



NORDUGRID-TECH-14

18/8/2008

THE ARC COMPUTATIONAL JOB MANAGEMENT COMPONENT - A-REX

Description and Administrator's Manual

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1 Introduction

A-REX is one of ARC middleware componets implementing functions of so called *Computing Element* (CE).

The aim of the A-REX is to take care of job pre- and post-processing. It provides functionality to stage-in files containing input data and program modules from wide range of sources and transfer or store output results.

The A-REX implements Web Service (WS) interface which provides a way to submit and control computational tasks (jobs) to be executed by the A-REX and undelying Local Resource Management System.

You should use this document for advanced configuration purposes and understanding of internals of the aforementioned tools. For general instalaltion and configuration of whole system refer to other documents availalble at <http://www.nordugrid.org/papers.html>.

2 Main concepts

A job is a set of input files (which may include executables), a main executable and a set of output files. The process of gathering input files, executing a job, and transferring/storing output files is called a *session*.

Each job gets a directory on the CE called the *session directory* (SD). Input files are gathered in the SD. The job is supposed to produce new data files in the SD as well. The A-REX does not guarantee the availability of any other places accessible by the job other than SD (unless such a place is part of a requested Runtime Environment). The SD is also the only place which is controlled by the A-REX. It is accessible by the user from outside through HTTP(S) protocol. Any file created outside the SD is not controlled by the A-REX. Any exchange of data between client and A-REX (including also program modules) is done through HTTP(S) protocol. A URL for accessing input/output files is obtained through the WS Local Information Description Interface (LIDI) of A-REX.

Each job gets an identifier (*jobid*). This is a handle - WS-Addressing [1] XML document - which identifies the job in the A-REX and the Information Interface.

Jobs are initiated and controlled through WS interface. Complete job descriptions (JD) are passed to the A-REX through WS in JSDL[1] coded description. Input data files and job executables are transferred separately through the same interface, as described in the next section.

3 Input/output data

One of the most important tasks of the A-REX is to take care of processing input and output data (files) of the job. Input files are gathered in the SD or associated cache area. There are two ways to put a file into the SD:

- Download is initiated by the A-REX – This is the case for files defined in the JD (with name and source). The A-REX alone is responsible to make sure that all required files will be available in the SD.
The supported protocols for sources at the moment are (in case of full installation): GridFTP, FTP, HTTP, HTTPS (HTTP over SSLv3). Also some less standard sources are supported. Those are described below. The A-REX fully relies on HED framework [?] for data transferring capabilities. Hence actual set of supported protocols depends on installed Data Management Components of the HED.
- Upload is initiated by the user directly or through the User Interface (UI). Because the SD becomes available immediately at the time of submission of JD, UI can (and should) use that to upload data files which are not otherwise accessible by the A-REX. Examples of such files are the main executable of the job, the job's input files, etc. These files can (and should) also be specified in the JD.

There is no other reliable way for a job to obtain input data on the CE based on the A-REX. Access to AFS, NFS, FTP, HTTP and any other remote data transport during execution of a job is not guaranteed (at least not by A-REX).

Jobs should store output files in their SD. Like input files, output files belong into two groups:

- Files which are supposed to be moved to a *Storage Element (SE)* and optionally registered in some *Indexing Service* like the *Globus Replica Location Service (RLS)* – The A-REX takes care of these files. They have to be specified in the JD. If the job fails during any stage of processing, no attempt is made to transfer those files to their final destination, unless the option *preserve=yes* is specified in their URLs.
- Files which are supposed to be fetched by the user – The user has to use a tool like the UI to obtain these files. They **must** also be specified in the JD.

All files not specified in the JD are deleted after job execution finished. If job execution fails for any reason (if exit code of main executable is not 0) all files from first group are transferred to second one.

4 Job flow

From the point of view of the A-REX a job passes through various states. Picture 1 presents a diagram of the possible states of a job. A user can examine the state of a job by querying the dedicated Local Information Description Interface

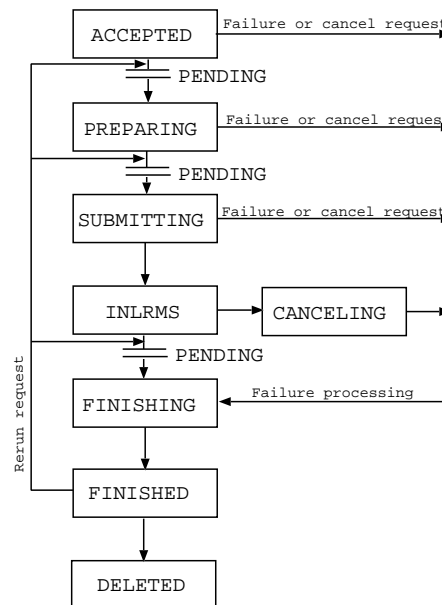


Figure 1: Job states

of A-REX using the UI or any other suitable tool or through query method of WS interface.

Configuration can put limits on the amount of simultaneous jobs in some states. If such a limit is reached, a job ready to enter into the state in question will stay in its current state waiting for a free slot. This situation is presented by additional state mark **PENDING** to the current state name in the job's status description.

Below is the description of all actions taken by the A-REX at every state:

- **Accepted** - In this state the job has been submitted to a CE but is not processed yet. The A-REX will analyze the JD and move to the next stage. If the JD can not be processed the job will be canceled and moved to the state **Finishing**.

- **Preparing** - The input data is being gathered in the SD (stage-in). The A-REX is downloading the files specified in the JD and is waiting for files which are supposed to be uploaded by the UI. If all files are successfully gathered the job moves to the next state. If **any** file can't be downloaded or it takes the UI too long to upload a file, the job moves to **Finishing** state. It is possible to put a limit on the number of simultaneous **Preparing** jobs. If this limit is exceeded, jobs ready to enter the **Preparing** state will stay in the **Accepted** state, but prefixed with the PENDING: mark. Exceptions are jobs which have no files to be downloaded. These are processed out of limits.
- **Submitting** - The job is being passed for execution to the *Local Resource Management System* (LRMS). The corresponding backends for many LRMSs are provided with the default installation. If the local job submission is successful the job moves to the **Executing** state. Otherwise it moves to **Finishing**. It is possible to limit the aggregate number of jobs in **Submitting** and **Executing** states.
- **Executing** - The job is queued or being executed in the LRMS. The A-REX takes no actions except waiting until the job finishes.
- **Killing** - Necessary action to cancel the job in the LRMS is being taken.
- **Finishing** - The output data is being processed (stage-out). Specified data files are moved to the specified SEs and are optionally registered at an Indexing Service. The user can download data files from the SD by using the UI or other adequate tool. All the files not specified as output files are removed from the SD at very beginning of this state. It is possible to limit number of simultaneous jobs in this state.
- **Finished** - No more processing is performed by the A-REX. The user can continue to download data files from the SD. The SD is kept available for some time (default is 1 week). After that the job is moved to the state **Deleted**. The 'deletion' time can be obtained by querying the Information Interface of the A-REX. If a job was moved to **Finished** because of failure, it may be restarted on request of a client. When restarted, a job is moved to the state previous to the one in which it failed and is assigned mark PENDING. This is needed in order to not break the configuration limits. Exception is a job failed in **Executing** state and lacking input files specified in JD. Such a job is treated like failed in **Preparing** state.
- **Deleted** - The job is moved to this state if the user have not requested job to be cleaned before the SD's lifetime expires. Only minimal subset of information about such job is kept. The SD is not available anymore.

In case of a failure special processing is applied to output files. All specified output files are treated as **downloadable by the user**. No files will be moved to their destination SE.

5 URLs

In full installation the A-REX and it's components support the following data transfer protocols and corresponding URLs: *ftp*, *gsiftp*, *http*, *https*, *lfc* and *rls*. For more information please see "The Hosting Environment of the Advanced Resource Connector middleware" document [?].

6 Internals

6.1 Internal Files of the A-REX

For each local UNIX user listed in the A-REX configuration - including a generic one which covers all local user identities - a *control directory* exists. In this directory the A-REX stores information about jobs belonging to that

user. Multiple users can share the same *control directory*. In most common configuration case A-REX serves all users defined by Operating System and stores their control file in same directory. To make it easier to recover in case of failure, the A-REX stores most information in files rather than in memory. All files belonging to the same job have names starting with **job.ID.**, where ID is the job identifier.

The files in the control directory and their formats are described below:

- *job.ID.status* - current state of the job. This is a plain text file containing a single word representing the internal name of current state of the job. Possible values and corresponding external job states are :
 - ACCEPTED/**Accepted**
 - PREPARING/**Preparing**
 - SUBMITTING/**Submitting**
 - INLRMS/**Executing**
 - FINISHING/**Finishing**
 - FINISHED/**Finished**
 - CANCELING/**Killing**
 - DELETED/**Deleted**

See section 4 for a description of the various states. Additionally each value can be prepended the prefix “PENDING:” (like PENDING:ACCEPTED, see section 4). This is used to show that a job is *ready* to be moved to the next state but it has to stay in it’s current state *only* because otherwise some limits set in the configuration would be exceeded.

- *job.ID.description* - contains the description of the job (JD).
- *job.ID.local* - information about the job used by the A-REX. It consists of lines of format “*name = value*”. Not all of them are always available. The following names are defined:
 - *subject* - user certificate’s subject, also known as the distinguished name (DN)
 - *starttime* - GMT time when the job was accepted represented in the Generalized Time format of LDAP
 - *lifetime* - time period to preserve the SD after the job has finished in seconds
 - *cleanup time* - GMT time when the job should be removed from the cluster and it’s SD deleted in Generalized Time format
 - *notify* - email addresses and flags to send mail to about the job specified status changes
 - *processtime* - GMT time when to start processing the job in Generalized Time format
 - *exec time* - GMT time when to start job execution in Generalized Time format
 - *expiretime* - GMT time when the credentials delegated to the job expire in Generalized Time format
 - *rerun* - number of retries left to rerun the job
 - *jobname* - name of the job as supplied by the user
 - *lrms* - name of the LRMS backend to be used for local submission
 - *queue* - name of the queue to run the job at
 - *localid* - job id in LRMS (appears only after the job has reached state **InLRMS**)
 - *args* - executable name followed by a list of command-line arguments
 - *downloads* - number of files to download into the SD before execution

- *uploads* - number of files to upload from the SD after execution
- *gmlog* - directory name which holds files containing information about the job when accessed through GridFTP interface
- *clientname* - name (as provided by the user interface) and ip address:port of the submitting client machine
- *clientsoftware* - version of software used to submit the job
- *sessiondir* - the job's SD
- *failedstate* - state in which job failed (available only if it is possible to restart the job)
- *jobreport* - URL of a user requested *logger service*. The A-REX will also send job records to this service in addition to the default logger service configured in the configuration (This feature does not work in current implementation).

This file is filled partially during job submission and fully when the job moves from the **Accepted** to the **Preparing** state.

- *job.ID.input* - list of input files. Each line contains 2 values separated by a space. First value contains name of the file relative to the SD. Second value is an URL or a file description. Example:

input.dat gsiftp://grid.domain.org/dir/input_12378.dat

url - ordinary URL for gsiftp, ftp, http, https protocols with the addition of '**replica location service url**' (RLS URL).

Each URL can contain additional options.

file description - [size][.checksum].

size - size of the file in bytes.

checksum - checksum of the file identical to the one produced by *cksum* (1).

Both size and checksum can be left out. Special kind of file description **,** is used to specify files which are **not** required to exist.

This file is used by the '**downloader**' utility. Files with '*url*' will be downloaded to the SD and files with '*file description*' will simply be checked to exist. Each time a new **valid** file appears in the SD it is removed from the list and *job.ID.input* is updated. Any external tool can thus track the process of collecting input files by checking *job.ID.input*.

- *job.ID.output* - list of output files. Each line contains 1 or 2 values separated by a space. First value is the name of the file relative to the SD. The second value, if present, is a URL. Supported URLs are the same as those supported by *job.ID.input*.

This file is used by the '**uploader**' utility. Files with *url* will be uploaded to SE and remaining files will be left in the SD. Each time a file is uploaded it is removed from the list and *job.ID.output* is updated. Files not mentioned as output files are removed from the SD at the the beginning of the **Finishing** state.

