The **NCBI C++ Toolkit**

23: Distributed Computing

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Overview

The overview for this chapter consists of the following topics:

- Introduction
- Chapter Outline

Introduction

This chapter describes the NCBI GRID framework. This framework allows creating, running and maintaining a scalable, load-balanced and fault-tolerant pool of network servers (Worker Nodes).

Note: Users within NCBI may find additional information on the internal Wiki page.

Chapter Outline

The following is an outline of the topics presented in this chapter:

Getting Help

Users at NCBI have the following sources for help:

- JIRA for submitting a request or bug report. Select project C++ Toolkit and component GRID.
- Mailing lists:

    - The grid mailing list (grid@ncbi.nlm.nih.gov) for general GRID-related discussion and announcements.
    - The grid-core mailing list (grid-core@ncbi.nlm.nih.gov) for getting help using or trouble-shooting a GRID service.
- The GRID developers:
    - Dmitry Kazimirov for questions about Client-side APIs, Worker Nodes, auxiliary tools and utilities, administration - setup, installation, upgrades, and documentation.
    - Pavel Ivanov for NetCache server questions.
    - Victor Joukov for NetSchedule server questions.
    - Denis Vakatov for supervision questions.

GRID Overview

The following sections provide an overview of the GRID system:

- Purpose
- Components
- Architecture and Data Flow
- The GRID Farm

Purpose

The NCBI GRID is a framework to create, run and maintain a scalable, load-balanced and fault-tolerant pool of network servers (Worker Nodes).

It includes independent components that implement distributed data storage and job queueing. It also provides APIs and frameworks to implement worker nodes and job submitters.

Worker nodes can be written from scratch, but there are also convenience APIs and frameworks to easily create worker nodes out of existing C++ CGI code, or even from CGI or command-line scripts and executables.

There is also a GRID farm where developers can jump-start their distributed computation projects.

Two PowerPoint presentations have additional information about the NCBI GRID:

- ftp://ftp.ncbi.nih.gov/toolbox/ncbi_tools++/DOC/PPT/GRID-Dec14-2006/GRID_Dec14_2006.pps
- ftp://ftp.ncbi.nih.gov/toolbox/ncbi_tools++/DOC/PPT/NCBI-Grid.ppt

Components

The NCBI GRID framework is built of the following components:

1. Network job queue (NetSchedule)
2. Network data storage (NetCache)
3. Server-side APIs and tools to develop Worker Nodes:
    a. Out of an existing command-line executable
    b. Out of an existing CGI executable

   - **c** Out of an existing CGI code (if it's written using the NCBI C++ CGI framework)
   - **d** Create a GRID Worker Node from scratch

4. Client-side API
5. Remote CGI -- enables moving the actual CGI execution to the grid.
6. GRID Utilities for remote administration, monitoring, retrieval and submission (netschedule_control, netcache_control, ns_remote_job_control, ns_submit_remote_job, etc.)

All these components are fully portable, in the sense that they can be built and then run and communicate with each other across all platforms that are supported by the NCBI C++ Toolkit (UNIX, MS-Windows, MacOSX).

The NetCache and NetSchedule components can be used independently of each other and the rest of the grid framework - they have their respective client APIs. Worker Nodes get their tasks from NetSchedule, and may also use NetCache to get the data related to the tasks and to store the results of computation. Remote-CGI allows one to easily convert an existing CGI into a back-end worker node -- by a minor, 1 line of source code, modification. It can solve the infamous "30-sec CGI timeout" problem.

All these components can be load-balanced and are highly scalable. For example, one can just setup 10 NetCache servers or 20 Worker Nodes on new machines, and the storage/computation throughput would increase linearly. Also, NetCache and NetSchedule are lighting-fast.

To provide more flexibility, load balancing, and fault-tolerance, it is highly advisable to pool NetSchedule and NetCache servers using NCBI Load Balancer and Service Mapper (LBSM).

