

Lawrence Berkeley National Laboratory

LBL Publications

Title

GASP: A Performance Analysis Tool Interface for Global Address Space Programming Models, Version 1.5

Permalink

<https://escholarship.org/uc/item/4rd889bn>

Authors

Leko, Adam
Bonachea, Dan
Su, Hung-Hsun
et al.

Publication Date

2006-09-14

DOI

10.2172/918569

Peer reviewed

GASP: A Performance Analysis Tool Interface for Global Address Space Programming Models

Lawrence Berkeley National Lab Tech Report LBNL-61606

Adam Leko¹, Dan Bonachea², Hung-Hsun Su¹, Alan D. George¹

¹Electrical and Computer Engineering Dept., University of Florida

²Computer Science Division, University of California at Berkeley

Specification Version 1.5, 09/14/2006

1 Introduction

1.1 Scope

Due to the wide range of compilers and the lack of a standardized performance tool interface, writers of performance tools face many challenges when incorporating support for global address space (GAS) programming models such as Unified Parallel C (UPC), Titanium, and Co-Array Fortran (CAF). This document presents a Global Address Space Performance tool interface (GASP) that is flexible enough to be adapted into current global address space compiler and runtime infrastructures with little effort, while allowing performance analysis tools to gather much information about the performance of global address space programs.

1.2 Organization

Section 2 gives a high-level overview of the GASP interface. As GASP can be used to support many global address space programming models, the interface has been broken down into model-independent and model-specific sections. Section 3 presents the model-independent portions of the GASP interface, and the subsequent sections detail the model-specific portions of the interface.

1.3 Definitions

- **Model** – a parallel programming language or library, such as UPC or MPI.
- **Users** – individuals using a GAS model such as UPC
- **Developers** – individuals who write parallel software infrastructure such as UPC, CAF, or Titanium compilers
- **Tools** – performance analysis tools such as Vampir, TAU, or KOJAK
- **Tool developers** – individuals who develop performance analysis tools
- **Tool code** – code or library implementing the tool developer’s portion of the GASP interface
- **Thread** – a thread of control in a GAS program, maps directly to UPC’s concept of threads or CAF’s concept of images

2 GASP overview

The GASP interface controls the interaction between a user's code, a performance tool, and GAS model compiler and/or runtime system. This interaction is event-based and comes in the form of callbacks to the `gasp_event_notify` function at runtime. The callbacks may come from instrumentation code placed directly in an executable, from an instrumented runtime library, or any other method; the interface only requires that `gasp_event_notify` is called at appropriate times in the manner described in the rest of this document.

The GASP interface allows tool developers to support GAS models on all platforms and implementations supporting the interface. The interface is used in the following three steps:

1. Users compile their GAS code using compiler wrapper scripts provided by tool developers. Users may specify which analysis they wish the tool to perform on their code through either command-line arguments, environment variables or through other tool-specific methods.
2. The compiler wrapper scripts pass appropriate flags to the compiler indicating which callbacks the tool wishes to receive. During the linking phase, the scripts link in appropriate code from the performance tool that handles the callbacks at runtime. This tool-provided code shall be written in C.
3. When a user runs their program, the tool-provided code receives callbacks at runtime and may perform some action such as storing all events in a trace file or performing basic statistical profiling.

The specifics of each step will be discussed in Section 3. The model-specific portions of the GASP interface will be discussed in the subsequent sections.

A GAS implementation may exclude any system-level event defined in the model-specific sections of this document if an application cannot be instrumented for that event (eg due to design limitations or other implementation-specific constraints).

Any action resulting in a violation of this specification shall result in undefined behavior. Tool and model implementors are strongly encouraged not to deviate from these specifications.

3 Model-independent interface

3.1 Instrumentation control

Instrumentation control is accomplished through either compilation arguments or compiler pragmas. Developers may use alternative names for the command-line arguments if the names specified below do not fit the conventions already used by the compiler.

3.1.1 User-visible instrumentation control

If a user wishes to instrument their code for use with a tool using the GASP interface, they shall pass one of the command-line arguments described in this section to the compiler wrapper scripts.

GASP system events are divided into the following broad categories, for the purposes of instrumentation control:

- **Local access events:** Events resulting from access to objects or variables contained in the portion of the global address space which is local to the accessing thread.
- **User function events:** Events resulting from entry and exit to user-defined functions, as described in section 4.3.1.
- **Other events:** Any system event which does not fall into the above categories.

The `--inst` argument specifies that the user's code shall be instrumented for all system events supported by the GAS model implementation which fall into the final category of events described above.