- *job.ID.failed* - the existence of this file marks the failure of the job. It can also contain one or more lines of text describing the reason of failure. Failure includes the return code different from zero of the job itself.
- *job.ID.errors* - this file contains the output produced by external utilities like **downloader**, **uploader**, script for job submission to LRMS, etc on their stderr handle. Those are not necessarily errors, but can be just useful information about actions taken during the job processing. In case of problem include content of that file while asking for help.

- *job.ID.diag* - information about resources used during execution of job and other information suitable for diagnostics and statistics. It's format is similar to that of *job.ID.local*. The following names are at least defined:
 - *nodename* - name of computing node which was used to execute job,
 - *runtimeenvironments* - used runtime environments separated by ';',
 - *exitcode* - numerical exit code of job,
 - *frontend_distribution* - name and version of operating system distribution on frontend computer,
 - *frontend_system* - name of operating on frontend computer,
 - *frontend_subject* - subject (DN) of certificate representing frontend computer,
 - *frontend_ca* - subject (DN) of issuer of certificate representing frontend computer,
 and other information provided by GNU *time* utility. Note that some implementation of *time* insert unrequested information in their output. Hence some lines can have broken format.
- *job.ID.proxy* -delegated X509 credentials.
- *job.ID.proxy.tmp* - temporary X509 credentials with different UNIX ownership used by processes run with effective *user id* different from job owner's *id*.

There are other files with names like *job.ID.** which are created and used by different parts of the A-REX. Their presence in the *control directory* can not be guaranteed and can change depending on changes in the A-REX code.

6.2 Web Service Interface

A-REX Web Service Interface provides means to submit a description of a computational job to a computing resource, to stage-in additional data, to monitor and control processing of jobs, and obtain data produced during the execution of a job. The WS Interface is built and deployed inside Hosting Environment Daemon (HED) infrastructure[?].

6.2.1 Basic Execution Service Interface

The job submission and control interface is based on document produced by the OGF OGSA Basic Execution Services (BES) Working Group[2]. The exchange of SOAP messages is performed over the HTTP(S) protocol. The BES interface is represented by two port-types - BES-Management and BES-Factory. The former is made to control the A-REX service itself and thus defines operations to start and stop the functionality of the BES service. The A-REX does not implement remote control of service functionality. Hence the BES-Management port-type is not functional. The BES-Factory port-type provides operations to submit new jobs (to create an activity in terms of BES) and to monitor its state. It also has an ability to provide information about the service. A-REX fully implements the functionality of this port-type.

For job descriptions A-REX accepts the Job Submission Description Language (JSDL)[1] documents as defined by the OGF Job Submission Description Language Working Group. Supported elements and extensions are described below.

6.2.2 Extensions to OGSA BES interface

A-REX introduces a new operation in addition to those provided by BES. It does that by defining its own port-type with the single operation *ChangeActivityStatus* (see Appendix C). This operation provides a way to request simple transfers between states of jobs and corresponding actions.

Table 1: Job states definitions and mappings

Applicable BES State	ARC Sub-state	Description
Pending	Accepting	Job is in the process of being submitted
	Accepted	Job was submitted
Running	Preparing	Stage-in process is going on
	Prepared	Stage-in process has finished
	Submitting	Communication with local batch system is in process
	Executing	Job is being executed in local batch system
	Killing	Communication with local batch system to terminate execution is in process
	Executed	Job execution in local batch system has finished
	Finishing	Stage-out process is going on
Cancelled	Failed	There was a failure during execution
Failed		
All	Pending	Job is prevented from going to the next state due to some internal limits; this sub-state appears in parallel with other sub-states
All	Held	Job processing is suspended on client request; this sub-state appears in parallel with other sub-states. This state is reserved for future and is not implemented yet.

- *ChangeActivityStatus*

- Input

- * *ActivityStatusType OldStatus*: Description of the state the job is supposed to be in during execution of this request. If the current state of the job is different from the one having been given, the operation is aborted and a fault is returned. This parameter is optional.

- * *ActivityStatusType NewStatus*: Description of the state the job is to be put into.

- Output

- * *ActivityStatusType NewStatus*: Description of the current state of the job.

- Fault(s)

- * *NotAuthorizedFault*: Indicates that the client is not allowed to do this operation.

- * *InvalidActivityIdentifierFault*: There is no such job/activity.

- * *CantApplyOperationToCurrentStateFault*: The requested transition is not possible.

On result of this command, the job should be put into the requested state. If such a procedure cannot be performed immediately then the corresponding sequence is initiated and fault *OperationWillBeAppliedEventuallyFault* will be returned.

Since BES allows implementators to extend their initial activity states with additional sub-states, A-REX defines a set of sub-states of activity processing in addition to those defined by the BES, as listed in Table 1. Their meaning is described in section 4.

6.2.3 Delegation Interface

The A-REX also supports the Delegation Interface (see Appendix D). This is a common purpose interface to be used by ARC services which accepts delegated credentials from clients. The Delegation Interface implements two

operations: initialization of credentials delegation (*DelegateCredentialsInit*) and update/renewal of credentials (*UpdateCredentials*).

- *DelegateCredentialsInit* operation - this operation performs the first half of the credentials delegation sequence.
 - Input
 - * *None*. On this request the service generates a pair of *public* and private keys. The public key is then sent to the client in response.
 - Output(s)
 - * *TokenRequestType TokenRequest*: Contains the public key generated by the service as a *Value* element. It also provides an identifier in the *Id* element which should be used to refer to the corresponding private key.
 - Fault(s)
 - * *UnsupportedFault*: Indicates that the service does not support this operation despite supporting the port-type.
 - * *ProcessingFault*: Internal problems during generation of the token.
- *UpdateCredentials* operation - this operation makes it possible to update the content of delegated credentials (like in the case of credentials being renewed) unrelated to other operations of the service.
 - Input
 - * *DelegatedTokenType DelegatedToken*: Contains an X509 proxy certificate based on the public key from the *DelegateCredentialsInit* signed by the user's proxy certificate. Also includes the *Id* element which identifies the private key stored at the service side associated with these credentials. The reference element refers to the object to which these credentials should be applied in a way specific to the service. The same element must also be used for delegating credentials as part of other operations on service.
 - Output(s)
 - * *None*.
 - Fault(s)
 - * *UnsupportedFault*: Indicates that service does not support this operation despite supporting the port-type.
 - * *ProcessingFault*: Internal problems during generation of the token.

Additionally, A-REX Web Service Interface allows delegation to be performed as part of the *CreateActivity* operation of the BES-Factory port-type. For this it accepts the element *DelegatedCredentials* inside the *CreateActivity* element. The *Id* element of *DelegatedCredentials* must contain an identifier obtained in response to the previous *DelegateCredentialsInit* operation. For more information about delegations and delegation interface refer to [3].

6.2.4 Local Information Description Interface

The A-REX implements the Local Information Description Interface (LIDI) interface common for all ARC services. This interface is based on OASIS Web Services Resource Properties specification[3]. Information about resources and maintained activities/jobs are represented in a *WS-Resource Properties* informational XML document. The document type is defined in the A-REX WSDL as a *ResourceInformationDocumentType*. It contains the following elements/resources:

nordugrid - description of computing resource that uses NorudGrid LDAP schema [] converted to XML document.

Domains - description of a computation resource that uses Glue2 schema.

All information can be accessed either through requests on particular resources or through XPath queries using WS-Resource Properties operations.

6.2.5 Supported JSDL elements

A-REX supports the following elements from the JSDL version 1.0 specification[1] including POSIX Applications extension and JSDL HPC Profile Application Extension []:

JobName - name of the job as assigned by the user.

Executable (POSIX,HPC) - name of the executable file.

Argument (POSIX,HPC) - arguments the executable will be launched with.

DataStaging

Filename - name of the data file on the executing node.

Source - source where the file will be taken from before execution.

Target - destination the file will be delivered to after execution.

Input (POSIX,HPC) - file to be used as standard input for the executable.

Output (POSIX,HPC) - file to be used as standard output for the executable.

Error (POSIX,HPC) - file to be used as standard error for the executable.

MemoryLimit (POSIX) - amount of physical memory needed for execution.

TotalPhysicalMemory - same as MemoryLimit.

IndividualPhysicalMemory - same as MemoryLimit.

CPUTimeLimit (POSIX) - maximal amount of CPU time needed for execution.

TotalCPUTime - same as CPUTimeLimit.

IndividualCPUTime - same as CPUTimeLimit.

WallTimeLimit (POSIX) - amount of clock time needed for execution.

TotalCPUCount - number of CPUs needed for execution.

IndividualCPUCount - same as TotalCPUCount.

Environment (POSIX) - environment variable.

6.2.6 ARC-specific JSDL Extensions

A-REX accepts JSDL documents having the following additional elements (see Appendix E):

IsExecutable - marks file to become executable after being delivered to the computing resource.

RunTimeEnvironment - specifies the name of the Runtime Environment needed for job execution.

Middleware - request for specific middleware on the computing resource frontend.

RemoteLogging - destination for the usage record report of the executed job.

LocalLogging - name for the virtual directory available through job interface and containing various debug information about job execution.

AccessControl - ACL expression which describes the identities of those clients who are allowed to perform operations on this job.

Notify - Email destination for notification of job state changes.

SessionLifeTime - duration for the directory containing job-related files to exist after the job finished executing.

JoinOutputs - specifies if standard output and standard error channels must be merged.

Reruns - defines how many times a job is allowed to rerun in case of failure.

CredentialServer - URL of MyProxy service which may be used for renewing the expired delegated job credentials.

CandidateTarget - specifies host name and queue of a computing resource.

7 Cache

The A-REX can cache input files. Caching is enabled if corresponding command is present in configuration file. The A-REX does not cache files marked as executable in job. Caching can also be explicitly turned off by user for each file by using *cache=no* option in URL (for URL options read “Protocols, Uniform Resource Locators (URL) and extensions supported in ARC” [4]). The disc space occupied by cache is controlled by removing unused files. For more information look in section 9.1.

NOTE: The caching algorithm used by A-REX and described above is currently being replaced by a better one which is no robust and provides better scalability.

7.1 Structure

Cache directory contains plain files. Those are

- *list* - stores names of the files (8 digit numbers) and corresponding URLs delimited by blank space. Each pair is delimited by some amount of \0 codes. Also creation and expiration times are stored if available
- *old* - stores URLs which have been removed from cache. Records are delimited by some amount of \0 codes and are meant to be removed by some external routine.
- *new* - stores URLs which have been added to cache. Records are delimited by some amount of \0 codes and are removed when corresponding files are removed from cache. They can also be handled by some external routines. Every time record is added to *old* it is removed from *new*.

- *statistics* - consists of strings containing *name=value* pairs. Following names are defined:
 - *hardsize* -size of file system for storing cached data
 - *hardfree* - amount of disc space available on that file system
 - *softsize* - if cache exceeds this size files are started being removed
 - *softfree* - space left till softsize (can be negative)
 - *claimed* - space used by files claimed by running jobs
 - *unclaimed* - space used by files not being currently used by any job
- *#####.info* - stores state of file (##### stands for 8 digits). State is represented by one character:
 - c* - just created, content is empty.
 - f* - failed to download (treated same as 'c').
 - r* - ready to be used, content is valid.
 - d* - being downloaded. 'd' is followed by identifier of application/job downloading that file. During content's download this file has write lock set.
- *#####.claim* - stores list of identifiers of applications/jobs using this file. Identifiers are stored one per line.
- *#####* - files storing content of corresponding URL. These can be stored in separate directory.

Files *list*, *old*, *new* and *#####.info* has to be stored on filesystem which has support for files' locking.

7.2 How it works

If a job requests an input file which is subject for cacheing, it is stored in the cache directory instead of the SD. The file is made available to the job by either soft-linking it in the SD or copying it to the SD. The latter option is more secure and hence advised.

Before downloading a file the A-REX tries to determine it's size and then tries to preallocate space in the cache directory by writing an empty file of the same size. If this fails (possibly because the file system has no more space), it tries to remove oldest cached files which are not being used by any job. This means that **the real hard limit of cache size is the space available in the file-system**. In case cache gets full and it is impossible to free enough space, the download fails and then is retried without using cache.