Architecture and Data Flow

NetSchedule and NetCache servers create a media which Submitters and Worker Nodes use to pass and control jobs and related data:

1. Submitter prepares input data and stores it in the pool of NetCache servers, recording keys to the data in the job's description.
2. Submitter submits the job to the appropriate queue in the pool of NetSchedule servers.
3. Worker Node polls "its" queue on the NetSchedule servers for jobs, and takes the submitted job for processing.
4. Worker Node retrieves the job's input data from the NetCache server(s) and processes the job.
5. Worker Node stores the job's results in NetCache and changes the job's status to "done" in NetSchedule.
6. Submitter sees that the job is done and reads its result from NetCache.

The following diagram illustrates this flow of control and data:

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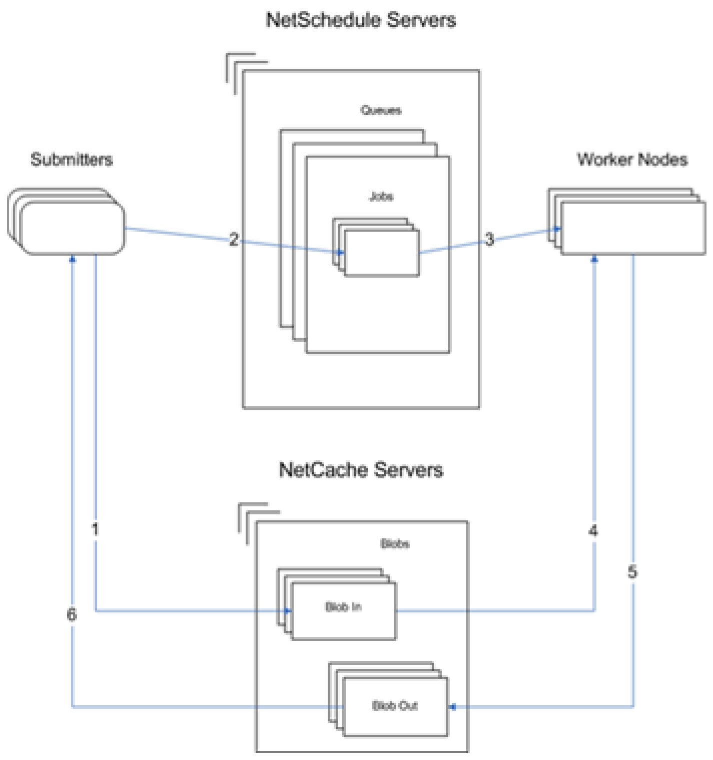

The GRID Farm

To help developers jump-start their distributed computation projects, there is a small farm of machines for general use, running:

- Several flavors of job queues
- Several flavors of network data storage
- A framework to run and maintain users' Worker Nodes

NOTE: Most of the GRID components can be deployed or used outside of the GRID framework (applications can communicate with the components directly via the components' own client APIs). However, in many cases it is beneficial to use the whole GRID framework from the start.

NCBI users can find more information on the GRID farm Wiki page.

Worker Nodes

The following sections describe how to create, configure and run worker nodes:

- Create a GRID Worker Node from scratch
- Converting an existing CGI application into a GRID Node
- Wrapping an existing CGI application into a GRID Node
- Wrapping an existing command-line application into a GRID Node
- Worker Node Cleanup Procedure

Create a GRID Worker Node from scratch

The following sections describe how to Create a GRID Worker Node from scratch:

- Purpose

- Diagram

Purpose

Framework to create a multithreaded server that can run on a number of machines and serve the requests using NetSchedule and NetCache services to exchange the job info and data.

Diagram

ftp://ftp.ncbi.nih.gov/toolbox/ncbi_tools++/DOC/PPT/IMAGES/GRID_Dec14_2006/Slide3.PNG

Converting an existing CGI application into a GRID Node

The following sections describe how to convert an existing CGI application into a GRID node:

- Purpose
- Converting a CGI into a Remote-CGI server
- Diagram
- Features and benefits

Purpose

With a rather simple and formal conversion, a CGI's real workload can be moved from the Web servers to any other machines. It also helps to work around the infamous "30-sec Web timeout problem".

