 ], "localhost", 26133 );
rec( object := 3628800,
     attributes := [ [ "call_ID", "localhost:26133:27096" ] ] )

gap> EvaluateBySCSCP( "WS_factorial", [ 10 ], "localhost", 26133 );
rec( object := "3628800",
     attributes := [ [ "call_ID", "localhost:26133:27096" ] ] )
```

Group identification: three possible approaches

group $\longrightarrow$ group id

- client: GAP (slow machine? no small groups library?)
- server: fast and complete GAP installation

list of permutations $\longrightarrow$ group id

- client: CAS which "understands" permutations
- server: complete GAP installation

pcgs code (integer that encodes the group) $\longrightarrow$ group id

- client: GAP in Windows - ANUPQ package is not working :(
- server: GAP in UNIX environment - ANUPQ works :)

Three approaches (continued)

group → group id

```
InstallSCSCPprocedure( "WS_IdGroup", IdGroup );
```

list of permutations → group id

```
IdGroupByGenerators := function( permlist )
return IdGroup( Group( permlist ) );
end;

InstallSCSCPprocedure( "GroupIdentificationService", IdGroupByGenerators );
```

pcgs code (integer that encodes the group) → group id

```
IdGroup512ByCode:=function( code )
local G, H;
G := PcGroupCode( code, 512 ); # recreate the group from code
H := PcGroupFpGroup( PqStandardPresentation( G ) );
return IdStandardPresented512Group( H );
end;

InstallSCSCPprocedure( "IdGroup512ByCode", IdGroup512ByCode );
```

How it works

Before, we need an auxiliary function ...

Client's counterpart for the 3rd example

```
IdGroup512:=function( G )
local code, result;
if Size( G ) <> 512 then
  Error( "G must be a group of order 512 !!!\n" );
fi;
code := CodePcGroup( G );
result := EvaluateBySCSCP( "IdGroup512ByCode",
                           [ code ],
                          "chrystal.mcs.st-and.ac.uk",
                           26133 );
return result.object;
end;
```

Now we can see the demo!

Example: remote objects

- Objects may "live" on the server while the client has only a reference (cookie) pointing to them
- There is no need to transmit objects repeatedly over the network
- The client may be a CAS which does not have objects of that type at all
- The client may retrieve object in its default OpenMath representation (be careful about its subobjects!)
- Also, the actual object may be deleted from the server

Example: stateful SCSCP service

Let $G = \langle \sigma_1, \sigma_2, \ldots, \sigma_n \rangle$ be a permutation group. For the orbit computation, we need a service that takes an integer k and returns a set of all distinct images of k under $\sigma_1, \sigma_2, \ldots, \sigma_n$

Code for the server

```
PointImages := function( G, n )
local g;
return Set( List( GeneratorsOfGroup(G), g -> n^g ) );
end;

InstallSCSCPprocedure( "PointImages", PointImages );
```

Now we can see the demo, in which the first argument will be a remote object!

Example: remote objects

- `EvaluateBySCSCP` uses a combination of `NewProcess` and `CompleteProcess`
- These works with new objects - *processes*
- Process is associated with corresponding *InputOutputTCPStream*
- You may start process, send a request and collect the result later, doing something else in the meantime
- There are functions for:
  - processes synchronization
  - waiting until the first available result and abandoning remaining processes
- We can terminate process locally (working on remote termination)

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Parallelizing existing code with SCSCP is easy

- See example of Karatsuba multiplication for polynomials in the SCSCP package manual
- We have master-slave version of the orbit computation algorithm
- This provides a way of using several version of GAP on multi-core machines
- Nevertheless, minimizing overhead might require some more tricks (optimizing data format, better scheduling, etc.)

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Example: communicating with other software

A Java program by Dan Roozemond searches in the On-Line Encyclopedia of Integer Sequences (`http://www.research.att.com/~njas/sequences/`)

What is the meaning of the following sequence:

1, 1, 1, 2, 1, 2, 1, 5, 2, 2, 1, 5, 1, 2, 1, 14 ?

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Example: communicating with other software

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	1	1	2	1	2	1	5	2	2	1	5	1	2	1	14

This is the number of groups of orders $1, 2, \ldots, 16$

Here we obtain a record with the search result:

```
gap> EvaluateBySCSCP("OnLineEncyclopediaOfIntegerSequences",
>    [ [ 1, 1, 1, 2, 1, 2, 1, 5, 2, 2, 1, 5, 1, 2, 1, 14 ] ],
>    "localhost", 26133 );
rec( object := [ 1, "A000001: Number of groups of order n." ],
attributes := [ [ "call_ID", "0" ] ] )
```

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*SCIEnce*tific work in progress

Next goals:

- Public releases of basic SCSCP implementations
- Extending OpenMath content dictionaries with more efficient encodings
- Adding support of selected OpenMath CDs to all participating systems
- Implementing higher level interfaces in all participating systems

Please let us know about computational services in which you might be interested !!!

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What should we have in the result

- low-overhead (compensated by easy-to-use), robust, cross-platforming, light-weight and reliable protocol
- possibility of communication not only between CASs but also between CAS and other software, including Web and Grid services
- besides the four participating systems (GAP, KANT, Maple and MuPAD), we expect more systems joining SCSCP framework later

References

SCIEnce — Symbolic Computation Infrastructure for Europe, project homepage
http://www.symbolic-computation.org/

S. Freundt, P. Horn, A. Konovalov, S. Linton, D. Roozemond. *Symbolic Computation Software Composability Protocol (SCSCP) specification*, Version 1.1, 2008
http://www.symbolic-computation.org/scscp

A. Konovalov, S. Linton. *SCSCP — Symbolic Computation Software Composability Protocol*, GAP package, in development
http://www.cs.st-andrews.ac.uk/~alexk/scscp.htm

D. Roozemond. *OpenMath Content Dictionary* **scscp1**
http://www.win.tue.nl/SCIEnce/cds/scscp1.html

D. Roozemond. *OpenMath Content Dictionary* **scscp2**
http://www.win.tue.nl/SCIEnce/cds/scscp2.html