The `--inst-local` argument implies `--inst`, and additionally requests that user code shall be instrumented to generate local access events supported by the GAS model implementation. Otherwise, such events need not be generated.

For models lacking a semantic concept of local or remote memory accesses, `--inst` shall have the same semantics as `--inst-local`, implying instrumentation of all global address space accesses.

The `--inst-functions` argument implies `--inst`, and additionally requests that user code shall be instrumented to generate user function events supported by the GAS model implementation. Otherwise, such events need not be generated.

3.1.2 Tool-visible instrumentation control

Compilers supporting the GASP interface shall provide the following command-line arguments for use by the tool-provided compiler wrapper scripts.

The arguments `--inst`, `--inst-local` and `--inst-functions` have the same semantics as the user-visible instrumentation flags specified in Section 3.1.1.

An additional argument `--inst-only` takes a single argument `filename` which is a file containing a list of symbolic event names (as defined in the model-specific sections of this document) separated by newlines. The file's contents indicate the events for which the performance tool wishes to receive callbacks. Events in this file may be ignored by the compiler if the events are not supported by the model implementation. Compiler implementations are encouraged to avoid any overheads associated with generating events not specified by `--inst-only`, however tools that pass `--inst-only` must still be prepared to receive and ignore events which are not included in the `--inst-only` list.

3.1.3 Interaction with instrumentation, measurement, and user events

When code is compiled without an `--inst` flag, all instrumentation control shall be ignored and all user event callbacks shall be compiled away. Systems may link “dummy” versions of `gasp_control` and `gasp_create_event` (described in Sections 3.3 and 3.4) for applications that have no code compiled with `--inst`.

Systems may support compiling parts of an application using one of the `--inst` flags and compiling other parts of an application normally; for systems where this is not possible, this behavior may be prohibited. Applications compiled using an `--inst` flag for at least one translation unit shall also pass the `--inst` flag during the linking phase to the compiler wrapper scripts.

Any model-specific instrumentation control shall not have any effect on user events or on the state of measurement control. As a result, any model-specific instrumentation controls shall not prevent user events from being instrumented during compilation (e.g., `#pragma pupc` shall not change the behavior of the `pupc_create_event` and `pupc_event_start` functions in UPC programs).

3.2 Callback structure

At runtime, all threads of an instrumented executable shall collectively call the `gasp_init` C function at the beginning of program execution after the model runtime has finished initialization but before executing the entry point in a user's code (e.g., `main` in UPC). The `gasp_init` function shall have the following signature:

```
typedef enum {
    GASP_MODEL_UPC,
    GASP_MODEL_TITANIUM,
    GASP_MODEL_CAF,
    GASP_MODEL_MPI,
    GASP_MODEL_SHMEM
} gasp_model_t;

struct _gasp_context_S;
typedef struct _gasp_context_S *gasp_context_t;

gasp_context_t gasp_init(gasp_model_t srcmodel,
                        int *argc, char ***argv);
```

The `gasp_init` function and an implementation of the `_gasp_context_S` struct shall be provided by tool developers. A single running instance of an executable may collectively call `gasp_init` multiple times if the executable contains code written in multiple models (such as a hybrid UPC and CAF program), with at most one call per model.

The `gasp_init` function returns a pointer to an opaque, thread-specific, tool-implemented struct. This pointer shall be passed in all subsequent calls to the tool developer's code made on behalf of this thread. This pointer shall only be used in event callbacks for events corresponding to the model indicated by the `srcmodel` argument.

Tool code may modify the contents of the `argc` and `argv` pointers to support the processing of command-line arguments.

After the `gasp_init` function has been called by each thread of execution, the tool code shall receive all other callbacks through the two functions whose signatures are shown below:

```

typedef enum {
    GASP_START,
    GASP_END,
    GASP_ATOMIC,
} gasp_evttype_t;

void gasp_event_notify(gasp_context_t context, unsigned int evttag,
                       gasp_evttype_t evttype, const char *filename,
                       int linenum, int colnum, ...);

void gasp_event_notifyVA(gasp_context_t context, unsigned int evttag,
                          gasp_evttype_t evttype, const char *filename,
                          int linenum, int colnum, va_list varargs);

```

Both functions may be used interchangeably; the VA variant is provided as a convenience to developers.