Before giving access to an already cached file, the A-REX contacts the original file source to check if the user has sufficient access rights to the file. Not all protocols make this check possible. Also, file creation or validity times are checked to make sure the cached file is fresh. If it is impossible to obtain creation and invalidation times, the file is invalidated 24 hours after it was downloaded.

The A-REX checks the cache periodically. If the space used by cache exceeds the high water-mark given in the configuration file (*softsize*), it tries to remove the oldest unused files until cache size drops below the low water-mark. This sets the soft limit of cache size.

There are two kinds of caches supported. Files in *private* cache are owned by the Unix user to which a Grid user is mapped. Those files are readable only by that particular Unix user. Another kind of cache is *shared*. Files in the shared cache are owned by the Unix user who started A-REX and are readable by everyone.

8 Files and directories

8.1 Modules

The A-REX consists of several separate modules. These are:

- *libarex.so* - The main module providing main functionality and web interface. It is implemented as HTTP and SOAP service inside HED. It is responsible for processing jobs, moving them through states and running other modules.
- *downloader* - This is a module responsible for gathering input files in the SD. It processes the *job.ID.input* file and updates it.
- *uploader* - This module is responsible for delivering output files to the specified SEs and registration at an Indexing Service (like RLS) as needed. It processes and updates the *job.ID.output* file.
- *cache-register* - Utility to register cached data into an Indexing Service. It reads and modifies cache informational files *old* and *new* (as described in section 7). Configuration is read directly from the A-REX's configuration file (see section 9.1). It is run by the A-REX every 5 minutes.
- *frontend-info-collector* - Utility to gather information about the frontend. It puts collected information into the *job.ID.diag* file.
- *gm-kick* - Sends a signal to the A-REX through a FIFO file to wake it up. It's used to increase responsiveness of A-REX.
- *cluster+qju.pl* - Collects and generates information about computing resource as XML document in NoruGrid and Glue 2 format.

The following modules are always run under the Unix account to which a Grid user is mapped.

- *smtp-send.sh* and *smtp-send* - These are the modules responsible for sending e-mail notifications to the user. The format of the mail messages can be easily changed by editing the simple shell script *smtp-send.sh*.
- *submit-*-job* - Here * stands for the name of the LRMS. Currently supported LRMS are PBS/Torque, Condor and SGE. Also *fork* pseudo-LRMS is supported for testing purposes. This module is responsible for job submission to the LRMS.
- *cancel-*-job* - This script is for canceling jobs which have been already submitted to the LRMS.
- *scan-*-job* - This shell script is responsible for notifying the A-REX about completion of jobs. It's implementation for PBS uses server logs to extract information about jobs. If logs are not available it uses the less reliable *qstat* command for that. Other backends use different techniques.

In addition, there is also an administration utility:

- *gm-jobs* - prints a list of jobs available on the cluster and the number of jobs in each state.
gm-jobs [-h] [-l] [-u uid] [-U name]
-l – print more information about each job,
-u – pretend utility is run by user with id *uid*,
-U – pretend utility is run by user with name *name*.

8.2 Directories

The A-REX is installed into a single installation point referred as `$ARC_LOCATION` and the following sub-directories are used:

- `$ARC_LOCATION/bin` – tools
- `$ARC_LOCATION/libexec` – program modules used by A-REX
- `/etc` – central configuration file - location used by default
- `$ARC_LOCATION/lib/arc` – service module

The A-REX also uses following directories:

- *session root directory* - This is the directory in which a user's SDs are created. It's location is configurable per UNIX user. Several (or even all) users may share the same session root directory.

The A-REX need to have permission to create new files and directories in the session root directory. If A-REX is run under a dedicated user account, that account needs full permissions in the *session root directory*.

If A-REX is run under the *root* account, make sure *session root directory* resides on a filesystem which does not limit the capabilities of the *root* user (as does for example NFS with *root_squash* option).

If there is a need to run A-REX under the *root* account (to be able to run jobs in LRMS under different users' accounts, for example) but there is no way to provide a suitable *session root directory*, use the *norootpower* command in configuration file. In that case A-REX will use the identity of the local user to which a Grid identity is mapped to access the *session root directory*. Hence those users will need full access there.

The A-REX creates SDs with proper ownership and permissions for the local identity used to run a job. Some filesystems require users to have *execute* permission on the *session root directory* in order to access any file or subdirectory there.

In order for jobs to access their input files, session root directories should be shared across cluster nodes. Otherwise, LRMS-specific methods must be used to transfer files to execution nodes. For more information see section 9.3.

- *control directory* - In this directory A-REX stores an information about accepted jobs. It must have full permissions there.

A subdirectory called *log* is created there. It is used to accumulate information about started and finished jobs. This information is periodically sent to the desired *logger service(s)*. For each job start and stop event, and for each logger service where that event must be sent, a separate file is written. Once an event is sent, the corresponding file is deleted.

9 Configuration

9.1 Configuration of the A-REX

Due to historical reasons configuration of the A-REX is split into 2 parts. The small part is located inside HED configuration (see appendix B) for schema and description of supported elements. It refers to file containing main part of configuration. The default location of main configuration file is `/etc/arc.conf`.

The configuration file can contain empty lines and comments in lines starting from `#`. It is separated into sections. Each sections starts from string containing pattern

- `[section name/subsection name/subsubsection name]`.

Each section continues till next section or end of file. One configuration file can have commands for multiple services/modules/programs. Each service get it's own section named after it. The A-REX uses section *[grid-manager]*. Some services can make use of multiple subsections to reflect their internal modular structure. Commands in section *[common]* apply to all services. Command lines have format

- *name="arguments string"*.

Following commands are defined:

- ***joblog***=[*path*] - specifies where to store log file containing information about started and finished jobs.
- ***jobreport***=[*URL ... number*] - specifies that A-REX has to report information about jobs being processed (started, finished) to centralized service running at given *URL*. Multiple entries and multiple URLs are allowed. *number* specifies how long old records have to be kept if failed to be reported. That value is specified in days. Last specified value becomes effective.
- ***securetransfer***=*yes|no* - specifies whether to use encryption while transferring data. Currently works for GridFTP only. Default is *no*. It is overridden by value specified in URL options.
- ***localtransfer***=*yes|no* - specifies whether to pass file downloading/uploading task to computing node. If set to *yes* the A-REX won't initiate download/upload files. Instead it composes script submitted to LRMS in way to make it do that. This requires installation of A-REX and all related software to be accessible from computing nodes and environment variable *ARC_LOCATION* to be set accordingly. Default is *no*.
- ***maxjobs***=[*max_processed_jobs [max_running_jobs]*] - specifies maximum number of jobs being processed by the A-REX at different stages:
max_processed_jobs - maximal amount of jobs being processed by A-REX. This does not limit amount of jobs, which can be submitted to A-REX
max_running_jobs - maximal amount of jobs passed to Local Resource Management System
Missing value or -1 means no limit.
- ***maxlod***=[*max_frontend_jobs [emergency_frontend_jobs [max_transferred_files]]*] - specifies maximum load caused by jobs being processed on frontend:
max_frontend_jobs - maximal amount of jobs heavily using resources of frontend (applied before moving job to PREPARING and FINISHING states)
emergency_frontend_jobs - if limit of *max_frontend_jobs* is used only by PREPARING or by FINISHING jobs aforementioned number of jobs can be moved to another state. This is used to avoid case then jobs can't finish due to big amount of recently submitted jobs.
max_transferred_files - maximal number of files being transferred in parallel by every job. Used to decrease load on not so powerful frontends.
Missing value or -1 means no limit.
- ***wakeupperiod***=*time* - specifies how often the A-REX checks for job state changes (like new arrived job, job finished in LRMS, etc.). *time* is a minimal time period specified in seconds. Default is *3 minutes*.
- ***cacheregistration***=*yes|no* - enables or disables registration of cache data into Indexing Services like RC or RLS. The default is *no*. Only files downloaded through *meta-url* are registered. Registration is done to same service used for obtaining information about file. For this operation credentials of the A-REX (host key and certificate) are used. If required new files storage location is registered at Indexing Service with quasi-url *cache://hostname/* and name *hostname:cache*.

- **authplugin=state options plugin** - specifies *plugin* (external executable) to be run every time job is going to switch to *state*. Following states are allowed: ACCEPTED, PREPARING, SUBMIT, FINISHING, FINISHED and DELETED. If exit code is not 0 job is canceled by default. *Options* consist of *name=value* pairs separated by a comma. Following *names* are supported:
timeout - specifies how long in seconds execution of the plugin allowed to last (mandatory, “*timeout=*“ can be skipped for backward compatibility).
onsuccess, *onfailure* and *ontimeout* - defines action taken in each case (*onsuccess* happens if exit code is 0). Possible actions are:
pass - continue execution,
log - write information about result into logfile and continue execution,
fail - write information about result into logfile and cancel job.
- **localcred=timeout plugin** - specifies *plugin* (external executable or function in shared library) to be run every time job has to do something on behalf of local user. Execution of *plugin* may not last longer than *timeout* seconds. If *plugin* looks like *function@path* then function *int function(char*,char*,char*,...)* from shared library *path* is called (*timeout* is not functional in that case). If exit code is not 0 current operation will fail.
- **norootpower=yes/no** - if set to *yes* all processes involved in job management will use local identity of a user to which Grid identity is mapped in order to access filesystem at path specified in **session** command (see below). Sometimes this may involve running temporary external process.
- **speedcontrol=min_speed min_time min_average_speed max_inactivity** - specifies how long/slow data transfer is allowed to take place. Transfer is canceled if transfer rate (bytes per second) is lower than *min_speed* for at least *min_time* seconds, or if average rate is lower than *min_average_speed*, or no data is received for longer than *max_inactivity* seconds.
- **copyurl=template replacement** - specifies that URLs, starting from template should be accessed in a different way (most probably Unix open). The *template* part of the URL will be replaced with *replacement*. *replacement* can be either URL or local path starting from '/'. It is advisable to end template with '/'.
- **linkurl=template replacement [node_path]** - mostly identical to *copyurl* but file won't be copied. Instead soft-link will be created. *replacement* specifies the way to access the file from the frontend, and is used to check permissions. The *node_path* specifies how the file can be accessed from computing nodes, and will be used for soft-link creation. If *node_path* is missing - *local_path* will be used instead. Both *node_path* and *replacement* should not be URLs.

NOTE: URLs which fit into *copyurl* or *linkurl* are treated as more easily accessible than other URLs. That means if A-REX has to choose between few URLs from which should it download input file, these will be tried first.

Per UNIX user commands:

- **mail=e-mail_address** - specifies an email address **from** which the notification mails are sent.
- **defaultttl=t1 [ttr]** - specifies the time in seconds for the SD to be available after job finished (*t1*) and after job was deleted (*ttr*) due to *t1*. Defaults are 7days for *t1* and 30 days for *ttr*.
- **defaultlrms=default_lrms_name default_queue_name** - specifies names for the LRMS and queue. Queue name can also be specified in the JD (currently it is not allowed to override used LRMS by using JD). In new configuration file this command is called **lrms**.

- ***session=path*** - specifies path to the directory in which the SD is created. If the path is * the default one is used - *\$HOME/.jobs* . In new configuration file this command is called ***sessiondir***.
- ***cachedir=path [link_path]*** - specifies the directory to store cached data. Empty *path* disables caching. Default is not to cache data. Optional *link_path* specifies the path at which cache is accessible at computing nodes. If *link_path* is set to '.' files are not soft-linked, but copied to session directory.
- ***privatecache=path [link_path]*** - same as *cache* command, but cache belongs (owned) to user. For shared caches use 'cache'.
- ***cachedata=path*** - allows to specify separate place to store cache files containing data itself. This can be useful in case of big data storage available only on NSF server which does not support file locking. If command or *path* is missing - default is to store data at place specified in *cache* or *privatecache* command, together with control files.
- ***cachesize=high_mark [low_mark]*** - specifies high and low water-mark for space used by cache. Values are specified in bytes. Both *high_mark* and *low_mark* can be negative values. In that case corresponding positive value means space left on filesystem. If *low_mark* is omitted it becomes equal to *high_mark*. By default this feature is turned off. To turn it off explicitly *cachesize* without parameters should be specified. If turned off cache will grow up till it fills whole file system.
- ***maxrerun=number*** - specifies maximal number of times job will be allowed to rerun after it failed at any stage. Default value is 5. This only specifies an upper limit. Actual number is provided in job description and defaults to 0.