Converting a CGI into a Remote-CGI server

1 Modify the code of your original CGI to make it a standalone Remote-CGI server (Worker Node). The code conversion is very easy and formal:

  a Change application's base class from CCgiApplication to CRemoteCgiApp

  b Link the application with the library xgridcgi rather than with xcgi

2 Replace your original CGIs by a one-line shell scripts that calls "remote CGI gateway" (cgi2rcgi.cgi) application.

3 Match "remote CGI gateways" against Remote-CGI servers:

  a Ask us to register your remote CGI in the GRID framework

  b Define some extra parameters in the configuration files of "remote CGI gateway" and Remote-CGI servers to connect them via the GRID framework

4 Install and run your Remote-CGI servers on as many machines as you need. They don't require Web server, and can be installed even on PCs and Macs.

Diagram

ftp://ftp.ncbi.nih.gov/toolbox/ncbi_tools++/DOC/PPT/IMAGES/GRID_Dec14_2006/Slide1.PNG

Features and benefits

- Solves 30-sec Web server timeout problem.
- Provides software infrastructure for back-end computation farm for CGIs. Cross-platform, Unix-Windows compatible, minimal administration.
- Existing CGIs can be easily converted into back-end worker nodes.

- While the request is being executed by the Remote-CGI server, the user can be interactively provided with a standard or customized progress report.
- Can be used for parallel network programming.
- High availability infrastructure. All central components can have 2-3 times reservation to accommodate request peak hours and possible hardware failures.
- Remote-CGI servers are extremely mobile.
- Remote-CGI servers can be administered (gentle shutdown, request statistics, etc.) using special tool.
- Easy to debug, as the Remote-CGI server can be run under debugger or any memory checker on any machine (UNIX or MS-Windows)

Wrapping an existing CGI application into a GRID Node

The following sections describe how to wrap an existing CGI application into a GRID Node:

- Running existing CGI executable through Grid Framework
- Diagram

Running existing CGI executable through Grid Framework

In this case a real CGI does not need to be modified at all and remote_cgi utility serves as an intermediate between NetSchedule service and a real CGI. The real CGI and remote_cgi utility go to the server side. The remote_cgi gets a job from NetSchedule service, deserializes the CGI request and stdin stream and runs the real CGI with this data. When the CGI finishes the remote_cgi utility serializes its stdout stream and sends it back to the client.

On the client side (front-end) cgi2rcgi sees that the job's status is changed to "done" gets the data sent by the server side (back-end), deserializes it and writes it on its stdout.

cgi2rcgi utility has two html template files to define its look. The first file is cgi2rcgi.html (can be redefined in cgi2rcgi.ini file) which is the main html template file and it contains all common html tags for the particular application. It also has to have two required tags.

<@REDIRECT@> should be inside <head> tag and is used to inject a page reloading code.

<@VIEW@> should be inside <body> tag and is to render information about a particular job's status.

The second file is cgi2rcgi.inc.html (can be redefined in cgi2.rcgi.ini) which defines tags for particular job's states. The tag for the particular job's state replaces <@VIEW@> tag in the main html template file.

Diagram

ftp://ftp.ncbi.nlm.nih.gov/toolbox/ncbi_tools++/DOC/PPT/IMAGES/GRID_Dec14_2006/Slide1.PNG

Wrapping an existing command-line application into a GRID Node

The following sections describe how to wrap an existing CGI application into a GRID Node:

- Running arbitrary applications through Grid Framework
- Diagram

Running arbitrary applications through Grid Framework

The client side collects a command line, a stdin stream and some other parameters, serialize them and through Grid Framework to the server side. On the server side remote_app utility picks up submitted job, deserializes the command line, the stdin and other parameters, and starts a new process with the application and the input data. Then remote_app waits for the process to finish collecting its stdout, stdin and errcode. After that it serializes collected data and sends it back to the client side. The application for run is set in remote_app.ini configuration file.

Source code: src/app/grid/remote_app/remote_app_wn.cpp

Config file: remote_app.ini

Classes that should be used to prepare an input data a remote application and get its results are CRemoteAppRequest and CRemoteAppResult. See also CGridClient, CGridClientApp.

Client example: src/sample/app/netschedule/remote_app_client_sample.cpp

Config file: src/sample/app/netschedule/remote_app_client_sample.ini

ns_submit_remote_job utility allows submitting a job for a remote application from its command line or a jobs file. See ns_submit_remote_job –help.