The `gasp_event_notify` implementation shall be written in C, but may make upcalls to code written in the model specified by the `srcmodel` argument passed to the `gasp_init` function on the thread that received the callback. If upcalls are used, the `gasp_event_notify` function implementation is responsible for handling re-entrant calls. Additionally, code that is used in upcalls shall be compiled using the same environmental specifications as the code in a user's application (e.g., `gasp_event_notify` shall only perform upcalls to UPC code compiled under a static threads environment when used with a UPC program compiled under the static threads environment).

Any user data referenced by pointers passed to `gasp_event_notify` shall not be modified by tool code.

For the first argument to `gasp_event_notify`, tool code shall receive the same `gasp_context_t` pointer that was returned from the `gasp_init` function for this thread. Tool developers may use the context struct to store thread-local information for each thread. The `gasp_event_notify` function shall be thread-safe in order to support model implementations that make use of `pthread`s or other thread libraries.

The `evttag` argument shall specify the event identifier as described in the model-specific sections of this document. The `evttype` argument shall be of type `gasp_evttype_t` and shall indicate whether the event `evttag` is a begin event, end event, or atomic event.

The `filename`, `linenum`, and `colnum` arguments shall indicate the line and column number in the model-level source code most closely associated with the generation of the event `evttag`. If `filename` is non-NULL, it references a character string whose contents must remain valid and unmodified for the remainder of the program execution. The same `filename` pointer is permitted to be passed in multiple calls and by multiple threads, and it is also permitted for different `filename` pointers (passed in different calls) to indicate the same file name (this implies the tool may store `filename` pointer values and use simple pointer comparison of non-NULL values to establish filename equality, but not inequality).

GAS model implementations that do not retain column information during compilation may pass 0 in place of the `colnum` parameter. GAS model implementations that do not retain any source-level information during compilation may pass 0 for the `filename`, `linenum`, and `colnum` parameters. GAS model implementations are strongly encouraged to support these arguments unless this information can be efficiently and accurately obtained through other documented methods.

GAS model implementations that use instrumented runtime libraries for GASP support may provide dummy implementations for the `gasp_event_notify`, `gasp_event_notifyVA`, `gasp_init` functions and `_gasp_context_S` struct to prevent link errors while linking a user's application that is not being used with any performance tool.

The contents of the `varargs` argument shall be specific to each event identifier and type and will be discussed in the model-specific sections of this document.

3.3 Measurement control

Tool developers shall provide an implementation for the following function:

```

int gasp_control(gasp_context_t context, int on);

```

The `gasp_control` function takes the `context` argument in the same manner as the `gasp_event_notify` function.

When the value 0 is passed for the `on` parameter, the tool shall cease measuring any performance data associated with subsequent system or user events generated on the calling thread, until the thread makes a future call to `gasp_control` with a nonzero value for the `on` parameter.

The `gasp_control` function shall return the last value for the `on` parameter the function received from this thread, or a nonzero value if `gasp_control` has never been called for this thread.

3.4 User events

Tool developers shall provide an implementation for the following function:

```
unsigned int gasp_create_event(gasp_context_t context,  
                             const char *name, const char *desc);
```

The `gasp_create_event` shall return a tool-generated event identifier.

Compilers shall translate the corresponding model-specific `_create_event` functions listed in the model-specific sections of this document into corresponding `gasp_create_event` calls. The semantics of the `name` and `desc` arguments and the return value shall be the same as defined by the `_create_event` function listed in the model-specific section of this document corresponding to the model indicated by `context`.

3.5 Header files

Developers shall distribute a `gasp.h` C header file with their GAS model implementations that contains at least the following definitions:

- Function prototypes for the `gasp_init`, `gasp_event_notify`, `gasp_control`, and `gasp_create_event` functions and associated typedefs, enums, and structs.
- A `GASP_VERSION` macro that shall be defined to an integral date (coded as YYYYMMDD) corresponding to the GASP version supported by this GASP implementation. For implementations that support the version of GASP defined in this document, this macro shall be set to the integral value 20060914.
- Macro definitions that map the symbolic event names listed in the model-specific sections of this document to 32-bit unsigned integers.

The `gasp.h` file shall be installed in a directory that is included in the compiler's default search path.

4 C interface

4.1 Instrumentation control

Instrumentation for the events defined in this section shall be controlled by using the corresponding instrumentation control mechanisms for UPC code defined in Section 5.1.

4.2 Measurement control

Measurement for the events defined in this section shall be controlled by using the corresponding measurement control mechanisms for UPC code defined in Section 5.2.

4.3 System events

4.3.1 Function events

Table 1 shows system events related to executing user functions.