All per-user commands should be put before *control* command which initiates serviced user.

- ***control=path username [username [...]]*** - This option initiates UNIX user as being serviced by the A-REX. *path* refers to the control directory (see section 6 for the description of control directory). If the path is * the default one is used - *\$HOME/.jobstatus* . *username* stands for UNIX name of the local user. Multiple names can be specified. If the name is * it is substituted by all names found in file */etc/grid-security/grid-mapfile* (for the format of this file one should study the Globus project [5]).
Also the special name '.' (dot) can be used. Corresponding control directory will be used for **any** user. This option should be the last one in the configuration file. There is also command ***controldir=path***. It uses special username '.' and is always executed last independent of placement in file.
- ***helper=username command [argument [argument [...]]]*** - associates external program with the local UNIX user. This program will be kept running under account of the specified user. *username* stands for the name of the user. Special names can be used: '*' - all names from */etc/grid-security/grid-mapfile*, '.' - root user. The user should be already configured with *control* option (except root, who is always configured). *command* is an executable and *arguments* are passed as arguments to it.

Following are global commands specific to communication with underlying LRMS (PBS in this case).

- ***pbs_bin_path=path*** - path to directory which contains PBS commands.
- ***pbs_log_path=path*** - path to directory with PBS server's log files.
- ***gnu_time=path*** - path to *time* utility.
- ***tmpdir=path*** - path to directory for temporary files.

- ***runtime_dir***=*path* - path to directory which contains *runtimeenvironment* scripts.
- ***shared_filesystem***=*yes|no* - if computing nodes have an access to session directory through a shared filesystem like NFS. Corresponds to an environment variable `RUNTIME_NODE_SEES_FRONTEND` (see section 9.3).
- ***nodename***=*command* - command to obtain hostname of computing node.
- ***scratchdir***=*path* - path on computing node where to move session directory before execution.
- ***shared_scratch***=*path* - path on frontend where ***scratchdir*** can be found.

In the command arguments (paths, executables, ...) following substitutions can be used:

%R	- session root - see command <i>session</i>
%C	- control dir - see command <i>control</i>
%U	- username
%u	- userid - numerical
%g	- groupid - numerical
%H	- home dir - home specified in <code>/etc/passwd</code>
%Q	- default queue - look command 'defaultlrms'
%L	- default lrms - look command 'defaultlrms'
%W	- installation path - <code>\${NORDUGRID_LOCATION}</code>
%G	- globus path - <code>\${GLOBUS_LOCATION}</code>
%c	- list of all control directories
%I	- job's ID (for plugins only, substituted in runtime)
%S	- job's state (for <i>authplugin</i> plugins only, substituted in runtime)
%O	- reason (for <i>localcred</i> plugins only, substituted in runtime). Possible reasons are:
new	- new job, new credentials
renew	- old job, new credentials
write	- write/delete file, create/delete directory
read	- read file, directory, etc.
extern	- call external program

9.2 Authorization

Authorization is performed by generic means provided by HED framework. Currently A-REX does not implement any internal authorization techniques except those imposed by Access Policy assigned to jobs through AccessControl element of assigned JSDL.

9.3 LRMS support

The A-REX comes with support for several LRMS. And this number is slowly growing. Features explained below are for **PBS/Torque** backend. This support is provided through *submit-pbs-job*, *cancel-pbs-job*, *scan-pbs-job* scripts. *submit-pbs-job* creates job's script and submits it to PBS. Created job's script is responsible for moving data between frontend machine and cluster node (if required) and execution of actual job. Alternatively it can download input files and upload output if "*localtransfer=no*" is specified in the configuration file.

Behavior of submission script is mostly controlled using environment variables. Most of them can be specified on frontend in A-REX's environment and overwritten on cluster's node through PBS configuration. Some of them may be set in configuration file too.

PBS_BIN_PATH - path to PBS executables. Like */usr/local/bin* for example. Corresponds to *pbs_bin_path* configuration command.

PBS_LOG_PATH - path to PBS server logs. Corresponds to *pbs_log_path* configuration command.

TMP_DIR - path to directory to store temporary files. Default value is */tmp*. Corresponds to *tmpdir* configuration command.

RUNTIME_CONFIG_DIR - path where runtime setup scripts can be found. Corresponds to *runtime_dir* configuration command.

GNU_TIME - path to GNU time utility. It is important to provide path to utility compatible with GNU time. If such utility is not available, modify *submit-pbs-job* to either reset this variable or change usage of available utility. Corresponds to *gnu_time* configuration command.

NODENAME - command to obtain name of cluster's node. Default is */bin/hostname -f*. Corresponds to *nodename* configuration command.

RUNTIME_LOCAL_SCRATCH_DIR - if defined should contain path to the directory on computing node, which can be used to store job's files during execution. *scratchdir* configuration command.

RUNTIME_FRONTEND_SEES_NODE - if defined should contain path corresponding to **RUNTIME_LOCAL_SCRATCH_DIR** as seen on **frontend** machine. Corresponds to *shared_scratch* configuration command.

RUNTIME_NODE_SEES_FRONTEND - if set to "*no*" means computing node does not share filesystem with frontend. In that case content of the SD is moved to computing node by using means provided by the LRMS. Results are moved back after job's execution in a same way. Corresponds to *shared_filesystem* configuration command.

Figures 2,3,4 present some possible combinations for **RUNTIME_LOCAL_SCRATCH_DIR** and **RUNTIME_FRONTEND_SEES_NODE** and explain how data movement is performed. Pictures a) correspond to the situation right after all input files have been gathered in the session directory and show the actions taken right after the job's script starts. Pictures b) show the situation while the job is running and the actions which are taken right after it has finished. Pictures c) illustrate the final situation, when the job's output files are ready to be uploaded to an external storage element or be downloaded by the user.

9.4 Runtime environment

The A-REX can run specially prepared **BASH** scripts prior creation of job's script, before and after executing job's main executable. Those scripts are requested by user through *runtimeenvironment* attribute in RSL and are run with only argument set equal to '0', '1' or '2' during creation of job's script, before execution of main executable and after main executable finished accordingly. They all are run through **BASH**'s 'source' command, and hence can manipulate

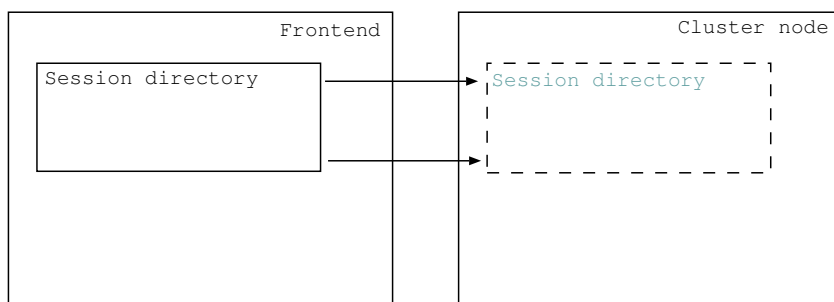


Figure 2: Both `RUNTIME_LOCAL_SCRATCH_DIR` and `RUNTIME_FRONTEND_SEES_NODE` are undefined. It is assumed that session directories are visible from computing nodes. The job is executed directly in the session directory prepared by the A-REX on the frontend.

shell variables. With argument '0' scripts are run by the A-REX on frontend. Some environment variables are defined in that case and can be changed to influence job's execution later:

- `joboption_directory` - session directory.
- `joboption_args` - command to be executed as specified in RSL.
- `joboption_env_#` - array of 'NAME=VALUE' environment variables (**not** bash array).
- `joboption_runtime_#` - array of requested *runtimeenvironment* names (**not** bash array).
- `joboption_num` - *runtimeenvironment* currently beeing processed (number starting from 0).
- `joboption_stdin` - name of file to be attached to stdin handle.
- `joboption_stdout` - same for stdout.
- `joboption_stderr` - same for stderr.
- `joboption_maxcputime` - amout of CPU time requested (minutes).
- `joboption_maxmemory` - amout of memory requested (megabytes).
- `joboption_count` - number of processors requested.
- `joboption_lrms` - LRMS to be used to run job.
- `joboption_queue` - name of a queue of LRMS to put job into.
- `joboption_nodeproperty_#` - array of properties of computing nodes (LRMS specific, **not** bash array).
- `joboption_jobname` - name of the job as given by user.
- `joboption_rsl` - whole RSL for very clever submission scripts.
- `joboption_rsl_name` - RSL attributes and values (like `joboption_rsl_executable="/bin/echo"`)

For example `joboption_args` could be changed to wrap main executable. Or `joboption_runtime` could be expanded if current one depends on others.

With argument '1' scripts are run just before main executable is run. They are executed on computing node. Such script can prepare environment for some third-party software package. A current directory in that case is one which would be used for execution of job. Variable `HOME` also points to that directory.

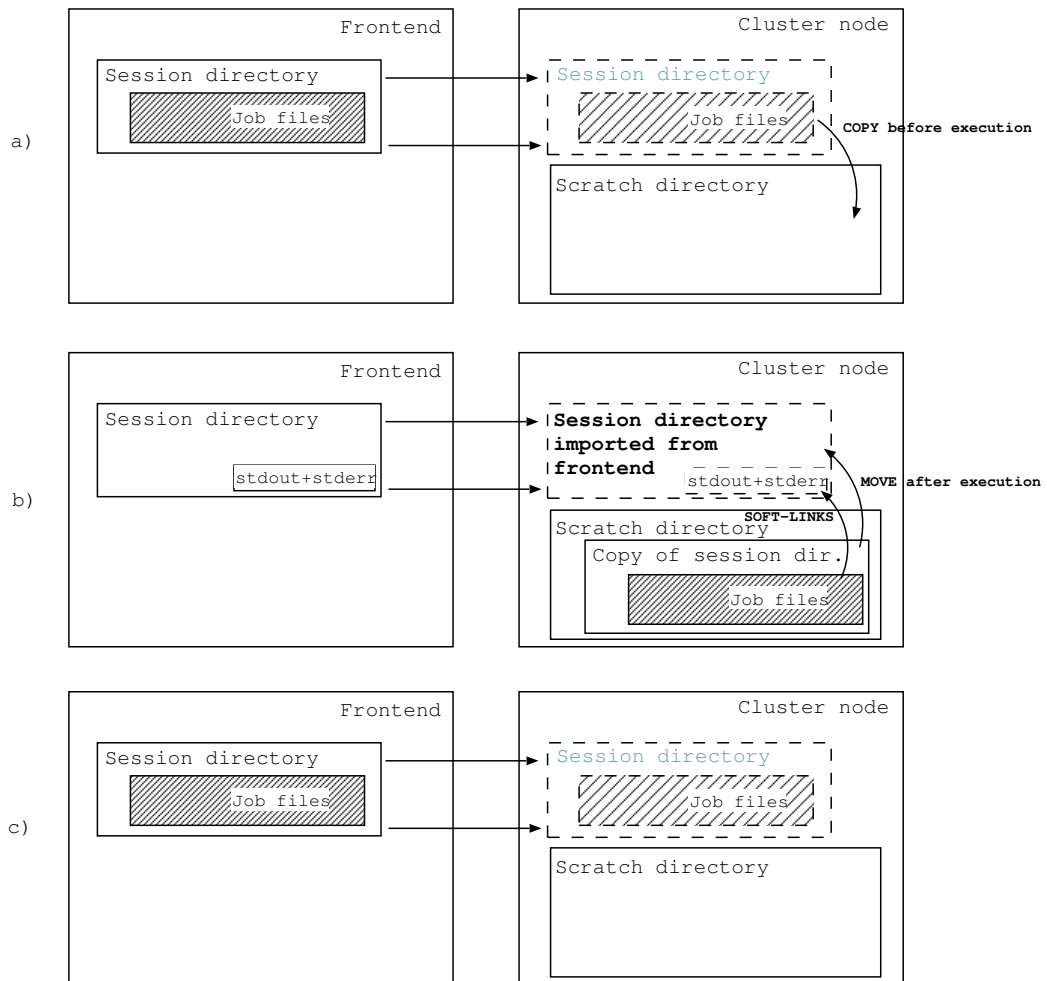


Figure 3: `RUNTIME_LOCAL_SCRATCH_DIR` is set to the location of the scratch directory on the computing node, `RUNTIME_FRONTEND_SEES_NODE` is undefined.