Jobs file format:

Each line in the file represents one job (lines starting with '#' are ignored). Each job consists of several parameters. Each parameter has in the form: name="value". The parameter's value must be wrapped in double quotes. All of these parameters are optional. Supported parameters:

- args – command line arguments.
- aff – affinity token.
- tfiles – a list of semicolon-separated file names which will be transferred to the server side.
- jout – a file name where the application's output to stdout will be stored.
- jerr – a file name where the application's output to stderr will be stored.
- runtime – a time in seconds of the remote application's running time. If the application is running longer then this time it is assumed to be failed and its execution is terminated.
- exclusive – instructs the remote_app to not get any other jobs from the NetSchedule service while this job is being executed.

Diagram

ftp://ftp.ncbi.nih.gov/toolbox/ncbi_tools++/DOC/PPT/IMAGES/GRID_Dec14_2006/Slide2.PNG

Worker Node Cleanup Procedure

The following sections describe the procedure for cleaning up Worker Nodes:

- Purpose
- Job Cleanup
- Worker Node Cleanup

Purpose

It is necessary to provide a framework to support worker node and job cleanup. For example, a job may create temporary files that need to be deleted, or a worker node may need to clean up resources shared by multiple jobs.

To receive cleanup events, the worker node must implement interface IWorkerNodeCleanupEventListener. The interface has a single abstract method:

void HandleEvent(EWorkerNodeCleanupEvent cleanup_event)

At the time of the call, cleanup_event will be set to either eRegularCleanup (for normal cleanup) or eOnHardExit (for an emergency shutdown).

There are two types of listeners: those called after each job is done and those called when the worker node is shutting down.

Job Cleanup

Listeners of the first type (per-job cleanup) are installed in the Do() method via a call to CWorkerNodeJobContext::GetCleanupEventSource()->AddListener():

```
class CMyWorkerNodeJob : public IWorkerNodeJob
/* ... */
virtual int Do(CWorkerNodeJobContext& context)
{
 context.GetCleanupEventSource()->AddListener( new
CMyWorkerNodeJobCleanupListener(resources_to_free));
}
```

Worker Node Cleanup

Listeners of the second type (worker node cleanup) are installed in the constructor of the IWorkerNodeJob-derived class via a call to IWorkerNodeInitContext::GetCleanupEventSource()->AddListener():

```
class CMyWorkerNodeJob : public IWorkerNodeJob
/* ... */
CMyWorkerNodeJob(const IWorkerNodeInitContext& context)
{
 context.GetCleanupEventSource()->AddListener( new
CMyWorkerNodeCleanupListener(resources_to_free));
}
```

Note that depending on the current value of the [server]/reuse_job_object configuration parameter, this constructor of CMyWorkerNodeJob can be called multiple times - either once per job or once per worker thread, so additional guarding may be required.

The approach of doing worker node cleanup described above is a newer approach, but there is an older approach which may also be used:

The IGridWorkerNodeApp_Listener interface has two methods, OnGridWorkerStart() and OnGridWorkerStop() which are called during worker node initialization and shutdown respectively. A handler implementing this interface can be installed using the SetListener()

method of CGridWorkerApp. The code that calls the OnGridWorkerStop() method will run in the context of the dedicated cleanup thread and also respect the force_close parameter.

The older method does not require the guarding that the new method requires.

Job Submitters

An API is available to submit tasks to Worker Nodes, and to monitor and control the submitted tasks.

CServer Multithreaded Network Server Framework

Useful resource links for high-performance servers:

1. The C10K problem
2. libevent
3. Porting of Win32 API WaitFor to Solaris

GRID Utilities

The following sections describe the GRID Utilities:

- netschedule_control
- ns_remote_job_control
- Alternate list input and output

netschedule_control

DESCRIPTION:

NCBI NetSchedule control utility. This program can be used to operate NetSchedule servers and server groups from the command line.

OPTIONS:

-h	Print brief usage and description; ignore other arguments.
-help	Print long usage and description; ignore other arguments.
-xmlhelp	Print long usage and description in XML format; ignore other arguments.
-version-full	Print extended version data; ignore other arguments.
-service <SERVICE_NAME>	Specifies a NetSchedule service name to use. It can be either an LBSMD service name or a server name / port number pair separated by a colon, such as: host:1234
-queue <QUEUE_NAME>	The queue name to operate with.
-jid <JOB_ID>	This option specifies a job ID for those operations that need it.
-shutdown	This command tells the specified server to shut down. The server address is defined by the -service option. An LBSMD service name cannot be used with -shutdown.
-shutdown_now	The same as -shutdown but does not wait for job termination.
-log <ON_OFF>	Switch server side logging on and off.
-monitor	Starts monitoring of the specified queue. Events associated with that queue will be dumped to the standard output of netschedule_control until it's terminated with Ctrl-C.