Symbolic name	Event type	vararg arguments
GASP_C_FUNC	Start, End	const char *funcsig

Table 1: User function events

These events occur upon each call to a user function (after entry into that function), and before exit from a user function (before returning to the caller as a result of executing a return statement or reaching the closing brace which terminates the function). The `funcsig` argument specifies the character string representing the full signature of the user function that is being entered or exited, or NULL if that information is not available.

If `funcsig` is non-NULL, it references a character string whose contents must remain valid and unmodified for the remainder of the program execution. The same `funcsig` pointer is permitted to be passed in multiple calls and by multiple threads, and it is also permitted for different `funcsig` pointers (passed in different calls) to indicate the same function signature (this implies the tool may store `funcsig` pointer values and use simple pointer comparison of non-NULL values to establish function equality, but not inequality).

4.3.2 Memory allocation events

Table 2 shows system events related to the standard memory allocation functions.

Symbolic name	Event type	vararg arguments
GASP_C_MALLOC	Start	size_t nbytes
GASP_C_MALLOC	End	size_t nbytes, void *returnptr
GASP_C_REALLOC	Start	void *ptr, size_t size
GASP_C_REALLOC	End	void *ptr, size_t size, void *returnptr
GASP_C_FREE	Start, End	void *ptr

Table 2: Memory allocation events

The `GASP_C_MALLOC`, `GASP_C_REALLOC`, and `GASP_C_FREE` stem directly from the standard C definitions of `malloc`, `realloc`, and `free`.

4.4 Header files

Supported C system events shall be handled in the same method as UPC events, which are described in Section 5.5.

5 UPC interface

5.1 Instrumentation control

Users may insert `#pragma pupc on` or `#pragma pupc off` directives in their code to instruct the compiler to avoid instrumenting lexically-scoped regions of a user's UPC code. These pragmas may be ignored by the compiler if the compiler cannot control instrumentation for arbitrary regions of code.

When an `--inst` argument is given to a compiler or compiler wrapper script, the `#pragma pupc` shall default to `on`.

5.2 Measurement control

At runtime, users may call the following functions to control the measurement of performance data:

```
int pupc_control(int on);
```

The `pupc_control` function shall behave in the same manner as the `gasp_control` function defined in Section 3.3.

5.3 User events

```
unsigned int pupc_create_event(const char *name, const char *desc);
void pupc_event_start(unsigned int evttag, ...);
void pupc_event_end(unsigned int evttag, ...);
void pupc_event_atomic(unsigned int evttag, ...);
```

The `pupc_create_event` function shall be translated into a corresponding `gasp_create_event` call, as defined in Section 3.4. The `name` argument shall be used to associate a user-specified name with the event, and the `desc` argument may contain either `NULL` or a `printf`-style format string. The memory referenced by both arguments need not remain valid once the function returns.

The event identifier returned by `pupc_create_event` shall be a unique value in the range from `GASP_UPC_USEREVT_START` to `GASP_UPC_USEREVT_END`, inclusive. The `GASP_UPC_USEREVT` macros shall be provided in the `gasp_upc.h` header file described in Section 5.5. The value returned is thread-specific. If the unique identifiers are exhausted for the calling thread, `pupc_create_event` shall issue a fatal error.

The `pupc_event_start`, `pupc_event_end`, and `pupc_event_atomic` functions may be called by a user's UPC program at runtime. The `evttag` argument shall be any value returned by a prior `pupc_create_event` function call from the same thread. Users may pass in any list of values for the `...` arguments, provided the argument types match the `printf`-style format string supplied in the corresponding `pupc_create_event` (according to the `printf` format string conventions specified by the target system). Any memory referenced by `...` arguments (e.g. string arguments) need not remain valid once the function returns. A performance tool may use these values to display performance information alongside application-specific data captured during runtime to a user. The UPC implementation shall translate the `pupc_event_start`, `pupc_event_end`, and `pupc_event_atomic` function calls into corresponding `gasp_event_notify` function calls.

When a compiler does not receive any `--inst` arguments, the `pupc_event` function calls shall be excluded from the executable or linked against dummy implementations of these calls. A user's program shall not depend on any side effects that occur from executing the `pupc_event` functions.

Users shall not pass a shared-qualified pointer as an argument to the `pupc_event` functions.

5.4 System events

For the event arguments below, the UPC-specific types `upc_flag_t` and `upc_op_t` shall be converted to C `ints`.