- a) After the job script starts all input files are moved to 'scratch directory' on the computing node.
- b) The job runs in a separate directory in 'scratch directory'. Only the files representing the job's *stdout* and *stderr* are placed in the original 'session directory' and soft-linked in 'scratch'. After execution all files from 'scratch' are moved back to the original 'session directory'.
- c) All output files are in 'session directory' and are ready to be uploaded/downloaded.

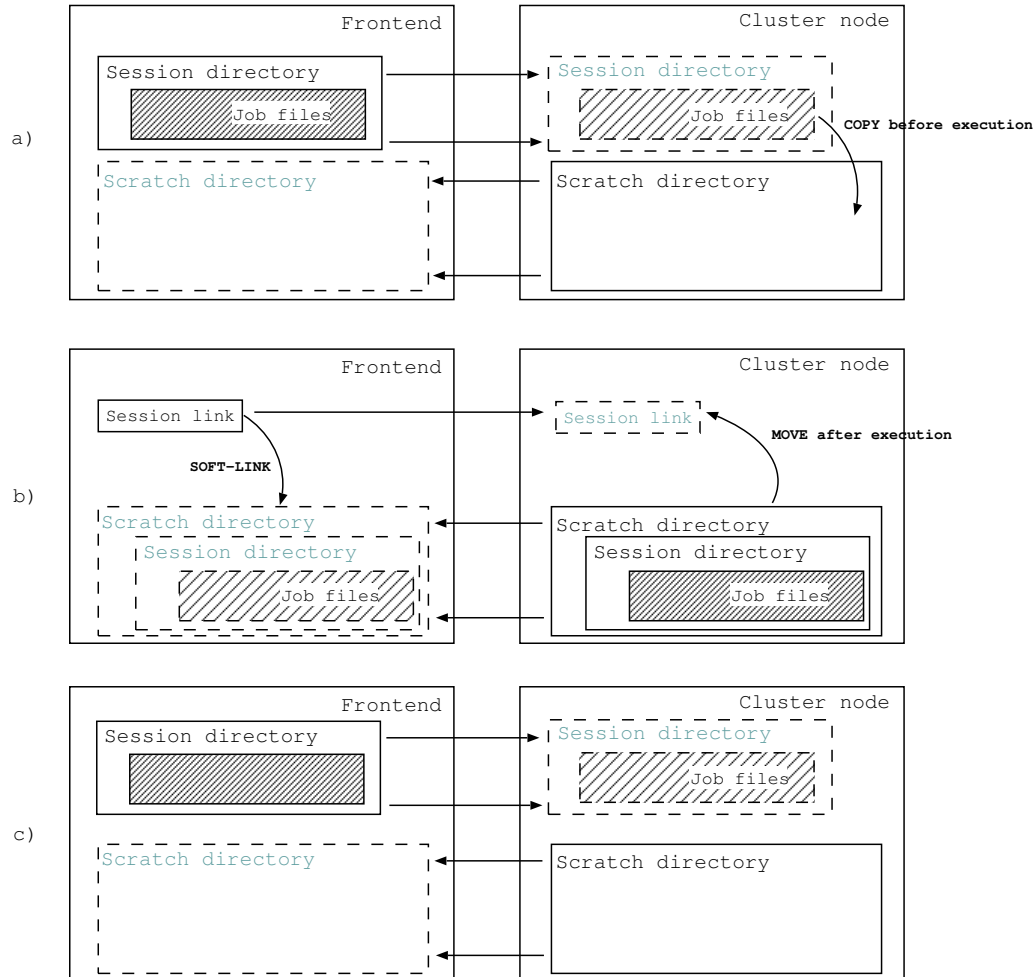


Figure 4: Both `RUNTIME_LOCAL_SCRATCH_DIR` and `RUNTIME_FRONTEND_SEES_NODE` are set to the location of the scratch directory on the computing node and the location where this scratch directory is accessible from the frontend, respectively.

- a) After the job script starts all input files are moved to 'scratch directory' on the computing node. The original 'session directory' is removed and replaced with a soft-link to copy of session directory in 'scratch directory' as seen on the frontend.
- b) The job runs in a separate directory in 'scratch directory'. All files are also available on frontend through the soft-link. After execution the soft-link is replaced with a directory and all files from 'scratch' are moved back to the original 'session directory'.
- c) All output files are in 'session directory' and are ready to be uploaded/downloaded.

With argument '2' scripts are executed after main executable finished. Main purpose is to clean possible changes done by scripts run with '1' (like removing temporary files). Execution of scripts at that stage also happens on computing node and is not reliable. If the job is killed by LRMS they most probably won't be executed.

For publicly available runtime environments please see RTE <http://gridrer.csc.fi/> .

10 Installation

The A-REX is installed as part of ARC 1 middleware and is available in NorduGrid download area at ARC1 Download <http://download.nordugrid.org/software/nordugrid-arc1/> .There are packages available for various Linux distributions. The A-REX comes in nordugrid-arc1-arex package. Source code ready for compilation is available too.

10.1 Requirements

If installed from binary packages all dependencies are handled automatically. For compilation from source code please read included README file.

10.2 Setup of the A-REX

The A-REX service is a pluggable module of the HED. Si first You need to setup your HED - see HED documentation. Then You need to add A-REX to the HED configuration. Add new <Name> element inside <Plugins> containing string *arex*. That will make HED load libarex plugin library. Then add new <Service> element with attribute name="a-rex". That will instantiate A-REX service. Now to make service accessible extend <Plexer> element with new <next> referring to service's id. Write <Service> element carefully - here is an example:

```
<!-- A-Rex service -->
<Service name="a-rex" id="a-rex">
  <!-- Optional endpoint element is advised in case of multiple IP adresses -->
  <arex:endpoint>https://localhost:60000/arex</arex:endpoint>
  <!-- Use information generated by identity.map plugin or default provided below -->
  <arex:usermap><arex:defaultLocalName>nobody</arex:defaultLocalName></arex:usermap>
  <!-- grid-manager part of a-rex requires legacy configuration file.
       Use arc_arex.conf example or write own. -->
  <arex:gmconfig>/etc/arc_arex.conf</arex:gmconfig>
</Service>
```

For in-depth information about available elements see Appendix B.

Use a template `arc_arex.conf` or write own A-REX configuration file. For information about format and available configuration commands see Section 9.1.

10.3 Usage

Please read *User Manual* [] for usage instructions.

10.4 Running as non-root

The A-REX is primarily designed to be run by the *root* UNIX account and serve multiple global Grid identities mapped to several UNIX accounts. Nevertheless it is possible to use *non-root* accounts to run that service at the cost of some functionality loss as described below.

There are no drawbacks of running A-REX under a *non-root* account as long as the only UNIX identity used is that of the user who runs the services and all served files and directories are owned by the server's account. Because A-REX has to impersonate a user's local account while communicating with the LRMS, it can serve only the account it is run under (unless it is run under the *root* account, of course).

Appendix A. Session directory access through HTTP(S) interface

In addition to the BES interface A-REX provides access to the SD through pure HTTP(S) interface. This functionality is used for uploading user-stageable files during job submission and for staging out result files produced by job. It can also be used to monitor job execution by checking content of application dependant files in SD.

The BES defines job identifier as WS Addressing [] Endpoint Reference (EPR) - XML document. The EPR is extendable and the A-REX adds its own element `JobSessionDir` belonging to namespace `http://www.nordugrid.org/schemas/a-rex` as direct child of `ReferenceParameters` element. This new element contains the URL of SD.

Obtained URL should be extended with file names relative to SD and HTTP methods PUT and GET may be used to upload/download content of those files. For directories - including SD itself - GET method is supported which returns HTML encoded non-recursive list of files and directories. The files and subdirectories have their URLs inside HTML element `<A>`.

Appendix B. Configuration schema of A-REX

```
<?xml version="1.0" encoding="UTF-8"?>
<xsd:schema
  xmlns:xsd="http://www.w3.org/2001/XMLSchema"
  xmlns="http://www.nordugrid.org/schemas/ArcConfig/2007/arex"
  xmlns:arc="http://www.nordugrid.org/schemas/ArcConfig/2007/arex"
  targetNamespace="http://www.nordugrid.org/schemas/ArcConfig/2007/arex"
  elementFormDefault="qualified">
  <xsd:complexType name="endpoint_Type">
    <!--
      This element defines URL of A-REX service as seen from outside.
    -->
    <xsd:simpleContent>
      <xsd:extension base="xsd:string">
      </xsd:extension>
    </xsd:simpleContent>
  </xsd:complexType>
  <xsd:element name="endpoint" type="endpoint_Type"/>
  <xsd:complexType name="gmconfig_Type">
    <!--
      This element defines path to arc0 Grid Manager configuration file.
```

```

By default it is /etc/arc.conf.
-->
<xsd:simpleContent>
  <xsd:extension base="xsd:string">
  </xsd:extension>
</xsd:simpleContent>
</xsd:complexType>
<xsd:element name="gmconfig" type="gmconfig_Type"/>
<xsd:simpleType name="gmruntime_Type">
  <!--
  This element defines how grid-manager part of A-Rex is run.
  * internal - as a thread inside service container.
  * none - no grid-manager is run.
  * external - as a separate executable (not supported anymore).
  Default is 'internal'.
  -->
  <xsd:restriction base="xsd:string">
    <xsd:enumeration value="internal"/>
    <xsd:enumeration value="external"/>
    <xsd:enumeration value="none"/>
  </xsd:restriction>
</xsd:simpleType>
<xsd:element name="gmruntime" type="gmruntime_Type"/>
<xsd:complexType name="usermap_Type">
  <xsd:sequence>
    <xsd:element name="defaultLocalName" type="xsd:string" minOccurs="0"/>
  </xsd:sequence>
</xsd:complexType>
<xsd:element name="usermap" type="usermap_Type"/>
<!-- CommonName attribute of bes-factory. -->
<xsd:element name="commonName" type="xsd:string"/>
<!-- LongDescription attribute of bes-factory. -->
<xsd:element name="longDescription" type="xsd:string"/>
<!-- Name of Local Resource Management System. -->
<xsd:element name="LRMSName" type="xsd:string"/>
<!--
Name of Operating System.
The values are based on the OStype field of the CIM_OperatingSystem model:
http://www.dmtf.org/standards/cim/cim_schema_v29
-->
<xsd:element name="OperatingSystem" type="xsd:string"/>
</xsd:schema>