-ver	Prints server version(s) of the server or the group of servers specified by the -service option.
-reconf	Send a request to reload server configuration.
-qlist	List available queues.
-qcreate	Create queue (qclass should be present, and comment is an optional parameter).
-qclass <QUEUE_CLASS>	Class for queue creation.
-comment <COMMENT>	Optional parameter for the -qcreate command
-qdelete	Delete the specified queue.
-drop	Unconditionally drop ALL jobs in the specified queue.
-stat <STAT_TYPE>	Print queue statistics. Available values for STAT_TYPE: all, brief.
-affstat <AFFINITY_NAME>	Print queue statistics summary based on affinity.
-dump	Print queue dump or job dump if -jid parameter is specified.
-reschedule <JOB_ID>	Reschedule the job specified by the JOB_ID parameter.
-cancel <JOB_ID>	Cancel the specified job.
-qprint <JOB_STATUS>	Print queue content for the specified job status.
-count <QUERY_STRING>	Count all jobs within the specified queue with tags set by query string.
-count_active	Count active jobs in all queues.
-show_jobs_id <QUERY_STRING>	Show all job IDs by query string.
-query <QUERY_STRING>	Perform a query on the jobs withing the specified queue.
-fields <FIELD_LIST>	Fields (separated by ','), which should be returned by one of the above query commands.
-select <QUERY_STRING>	Perform a select query on the jobs withing the specified queue.
-showparams	Show service parameters.

-
read <BATCH_ID_OUTPUT,JOB_IDS_OUTPUT,LIMIT,TIMEOUT>
	Retrieve IDs of the completed jobs and change their state to Reading.
	
	For the first two parameters, the Alternate list output format can be used.
	
	Parameter descriptions:
	BATCH_ID_OUTPUT
	Defines where to send the ID of the retrieved jobs. Can be either a file name or '-'.
	JOB_IDS
	Defines where to send the list of jobs that were switched to the state Reading. Can be either a file name or '-'.
	LIMIT
	Maximum number of jobs retrieved.
	TIMEOUT
	Timeout before jobs will be switched back to the state Done so that they can be returned again in response to another -read.
	
	Examples:
	
	`netschedule_control -service NS_Test -queue test \`
	`-read batch_id.txt,job_ids.lst,100,300`
	`netschedule_control -service NS_Test -queue test \`
	`-read -,job_ids.lst,100,300`
	`netschedule_control -service NS_Test -queue test \`
	`-read batch_id.txt,-,100,300`

-read_confirm <JOB_LIST>	Mark jobs in JOB_LIST as successfully retrieved. The Alternate list input format can be used to specify JOB_LIST. If this operation succeeds, the specified jobs will change their state to Confirmed.
	
	Examples:
	
	`netschedule_control -service NS_Test -queue test \`
	`-read_confirm @job_ids.lst`
	`netschedule_control -service NS_Test -queue test \`
	`-read_confirm - < job_ids.lst`
	`netschedule_control -service NS_Test -queue test \`
	`-read_confirm`
	`JSID_01_4_130.14.24.10_9100,JSID_01_5_130.14.24.10_9100`

-read_rollback <JOB_LIST>	Undo the -read operation for the specified jobs thus making them available for the subsequent -read operations. See the description of -read_confirm for information on the JOB_LIST argument and usage examples.
-read_fail <JOB_LIST>	Undo the -read operation for the specified jobs thus making them available for the subsequent -read operations. This command is similar to -read_rollback with the exception that it also increases the counter of the job result reading failures for the specified jobs. See the description of -read_confirm for information on the JOB_LIST argument and usage examples.
-logfile <LOG_FILE>	File to which the program log should be redirected.
-conffile <INI_FILE>	Override configuration file name (by default, netschedule_control.ini).
-version	Print version number; ignore other arguments.
-dryrun	Do nothing, only test all preconditions.

ns_remote_job_control

DESCRIPTION:

This utility acts as a submitter for the remote_app daemon. It initiates job execution on remote_app, and then checks the status and the results of the job.