Pointers to shared data shall be passed with an extra level of indirection, and may only be dereferenced through UPC upcalls. UPC implementations shall provide two opaque types, `gasp_upc_pts_t` and `gasp_upc_lock_t`, which shall represent a generic pointer-to-shared (ie. `shared void *`), and a UPC lock pointer (ie. `upc_lock_t *`), respectively. These opaque types shall be typedef'ed to `void` to prevent C code from attempting to dereference them without using a cast in a UPC upcall. The content of any `gasp_upc_pts_t` or `gasp_upc_lock_t` location passed to an event is only guaranteed to remain valid for the duration of the `gasp_event_notify` call, and must not be modified by the tool.

5.4.1 Exit events

Table 3 shows system events related to the end of a program's execution.

Symbolic name	Event type	vararg arguments
<code>GASP_UPC_COLLECTIVE_EXIT</code>	Start, End	<code>int</code> status
<code>GASP_UPC_NONCOLLECTIVE_EXIT</code>	Atomic	<code>int</code> status

Table 3: Exit events

The `GASP_UPC_COLLECTIVE_EXIT` events shall occur at the end of a program's execution on each thread when a collective exit occurs. These events correspond to the execution of the final implicit barrier for UPC programs.

The `GASP_UPC_NONCOLLECTIVE_EXIT` event shall occur at the end of a program's execution on a single thread when a non-collective exit occurs.

5.4.2 Synchronization events

Table 4 shows events related to synchronization constructs.

Symbolic name	Event type	vararg arguments
GASP_UPC_NOTIFY	Start, End	int named, int expr
GASP_UPC_WAIT	Start, End	int named, int expr
GASP_UPC_BARRIER	Start, End	int named, int expr
GASP_UPC_FENCE	Start, End	(none)

Table 4: Synchronization events

These events shall occur before and after execution of the notify, wait, barrier, and fence synchronization statements. The named argument to the notify, wait, and barrier start events shall be nonzero if the user has provided an integer expression for the corresponding notify, wait, and barrier statements. In this case, the `expr` variable shall be set to the result of evaluating that integer expression. If the user has not provided an integer expression for the corresponding notify, wait, or barrier statements, the named argument shall be zero and the value of `expr` shall be undefined.

5.4.3 Work-sharing events

Table 5 shows events related to work-sharing constructs.

Symbolic name	Event type	vararg arguments
GASP_UPC_FORALL	Start, End	(none)

Table 5: Work-sharing events

These events shall occur on each thread before and after `upc_forall` constructs are executed.

5.4.4 Library-related events

Table 6 shows events related to library functions.

Symbolic name	Event type	vararg arguments
GASP_UPC_GLOBAL_ALLOC	Start	<code>size_t</code> nblocks, <code>size_t</code> nbytes
GASP_UPC_GLOBAL_ALLOC	End	<code>size_t</code> nblocks, <code>size_t</code> nbytes, <code>gasp_upc_PTS_t</code> *newshrd_ptr
GASP_UPC_ALL_ALLOC	Start	<code>size_t</code> nblocks, <code>size_t</code> nbytes
GASP_UPC_ALL_ALLOC	End	<code>size_t</code> nblocks, <code>size_t</code> nbytes, <code>gasp_upc_PTS_t</code> *newshrd_ptr
GASP_UPC_ALLOC	Start	<code>size_t</code> nbytes
GASP_UPC_ALLOC	End	<code>size_t</code> nbytes, <code>gasp_upc_PTS_t</code> *newshrd_ptr
GASP_UPC_FREE	Start, End	<code>gasp_upc_PTS_t</code> *shrd_ptr
GASP_UPC_GLOBAL_LOCK_ALLOC	Start	(none)
GASP_UPC_GLOBAL_LOCK_ALLOC	End	<code>gasp_upc_lock_t</code> *lck
GASP_UPC_ALL_LOCK_ALLOC	Start	(none)
GASP_UPC_ALL_LOCK_ALLOC	End	<code>gasp_upc_lock_t</code> *lck
GASP_UPC_LOCK_FREE	Start, End	<code>gasp_upc_lock_t</code> *lck
GASP_UPC_LOCK	Start, End	<code>gasp_upc_lock_t</code> *lck
GASP_UPC_LOCK_ATTEMPT	Start	<code>gasp_upc_lock_t</code> *lck
GASP_UPC_LOCK_ATTEMPT	End	<code>gasp_upc_lock_t</code> *lck, int result
GASP_UPC_UNLOCK	Start, End	<code>gasp_upc_lock_t</code> *lck

Continued on next page

Symbolic name	Event type	vararg arguments
GASP_UPC_MEMCPY	Start, End	gasp_upc_PTS_t *dst, gasp_upc_PTS_t *src, size_t n
GASP_UPC_MEMGET	Start, End	void *dst, gasp_upc_PTS_t *src, size_t n
GASP_UPC_MEMPUT	Start, End	gasp_upc_PTS_t *dst, void *src, size_t n
GASP_UPC_MEMSET	Start, End	gasp_upc_PTS_t *dst, int c, size_t n

Table 6: Library-related events

These events stem directly from the UPC library functions defined in the UPC specification. The `vararg` arguments for each event callback mirror those defined in the UPC language specification.