```

Appendix C. A-REX WSDL

```
<?xml version="1.0" encoding="UTF-8"?>
```

```

<wsdl:definitions targetNamespace="http://www.nordugrid.org/schemas/a-rex"
  xmlns:SOAP-ENV="http://schemas.xmlsoap.org/soap/envelope/"
  xmlns:SOAP-ENC="http://schemas.xmlsoap.org/soap/encoding/"
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xmlns:xsd="http://www.w3.org/2001/XMLSchema"
  xmlns:soap="http://schemas.xmlsoap.org/wsdl/soap/"
  xmlns:wsdl="http://schemas.xmlsoap.org/wsdl/"
  xmlns:wsa="http://www.w3.org/2005/08/addressing"
  xmlns:bes-factory="http://schemas.ggf.org/bes/2006/08/bes-factory"
  xmlns:bes-mgmt="http://schemas.ggf.org/bes/2006/08/bes-management"
  xmlns:deleg="http://www.nordugrid.org/schemas/delegation"
  xmlns:wsrf-rpw="http://docs.oasis-open.org/wsrf/rpw-2"
  xmlns:a-rex="http://www.nordugrid.org/schemas/a-rex">
  <wsdl:import namespace="http://schemas.ggf.org/bes/2006/08/bes-factory" location="./bes-factory.wsdl"/>
  <wsdl:import namespace="http://schemas.ggf.org/bes/2006/08/bes-management" location="./bes-management.wsdl"/>
  <wsdl:import namespace="http://www.nordugrid.org/schemas/delegation" location="./schemas/delegation.wsdl"/>
  <wsdl:import namespace="http://docs.oasis-open.org/wsrf/rpw-2" location="http://docs.oasis-open.org/wsrf/rpw-2/wsrf-rpw-2.xsd"/>
  <wsdl:types>
    <xsd:schema targetNamespace="http://www.nordugrid.org/schemas/a-rex">
      <xsd:import namespace="http://www.w3.org/2005/08/addressing" schemaLocation="./ws-addr.xsd"/>
      <xsd:simpleType name="ActivitySubStateType">
        <xsd:restriction base="xsd:string">
          <xsd:enumeration value="Accepting"/>
          <xsd:enumeration value="Accepted"/>
          <xsd:enumeration value="Preparing"/>
          <xsd:enumeration value="Prepared"/>
          <xsd:enumeration value="Submitting"/>
          <xsd:enumeration value="Executing"/>
          <xsd:enumeration value="Killing"/>
          <xsd:enumeration value="Executed"/>
          <xsd:enumeration value="Finishing"/>
          <xsd:enumeration value="Finished"/>
          <xsd:enumeration value="Failed"/>
          <xsd:enumeration value="Deleted"/>
          <xsd:enumeration value="Pending"/>
          <xsd:enumeration value="Held"/>
        </xsd:restriction>
      </xsd:simpleType>
      <xsd:element name="State" type="a-rex:ActivitySubStateType"/>
      <xsd:complexType name="ResourceInformationDocumentType">
        <xsd:sequence>
          <xsd:element name="BESFactory" type="bes-factory:FactoryResourceAttributesDocumentType"/>
          <xsd:complexType name="Glue2Resource" minOccurs="0">
            <xsd:sequence>
              <xsd:any namespace="##other" processContents="lax" minOccurs="0" maxOccurs="unbounded"/>
            </xsd:sequence>
          </xsd:complexType>
        </xsd:sequence>
      </xsd:complexType>
    </xsd:schema>
  </wsdl:types>
</wsdl:definitions>

```

```

    <xsd:complexType name="Activities" minOccurs='0'>
      <xsd:sequence>
        <xsd:complexType name="Activity" minOccurs='0' maxOccurs='unbounded'>
          <xsd:sequence>
            <xsd:element name="ActivityIdentifier" type="wsa:EndpointReferenceType"/>
            <xsd:element ref="bes-factory:ActivityDocument" minOccurs='0' />
            <xsd:complexType name="Glue2Job" minOccurs='0'>
              <xsd:sequence>
                <xsd:any namespace="##other" processContents="lax" minOccurs="0" maxOccurs="1" />
              </xsd:sequence>
            </xsd:complexType>
          </xsd:sequence>
        </xsd:complexType>
      </xsd:sequence>
    </xsd:complexType>
  </xsd:sequence>
</xsd:complexType>
<xsd:complexType name="ChangeActivityStatusRequestType">
  <xsd:sequence>
    <xsd:element name="ActivityIdentifier" type="wsa:EndpointReferenceType"/>
    <xsd:element name="OldStatus" type="bes-factory:ActivityStatusType" minOccurs="0"/>
    <xsd:element name="NewStatus" type="bes-factory:ActivityStatusType"/>
  </xsd:sequence>
</xsd:complexType>
<xsd:element name="ChangeActivityStatus" type="a-rex:ChangeActivityStatusRequestType"/>
<xsd:complexType name="ChangeActivityStatusResponseType">
  <xsd:sequence>
    <xsd:element name="NewStatus" type="bes-factory:ActivityStatusType"/>
  </xsd:sequence>
</xsd:complexType>
<xsd:element name="ChangeActivityStatusResponse" type="a-rex:ChangeActivityStatusResponseType"/>
</xsd:schema>
</wsdl:types>
<wsdl:message name="ChangeActivityStatusRequest">
  <wsdl:part name="ChangeActivityStatusRequest" element="a-rex:ChangeActivityStatus"/>
</wsdl:message>
<wsdl:message name="ChangeActivityStatusResponse">
  <wsdl:part name="ChangeActivityStatusResponse" element="a-rex:ChangeActivityStatusResponse"/>
</wsdl:message>
<wsdl:portType name="a-rex">
  <wsdl:operation name="ChangeActivityStatus">
    <wsdl:documentation>
      This operation allows any simple status change request
      which involves no additional parameters. It should be
      used to modify job/activity execution flow:
      - To put job on hold
      - To rerun job in case of failure
    </wsdl:documentation>
  </wsdl:operation>
</wsdl:portType>
</wsdl:binding>
</wsdl:service>
</wsdl:definitions>

```

- To cancel job (same as TerminateActivity of BESFactory)
- To remove/release job - as long as non-existence is a state
- Any other status change not supported by BES

```

</wsdl:documentation>
<wsdl:input name="ChangeActivityStatusRequest"
  message="a-rex:ChangeActivityStatusRequest"/>
<wsdl:output name="ChangeActivityStatusResponse"
  message="a-rex:ChangeActivityStatusResponse"/>
<wsdl:fault name="NotAuthorizedFault"
  message="bes-factory:NotAuthorizedFault"
  wsa:Action="http://schemas.ggf.org/bes/2006/08/bes-factory/BESFactoryPortType/Fault"/>
<wsdl:fault name="InvalidActivityIdentifierFault"
  message="bes-factory:InvalidActivityIdentifierFault"
  wsa:Action="http://schemas.ggf.org/bes/2006/08/bes-factory/BESFactoryPortType/Fault"/>
<wsdl:fault name="CantApplyOperationToCurrentStateFault"
  message="bes-factory:CantApplyOperationToCurrentStateFault"
  wsa:Action="http://schemas.ggf.org/bes/2006/08/bes-factory/BESFactoryPortType/Fault"/>
<wsdl:fault name="OperationWillBeAppliedEventuallyFault"
  message="bes-factory:OperationWillBeAppliedEventuallyFault"
  wsa:Action="http://schemas.ggf.org/bes/2006/08/bes-factory/BESFactoryPortType/Fault"/>
</wsdl:operation>
</wsdl:portType>
<wsdl:binding name="a-rex" type="a-rex:a-rex">
  <soap:binding style="document" transport="http://schemas.xmlsoap.org/soap/http"/>
  <wsdl:operation name="ChangeActivityStatus">
    <soap:operation soapAction="ChangeActivityStatus"/>
    <wsdl:input name="ChangeActivityStatusRequest">
      <soap:body use="literal"/>
    </wsdl:input>
    <wsdl:output name="ChangeActivityStatusResponse">
      <soap:body use="literal"/>
    </wsdl:output>
    <wsdl:fault name="NotAuthorizedFault">
      <soap:fault name="NotAuthorizedFault" use="literal" />
    </wsdl:fault>
    <wsdl:fault name="InvalidActivityIdentifierFault">
      <soap:fault name="InvalidActivityIdentifierFault" use="literal" />
    </wsdl:fault>
    <wsdl:fault name="CantApplyOperationToCurrentStateFault">
      <soap:fault name="CantApplyOperationToCurrentStateFault" use="literal" />
    </wsdl:fault>
    <wsdl:fault name="OperationWillBeAppliedEventuallyFault">
      <soap:fault name="OperationWillBeAppliedEventuallyFault" use="literal" />
    </wsdl:fault>
  </wsdl:operation>
</wsdl:binding>
<wsdl:binding name="GetResourcePropertyDocument" type="wsrf-rpw:GetResourcePropertyDocument">

```

```

<soap:binding style="document" transport="http://schemas.xmlsoap.org/soap/http"/>
<wsdl:operation name="GetResourcePropertyDocument">
  <soap:operation soapAction="GetResourcePropertyDocument"/>
  <wsdl:input name="wsrf-rpw:GetResourcePropertyDocumentRequest">
    <soap:body use="literal"/>
  </wsdl:input>
  <wsdl:output name="wsrf-rpw:GetResourcePropertyDocumentResponse">
    <soap:body use="literal"/>
  </wsdl:output>
  <wsdl:fault name="ResourceUnknownFault">
    <soap:fault name="ResourceUnknownFault" use="literal" />
  </wsdl:fault>
  <wsdl:fault name="ResourceUnavailableFault">
    <soap:fault name="ResourceUnavailabbleFault" use="literal" />
  </wsdl:fault>
</wsdl:operation>
</wsdl:binding>
<wsdl:binding name="GetResourceProperty" type="wsrf-rpw:GetResourceProperty">
  <soap:binding style="document" transport="http://schemas.xmlsoap.org/soap/http"/>
  <wsdl:operation name="GetResourceProperty">
    <soap:operation soapAction="GetResourceProperty"/>
    <wsdl:input name="wsrf-rpw:GetResourcePropertyRequest">
      <soap:body use="literal"/>
    </wsdl:input>
    <wsdl:output name="wsrf-rpw:GetResourcePropertyResponse">
      <soap:body use="literal"/>
    </wsdl:output>
    <wsdl:fault name="ResourceUnknownFault">
      <soap:fault name="ResourceUnknownFault" use="literal" />
    </wsdl:fault>
    <wsdl:fault name="ResourceUnavailableFault">
      <soap:fault name="ResourceUnavailabbleFault" use="literal" />
    </wsdl:fault>
    <wsdl:fault name="InvalidResourcePropertyQNameFault">
      <soap:fault name="InvalidResourcePropertyQNameFault" use="literal" />
    </wsdl:fault>
  </wsdl:operation>
</wsdl:binding>
<wsdl:binding name="QueryResourceProperties" type="wsrf:QueryResourceProperties">
  <soap:binding style="document" transport="http://schemas.xmlsoap.org/soap/http"/>
  <wsdl:operation name="QueryResourceProperties">
    <soap:operation soapAction="QueryResourceProperties"/>
    <wsdl:input name="wsrf-rpw:QueryResourcePropertiesRequest">
      <soap:body use="literal"/>
    </wsdl:input>
    <wsdl:output name="wsrf-rpw:QueryResourcePropertiesResponse">
      <soap:body use="literal"/>
    </wsdl:output>
  </wsdl:operation>
</wsdl:binding>

```

```

</wsdl:output>
<wsdl:fault name="ResourceUnknownFault">
  <soap:fault name="ResourceUnknownFault" use="literal" />
</wsdl:fault>
<wsdl:fault name="ResourceUnavailableFault">
  <soap:fault name="ResourceUnavailabbbleFault" use="literal" />
</wsdl:fault>
<wsdl:fault name="InvalidResourcePropertyQNameFault">
  <soap:fault name="InvalidResourcePropertyQNameFault" use="literal" />
</wsdl:fault>
<wsdl:fault name="UnknownQueryExpressionDialectFault">
  <soap:fault name="UnknownQueryExpressionDialectFault" use="literal" />
</wsdl:fault>
<wsdl:fault name="InvalidQueryExpressionFault">
  <soap:fault name="InvalidQueryExpressionFault" use="literal" />
</wsdl:fault>
<wsdl:fault name="QueryEvaluationErrorFault">
  <soap:fault name="QueryEvaluationErrorFault" use="literal" />
</wsdl:fault>
</wsdl:operation>
</wsdl:binding>
<wsdl:service name="a-rex">
  <wsdl:port name="delegation" binding="deleg:DelegationBinding">
  </wsdl:port>
  <wsdl:port name="bes-factory" binding="bes-factory:BESFactoryBinding">
  </wsdl:port>
  <wsdl:port name="bes-mgmt" binding="bes-mgmt:BESManagementBinding">
  </wsdl:port>
  <wsdl:port name="GetResourcePropertyDocument" binding="a-rex:GetResourcePropertyDocument">
  </wsdl:port>
  <wsdl:port name="GetResourceProperty" binding="a-rex:GetResourceProperty">
  </wsdl:port>
  <wsdl:port name="QueryResourceProperties" binding="a-rex:QueryResourceProperties">
  </wsdl:port>
  <wsdl:port name="a-rex" binding="a-rex:a-rex">
  </wsdl:port>
</wsdl:service>
</wsdl:definitions>

```

Appendix D. Delegation WSDL

```

<?xml version="1.0" encoding="UTF-8"?>
<wsdl:definitions targetNamespace="http://www.nordugrid.org/schemas/delegation"
  xmlns:SOAP-ENV="http://schemas.xmlsoap.org/soap/envelope/"
  xmlns:SOAP-ENC="http://schemas.xmlsoap.org/soap/encoding/"
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"