OPTIONS:

-h	Print brief usage and description; ignore other arguments.
-help	Print long usage and description; ignore other arguments.
-xmlhelp	Print long usage and description in XML format; ignore other arguments.
-q <QUEUE>	NetSchedule queue name.
-ns <SERVICE>	NetSchedule service address (service_name or host:port).
-nc <SERVICE>	NetCache service address (service_name or host:port).
-jlist <STATUS>	Show jobs by status. STATUS can be one of the following: • all • canceled • done • failed • pending • returned • running
-qlist	Print the list of queues available on the specified NetSchedule server or a group of servers identified by the service name.
-wnlist	Show registered worker nodes.
-jid <JOB_ID>	Show information on the specified job.
-bid <BLOB_ID>	Show NetCache blob contents.
-attr <ATTRIBUTE>	Show one of the following job attributes: • cmdline • progress • raw_input • raw_output • retcode • status • stdin • stdout • stderr Alternatively, the ATTRIBUTE parameter can be specified as one of the following attribute sets: • standard • full • minimal

-stdout <JOB_IDS>	Dump concatenated standard output streams of the specified jobs. The JOB_IDS argument can be specified in the Alternate list input format.
	Examples:
	`ns_remote_job_control -ns NS_Test -q test \`
	`-stdout JSID_01_4_130.14.24.10_9100,JSID_01_5_130.14.24.10_9100`
	`ns_remote_job_control -ns NS_Test -q test -stdout @job_ids.lst`
	`ns_remote_job_control -ns NS_Test -q test -stdout - < job_ids.lst`

-stderr <JOB_IDS>	Dump concatenated standard error streams of the specified jobs. The JOB_IDS argument can be specified in the Alternate list input format. See the description of the -stdout command for examples.
-cancel <JOB_ID>	Cancel the specified job.
-cmd <COMMAND>	Apply one of the following commands to the queue specified by the -q option: • drop_jobs • kill_nodes • shutdown_nodes
-render <OUTPUT_FORMAT>	Set the output format of the informational commands like -qlist. The format can be either of the following: text, xml.
-of <OUTPUT_FILE>	Output file for operations that actually produce output.
-logfile <LOG_FILE>	File to which the program log should be redirected.
-conffile <INI_FILE>	Override configuration file name (by default, ns_remote_job_control.ini).
-version	Print version number; ignore other arguments.
-version-full	Print extended version data; ignore other arguments.
-dryrun	Do nothing, only test all preconditions.

Alternate list input and output

This section describes two alternative methods of printing the results of operations that generate lists (e.g. lists of job IDs) and three methods of inputting such lists as command line arguments.

Alternate list output

The -read command of netschedule_control produces a list of job IDs as its output. This list can be sent either to a file (if a file name is specified) or to stdout (if a dash ('-') is specified in place of the file name).

Example:

```
# Read job results: send batch ID to STDOUT,
# and the list of jobs to job_ids.lst
netschedule_control -service NS_Test -queue test \
-read -,job_ids.lst,10,300
```

Alternate list input

There are three ways one can specify a list of arguments in a command line option that accepts the Alternate list input format (like the -stdout and stderr options of ns_remote_job_conrol):

1 Via a comma-separated (or a space-separated) list.

2 By using a text file (one argument per line). The name of the file must be prefixed with '@' to distinguish from the explicit enumeration of the previous case.

3 Via stdin (denoted by '-'). This variant does not differ from using a text file except that list items are red from the standard input - one item per line.

Examples:

```
# Concatenate and print stdout
ns_remote_job_control -ns NS_Test -q rmcgi_sample \
-stdout JSID_01_4_130.14.24.10_9100,JSID_01_5_130.14.24.10_9100

# Confirm job result reading for batch #6
netschedule_control -service NS_Test -queue test \
-read_confirm 6,@job_ids.lst

# The same using STDIN
netschedule_control -service NS_Test -queue test \
-read_confirm 6,- < job_ids.lst
```