```



```

xmlns:xsd="http://www.w3.org/2001/XMLSchema"
xmlns:soap="http://schemas.xmlsoap.org/wsdl/soap/"
xmlns:wsdl="http://schemas.xmlsoap.org/wsdl/"
xmlns:wsa="http://www.w3.org/2005/08/addressing"
xmlns:deleg="http://www.nordugrid.org/schemas/delegation">
  <wsdl:types>
    <xsd:schema targetNamespace="http://www.nordugrid.org/schemas/delegation">
      <!-- Common types -->
      <xsd:simpleType name="TokenFormatType">
        <xsd:restriction base="xsd:string">
          <xsd:enumeration value="x509"/>
        </xsd:restriction>
      </xsd:simpleType>
      <xsd:complexType name="ReferenceType">
        <xsd:sequence>
          <xsd:any namespace="##other" processContents="lax" minOccurs="0" maxOccurs="unbounded"/>
        </xsd:sequence>
      </xsd:complexType>
      <xsd:complexType name="DelegatedTokenType">
        <xsd:sequence>
          <xsd:element name="Id" type="xsd:string"/>
          <xsd:element name="Value" type="xsd:string"/>
          <xsd:element name="Reference" type="deleg:ReferenceType" minOccurs="0" maxOccurs="unbounded"/>
        </xsd:sequence>
        <xsd:attribute name="Format" type="deleg:TokenFormatType" use="required"/>
      </xsd:complexType>
      <xsd:element name="DelegatedToken" type="deleg:DelegatedTokenType"/>
      <xsd:complexType name="TokenRequestType">
        <xsd:sequence>
          <xsd:element name="Id" type="xsd:string"/>
          <xsd:element name="Value" type="xsd:string"/>
        </xsd:sequence>
        <xsd:attribute name="Format" type="deleg:TokenFormatType" use="required"/>
      </xsd:complexType>
      <xsd:element name="TokenRequest" type="deleg:TokenRequestType"/>
      <!-- Types for messages -->
      <xsd:complexType name="DelegateCredentialsInitRequestType">
        <xsd:sequence>
          <xsd:element name="TokenRequest" type="deleg:TokenRequestType"/>
        </xsd:sequence>
      </xsd:complexType>
      <xsd:element name="DelegateCredentialsInit" type="deleg:DelegateCredentialsInitRequestType"/>
      <xsd:complexType name="DelegateCredentialsInitResponseType">
        <xsd:sequence>
          <xsd:element name="TokenRequest" type="deleg:TokenRequestType"/>
        </xsd:sequence>
      </xsd:complexType>
      <xsd:element name="DelegateCredentialsInitResponse" type="deleg:DelegateCredentialsInitResponseType"/>
    </xsd:schema>
  </wsdl:types>

```

```

<xsd:complexType name="UpdateCredentialsRequestType">
  <xsd:sequence>
    <xsd:element name="DelegatedToken" type="deleg:DelegatedTokenType"/>
  </xsd:sequence>
</xsd:complexType>
<xsd:element name="UpdateCredentials" type="deleg:UpdateCredentialsRequestType"/>
<xsd:complexType name="UpdateCredentialsResponseType">
  <xsd:sequence>
  </xsd:sequence>
</xsd:complexType>
<xsd:element name="UpdateCredentialsResponse" type="deleg:UpdateCredentialsResponseType"/>
<!-- Faults -->
<xsd:complexType name="UnsupportedFaultType">
  <xsd:sequence>
    <xsd:element name="Description" type="xsd:string" minOccurs="0"/>
  </xsd:sequence>
</xsd:complexType>
<xsd:element name="UnsupportedFault" type="deleg:UnsupportedFaultType"/>
<xsd:complexType name="ProcessingFaultType">
  <xsd:sequence>
    <xsd:element name="Description" type="xsd:string" minOccurs="0"/>
  </xsd:sequence>
</xsd:complexType>
<xsd:element name="ProcessingFault" type="deleg:ProcessingFaultType"/>
<xsd:complexType name="WrongReferenceFaultType">
  <xsd:sequence>
    <xsd:element name="Description" type="xsd:string" minOccurs="0"/>
  </xsd:sequence>
</xsd:complexType>
<xsd:element name="WrongReferenceFault" type="deleg:WrongReferenceFaultType"/>
</xsd:schema>
</wsdl:types>
<wsdl:message name="DelegateCredentialsInitRequest">
  <wsdl:part name="DelegateCredentialsInitRequest" element="deleg:DelegateCredentialsInit"/>
</wsdl:message>
<wsdl:message name="DelegateCredentialsInitResponse">
  <wsdl:part name="DelegateCredentialsInitResponse" element="deleg:DelegateCredentialsInitResponse"/>
</wsdl:message>
<wsdl:message name="UpdateCredentialsRequest">
  <wsdl:part name="UpdateCredentialsRequest" element="deleg:UpdateCredentials"/>
</wsdl:message>
<wsdl:message name="UpdateCredentialsResponse">
  <wsdl:part name="UpdateCredentialsResponse" element="deleg:UpdateCredentialsResponse"/>
</wsdl:message>
<wsdl:message name="UnsupportedFault">
  <wsdl:part name="Detail" element="deleg:UnsupportedFault"/>
</wsdl:message>

```

```

<wsdl:message name="ProcessingFault">
  <wsdl:part name="Detail" element="deleg:ProcessingFault"/>
</wsdl:message>
<wsdl:message name="WrongReferenceFault">
  <wsdl:part name="Detail" element="deleg:WrongReferenceFault"/>
</wsdl:message>
<wsdl:portType name="DelegationPortType">
  <wsdl:operation name="DelegateCredentialsInit">
    <wsdl:documentation>
    </wsdl:documentation>
    <wsdl:input name="DelegateCredentialsInitRequest"
      message="deleg:DelegateCredentialsInitRequest"/>
    <wsdl:output name="DelegateCredentialsInitResponse"
      message="deleg:DelegateCredentialsInitResponse"/>
    <wsdl:fault name="UnsupportedFault"
      message="deleg:UnsupportedFault"/>
    <wsdl:fault name="ProcessingFault"
      message="deleg:ProcessingFault"/>
  </wsdl:operation>
  <wsdl:operation name="UpdateCredentials">
    <wsdl:documentation>
    </wsdl:documentation>
    <wsdl:input name="UpdateCredentialsRequest"
      message="deleg:UpdateCredentialsRequest"/>
    <wsdl:output name="UpdateCredentialsResponse"
      message="deleg:UpdateCredentialsResponse"/>
    <wsdl:fault name="UnsupportedFault"
      message="deleg:UnsupportedFault"/>
    <wsdl:fault name="ProcessingFault"
      message="deleg:ProcessingFault"/>
    <wsdl:fault name="WrongReferenceFault"
      message="deleg:WrongReferenceFault"/>
  </wsdl:operation>
</wsdl:portType>
<wsdl:binding name="DelegationBinding" type="deleg:DelegationPortType">
  <soap:binding style="document" transport="http://schemas.xmlsoap.org/soap/http"/>
  <wsdl:operation name="DelegateCredentialsInit">
    <soap:operation soapAction="DelegateCredentialsInit"/>
    <wsdl:input name="DelegateCredentialsInitRequest">
      <soap:body use="literal"/>
    </wsdl:input>
    <wsdl:output name="DelegateCredentialsInitResponse">
      <soap:body use="literal"/>
    </wsdl:output>
  </wsdl:operation>
  <wsdl:operation name="UpdateCredentials">
    <soap:operation soapAction="UpdateCredentials"/>

```

```

    <wsdl:input name="UpdateCredentialsRequest">
      <soap:body use="literal"/>
    </wsdl:input>
    <wsdl:output name="UpdateCredentialsResponse">
      <soap:body use="literal"/>
    </wsdl:output>
  </wsdl:operation>
</wsdl:binding>
</wsdl:definitions>

```

Appendix E. ARC extensions for JSDL schema

```

<?xml version="1.0" encoding="UTF-8"?>
<xsd:schema xmlns:xsd="http://www.w3.org/2001/XMLSchema"
  xmlns="http://www.nordugrid.org/ws/schemas/jsdl-arc"
  xmlns:jsdl-arc="http://www.nordugrid.org/ws/schemas/jsdl-arc"
  targetNamespace="http://www.nordugrid.org/ws/schemas/jsdl-arc">
  <xsd:simpleType name="GMState_Type">
    <xsd:restriction base="xsd:string">
      <xsd:enumeration value="ACCEPTED"/>
      <xsd:enumeration value="PREPARING"/>
      <xsd:enumeration value="SUBMIT"/>
      <xsd:enumeration value="INLRMS"/>
      <xsd:enumeration value="FINISHING"/>
      <xsd:enumeration value="FINISHED"/>
      <xsd:enumeration value="DELETED"/>
      <xsd:enumeration value="CANCELING"/>
    </xsd:restriction>
  </xsd:simpleType>
  <xsd:complexType name="Version_Type">
    <xsd:sequence>
      <xsd:element name="UpperExclusive" type="xsd:string" minOccurs="0"/>
      <xsd:element name="LowerExclusive" type="xsd:string" minOccurs="0"/>
      <xsd:element name="Exact" type="xsd:string" minOccurs="0" maxOccurs="unbounded"/>
      <xsd:element name="Exclusive" type="xsd:boolean" minOccurs="0"/>
    </xsd:sequence>
  </xsd:complexType>
  <xsd:simpleType name="SessionType_Type">
    <xsd:documentation> For jsdl:Resources_Type </xsd:documentation>
    <!-- xsd:element ref="SessionType" minOccurs="0" / -->
    <xsd:restriction base="xsd:string">
      <xsd:enumeration value="INTERNAL"/>
      <xsd:enumeration value="LIMITED"/>
      <xsd:enumeration value="READONLY"/>
      <xsd:enumeration value="FULL"/>
    </xsd:restriction>
  </xsd:simpleType>

```

```

</xsd:simpleType>
<xsd:simpleType name="IsExecutable_Type">
  <xsd:documentation> For jsdl:DataStaging_Type (default: false) </xsd:documentation>
  <!-- xsd:element ref="IsExecutable" minOccurs="0"/ -->
  <xsd:restriction base="xsd:boolean"/>
</xsd:simpleType>
<xsd:simpleType name="FileParameters_Type">
  <xsd:documentation> For jsdl:DataStaging_Type </xsd:documentation>
  <!-- xsd:element ref="IsExecutable" minOccurs="0"/ -->
  <xsd:restriction base="xsd:string"/>
</xsd:simpleType>
<xsd:simpleType name="JoinOutputs_Type">
  <xsd:documentation> For jsdl:JobDescription_Type (default: false) </xsd:documentation>
  <!-- xsd:element ref="JoinOutputs" minOccurs="0"/ -->
  <xsd:restriction base="xsd:boolean"/>
</xsd:simpleType>
<xsd:simpleType name="Reruns_Type">
  <xsd:documentation> For jsdl:JobDescription_Type (default: false) </xsd:documentation>
  <!-- xsd:element ref="Reruns" minOccurs="0"/ -->
  <xsd:restriction base="xsd:integer"/>
</xsd:simpleType>
<xsd:complexType name="RunTimeEnvironment_Type">
  <xsd:documentation> For jsdl:Resources_Type </xsd:documentation>
  <!-- xsd:element ref="RunTimeEnvironment" minOccurs="0" maxOccurs="unbounded"/ -->
  <xsd:sequence>
    <xsd:element name="Name" type="xsd:string"/>
    <xsd:element name="Version" type="Version_Type" minOccurs="0"/>
  </xsd:sequence>
</xsd:complexType>
<xsd:complexType name="Middleware_Type">
  <xsd:documentation> For jsdl:Resources_Type </xsd:documentation>
  <!-- xsd:element ref="Middleware" minOccurs="0" maxOccurs="unbounded"/ -->
  <xsd:sequence>
    <xsd:element name="Name" type="xsd:string"/>
    <xsd:element name="Version" type="Version_Type" minOccurs="0"/>
  </xsd:sequence>
</xsd:complexType>
<xsd:complexType name="RemoteLogging_Type">
  <xsd:documentation> For jsdl:JobDescription_Type </xsd:documentation>
  <!-- xsd:element ref="RemoteLogging" minOccurs="0" maxOccurs="3"/ -->
  <xsd:sequence>
    <xsd:element name="URL" minOccurs="1" maxOccurs="1" type="xsd:anyURI"/>
  </xsd:sequence>
</xsd:complexType>
<xsd:complexType name="CredentialServer_Type">
  <xsd:documentation> For jsdl:JobDescription_Type </xsd:documentation>
  <!-- xsd:element ref="CredentialServer" minOccurs="0"/ -->

```

```

<xsd:sequence>
  <xsd:element name="URL" minOccurs="1" maxOccurs="1" type="xsd:anyURI"/>
</xsd:sequence>
</xsd:complexType>
<xsd:complexType name="LocalLogging_Type">
  <xsd:documentation> For jsdl:JobDescription_Type </xsd:documentation>
  <!-- xsd:element ref="LocalLogging" minOccurs="0" maxOccurs="1"/ -->
  <xsd:sequence>
    <xsd:element name="Directory" minOccurs="1" maxOccurs="1" type="xsd:string"/>
  </xsd:sequence>
</xsd:complexType>
<xsd:simpleType name="AccessControlType_Type">
  <xsd:restriction base="xsd:string">
    <xsd:enumeration value="GACL"/>
  </xsd:restriction>
</xsd:simpleType>
<xsd:complexType name="AccessControl_Type">
  <xsd:documentation> For jsdl:JobDescription_Type </xsd:documentation>
  <!-- xsd:element ref="AccessControl" minOccurs="0"/ -->
  <xsd:sequence>
    <xsd:element name="OwnerAlwaysAllowed" type="xsd:boolean" minOccurs="0"/>
    <xsd:element name="Type" type="AccessControlType_Type" minOccurs="0"/>
    <xsd:element name="Content" minOccurs="0" type="xsd:string"/>
  </xsd:sequence>
</xsd:complexType>
<xsd:simpleType name="NotificationType_Type">
  <xsd:restriction base="xsd:string">
    <xsd:enumeration value="Email"/>
  </xsd:restriction>
</xsd:simpleType>
<xsd:complexType name="Notify_Type">
  <xsd:documentation> For jsdl:JobDescription_Type </xsd:documentation>
  <!-- xsd:element ref="Notify" minOccurs="0" maxOccurs="3"/ -->
  <xsd:sequence>
    <xsd:element name="Type" type="NotificationType_Type" minOccurs="0"/>
    <xsd:element name="Endpoint" minOccurs="0" type="xsd:string"/>
    <xsd:element name="State" minOccurs="1" maxOccurs="unbounded" type="GMState_Type"/>
  </xsd:sequence>
</xsd:complexType>
<xsd:simpleType name="SessionLifeTime_Type">
  <xsd:documentation> For jsdl:Resources_Type </xsd:documentation>
  <!-- xsd:element ref="SessionLifeTime" minOccurs="0" maxOccurs="1"/ -->
  <xsd:restriction base="xsd:long"/>
</xsd:simpleType>
<xsd:simpleType name="GridTimeLimit_Type">
  <xsd:documentation> For jsdl:Resources_Type </xsd:documentation>
  <!-- xsd:element ref="GridTimeLimit" minOccurs="0" maxOccurs="1"/ -->

```

```

    <xsd:restriction base="xsd:positiveInteger"/>
</xsd:simpleType>
<xsd:complexType name="CandidateTarget_Type">
  <xsd:documentation> For jsdl:Resources_Type </xsd:documentation>
  <!-- xsd:element ref="jsdl-arc:CandidateTarget" minOccurs="0" maxOccurs="1"/ -->
  <xsd:sequence>
    <xsd:element name="HostName" minOccurs="0" type="xsd:string"/>
    <xsd:element name="QueueName" minOccurs="0" type="xsd:string"/>
  </xsd:sequence>
</xsd:complexType>
<xsd:simpleType name="Time_Type">
  <xsd:documentation> For jsdl:JobDescription_Type </xsd:documentation>
  <!-- xsd:element ref="ProcessingStartTime" minOccurs="0" maxOccurs="1"/ -->
  <xsd:restriction base="xsd:dateTime"/>
</xsd:simpleType>
<!--=====-->
<xsd:element name="IsExecutable" type="IsExecutable_Type"/>
<xsd:element name="FileParameters" type="FileParameters_Type"/>
<xsd:element name="RunTimeEnvironment" type="RunTimeEnvironment_Type"/>
<xsd:element name="Middleware" type="Middleware_Type"/>
<xsd:element name="RemoteLogging" type="RemoteLogging_Type"/>
<xsd:element name="LocalLogging" type="LocalLogging_Type"/>
<xsd:element name="AccessControl" type="AccessControl_Type"/>
<xsd:element name="Notify" type="Notify_Type"/>
<xsd:element name="SessionLifeTime" type="SessionLifeTime_Type"/>
<xsd:element name="SessionType" type="SessionType_Type"/>
<xsd:element name="JoinOutputs" type="JoinOutputs_Type"/>
<xsd:element name="Reruns" type="Reruns_Type"/>
<xsd:element name="CredentialServer" type="CredentialServer_Type"/>
<xsd:element name="GridTimeLimit" type="GridTimeLimit_Type"/>
<xsd:element name="CandidateTarget" type="CandidateTarget_Type"/>
<xsd:element name="ProcessingStartTime" type="Time_Type"/>
</xsd:schema>

```

Appendix F. Error messages of A-REX

If job has not finished successfully the A-REX puts one or more lines into *job.ID.failed*. Possible values include those generated by the A-REX itself:

<i>Error string</i>	<i>Reason/description</i>
Internal error	Error in internal algorithm
Internal error: can't read local file	Error manipulating files in the control directory
Failed reading local job information	-/-
Failed reading status of the job	-/-
Failed writing job status	-/-
Failed during processing failure	-/-
Serious troubles (problems during processing problems)	-/-
Failed initiating job submission to LRMS	Could not run backend executable to pass job to LRMS
Job submission to LRMS failed	Backend executable supposed to pass job to LRMS returned non-zero exit code
Failed extracting LRMS ID due to some internal error	Output of Backend executable supposed to contain local ID of passed job could not be parsed
Failed in files upload (post-processing)	Failed to upload some or all output files
Failed in files upload due to expired credentials - try to renew	Failed to upload some or all output files most probably due to expired credentials (proxy certificate)
Failed to run uploader (post-processing)	Could not run <i>uploader</i> executable
uploader failed (postprocessing)	Generic error related to <i>uploader</i> component
Failed in files download (pre-processing)	Failed to upload some or all input files
Failed in files download due to expired credentials - try to renew	Failed to download some or all input files most probably due to expired credentials (proxy certificate)
Failed to run downloader (pre-processing)	Could not run <i>downloader</i> executable
downloader failed (preprocessing)	Generic error related to <i>downloader</i> component
User requested to cancel the job	A-REX detected external request to cancel this job, most probably issued by user
Could not process RSL	Job description could not be processed to syntax errors or missing elements
User requested dryrun. Job skipped.	Job description contains request not to process this job
LRMS error: (CODE) DESCRIPTION	LRMS returned error. CODE is replaced with numeric code of LRMS, and DESCRIPTION with textual description
Plugin at state STATE failed: OUTPUT	External plugin specified in A-REX configuration returned non-zero exit code. STATE is replaced by name of state to which job was going to be passed, OUTPUT by textual output generated by plugin.
Failed running plugin at state STATE	External plugin specified in A-REX configuration could not be executed.

Provided by downloader component (URL is replaced by source of input file, FILE by name of file):

<i>Error string</i>	<i>Reason/description</i>
Internal error in downloader	Generic error
Input file: URL - unknown error	Generic error
Input file: URL - unexpected error	Generic error
Input file: URL - bad source URL	Source URL is either malformed or not supported
Input file: URL - bad destination URL	Shouldn't happen
Input file: URL - failed to resolve source locations	File either not registred or other problems related to Data Indexing service.
Input file: URL - failed to resolve destination locations	Shouldn't happen
Input file: URL - failed to register new destination file	Shouldn't happen
Input file: URL - can't start reading from source	Problems related to accessing instance of file at Data Storing service.
Input file: URL - can't read from source	-//-
Input file: URL - can't start writing to destination	Access problems in a session directory
Input file: URL - can't write to destination	-//-
Input file: URL - data transfer was too slow	Timeouted while trying to download file
Input file: URL - failed while closing connection to source	Shouldn't happen
Input file: URL - failed while closing connection to destination	Shouldn't happen
Input file: URL - failed to register new location	Shouldn't happen
Input file: URL - can't use local cache	Problems with A-REX cache
Input file: URL - system error	Operating System returned error code where unexpected
Input file: URL - delegated credentials expired	Access to source requires credentials and they are either outdated or missing (not delegated).
User file: FILENAME - Bad information about file: checksum can't be parsed.	In job description there is a checksum provided for file uploadable by user interface and this record can't be interpreted.
User file: FILENAME - Bad information about file: size can't be parsed.	In job description there is a size provided for file uploadable by user interface and this record can't be interpreted.
User file: FILENAME - Expected file. Directory found.	Instead of file uploadable by user interface A-REX found directory with same name in a session directory.
User file: FILENAME - Expected ordinary file. Special object found.	Instead of file uploadable by user interface A-REX found special object with same name in a session directory.
User file: FILENAME - Delivered file is bigger than specified.	The size of file uploadable by user interface is bigger
User file: FILENAME - Delivered file is unreadable.	A-REX can't check user uploadable file due to some internal error. Most probably ⁴¹ due to improperly configured local permissions.
User file: FILENAME - Could not read file to compute checksum.	A-REX can't read user uploadable file due to some internal error. Most probably due to improperly configured local permissions.

Provided by uploader component (URL is replaced by destination of output file) :

<i>Error string</i>	<i>Reason/description</i>
Internal error in uploader	Generic error
Output file: URL - unknown error	Generic error
Output file: URL - unexpected error	Generic error
User requested to store output locally URL	Destination is URL of type <i>file</i> .
Output file: URL - bad source URL	Shouldn't happen
Output file: URL - bad destination URL	Destination URL is either malformed or not supported
Output file: URL - failed to resolve source locations	Shouldn't happen
Output file: URL - failed to resolve destination locations	Problems related to Data Indexing service.
Output file: URL - failed to register new destination file	-//-
Output file: URL - can't start reading from source	User request to store output file, but there is no such file or there are problems accessing session directory
Output file: URL - can't start writing to destination	Problems with Data Storing services
Output file: URL - can't read from source	Problems accessing session directory
Output file: URL - can't write to destination	Problems with Data Storing services
Output file: URL - data transfer was too slow	Timeout during transfer
Output file: URL - failed while closing connection to source	Shouldn't happen
Output file: URL - failed while closing connection to destination	Shouldn't happen
Output file: URL - failed to register new location	Problems related to Data Indexing service.
Output file: URL - can't use local cache	Shouldn't happen
Output file: URL - system error	Operating System returned error code where unexpected
Output file: URL - delegated credentials expired	Access to destination requires credentials and they are either outdated or missing (not delegated).

Coming from LRMS (PBS) backend:

<i>Error string</i>	<i>Reason/description</i>
Submission: Configuration error.	
Submission: System error.	
Submission: Job description error.	
Submission: Local submission client behaved unexpectedly.	
Submission: Local submission client failed.	

References

- [1] A. Anjomshoaa *et al.* (2005, December) Job submission description language (jsdl) specification v1.0. GFD-R-P.056. [Online]. Available: http://www.ggf.org/ggf_docs_final.htm
- [2] I.Foster *et al.* (2007, August) Ogsa basic execution service version 1.0. GFD.108. [Online]. Available: <http://www.ogf.org/gf/docs/?final>
- [3] OASIS. (2006, April) Oasis web services resourceproperties specification. . [Online]. Available: http://docs.oasis-open.org/wsrf/wsrfl-ws_resource_properties-1.2-spec-os.pdf
- [4] A. Konstantinov, *Protocols, Uniform Resource Locators (URL) and Extensions Supported in ARC*, The NorduGrid Collaboration, NORDUGRID-TECH-7.
- [5] I. Foster and C. Kesselman, "Globus: A Metacomputing Infrastructure Toolkit," *International Journal of Super-computer Applications*, vol. 11, no. 2, pp. 115–128, 1997.