5.4.5 Blocking shared variable access events

Table 7 shows events related to blocking shared variable accesses.

Symbolic name	Event type	vararg arguments
GASP_UPC_GET	Start, End	int is_relaxed, void *dst, gasp_upc_PTS_t *src, size_t n
GASP_UPC_PUT	Start, End	int is_relaxed, gasp_upc_PTS_t *dst, void *src, size_t n

Table 7: Blocking shared variable access events

These events shall occur whenever shared variables are assigned to or read from using the direct syntax (not using the `upc.h` library functions). The arguments to these events mimic those of the `upc_memget` and `upc_mempu` event callback arguments, but differ from the ones presented in the previous section because they only arise from accessing shared variables directly. If the memory access occurs under the relaxed memory model, the `is_relaxed` parameter shall be nonzero; otherwise the `is_relaxed` parameter shall be zero.

5.4.6 Nonblocking shared variable access events

Table 8 shows events related to direct shared variable accesses implemented through nonblocking communication.

Symbolic name	Event type	vararg arguments
GASP_UPC_NB_GET_INIT	Start	int is_relaxed, void *dst, gasp_upc_PTS_t *src, size_t n
Continued on next page		

Symbolic name	Event type	vararg arguments
GASP_UPC_NB_GET_INIT	End	int is_relaxed, void *dst, gasp_upc_PTS_t *src, size_t n, gasp_upc_nb_handle_t handle
GASP_UPC_NB_GET_DATA	Start, End	gasp_upc_nb_handle_t handle
GASP_UPC_NB_PUT_INIT	Start	int is_relaxed, gasp_upc_PTS_t *dst, void *src, size_t n
GASP_UPC_NB_PUT_INIT	End	int is_relaxed, gasp_upc_PTS_t *dst, void *src, size_t n, gasp_upc_nb_handle_t handle
GASP_UPC_NB_PUT_DATA	Start, End	gasp_upc_nb_handle_t handle
GASP_UPC_NB_SYNC	Start, End	gasp_upc_nb_handle_t handle

Table 8: Nonblocking shared variable access events

These nonblocking direct shared variable access events are similar to the regular direct shared variable access events in Section 5.4.5. The **INIT** events shall correspond to the nonblocking communication initiation, the **DATA** events shall correspond to when the data starts to arrive and completely arrives on the destination node (these events may be excluded for most implementations that use hardware-supported DMA), and the **GASP_UPC_NB_SYNC** function shall correspond to the final synchronization call that blocks until the corresponding data of the nonblocking operation is no longer in flight.

gasp_upc_nb_handle_t shall be an opaque type defined by the UPC implementation. Several outstanding nonblocking get or put operations may be attached to a single **gasp_upc_nb_handle_t** instance. When a sync callback is received, the tool code shall assume all get and put operations for the corresponding handle in the sync callback have been retired.

The implementation may pass the handle **GASP_NB_TRIVIAL** to **GASP_UPC_NB_{PUT,GET}_INIT** to indicate the operation was completed synchronously in the initiation interval. The tool should ignore any **DATA** or **SYNC** event callbacks with the handle **GASP_NB_TRIVIAL**.

5.4.7 Shared variable cache events

Table 9 shows events related to shared variable cache events.

Symbolic name	Event type	vararg arguments
GASP_UPC_CACHE_MISS	Atomic	size_t n, size_t n_lines
GASP_UPC_CACHE_HIT	Atomic	size_t n
GASP_UPC_CACHE_INVALIDATE	Atomic	size_t n_dirty

Table 9: Shared variable cache events

The **GASP_UPC_CACHE** events may be sent for UPC runtime systems containing a software cache after a corresponding get or put start event but before a corresponding get or put end event (including nonblocking communication events). UPC runtimes using write-through cache systems may send **GASP_UPC_CACHE_MISS** events for each corresponding put event.

The **size_t n** argument for the **MISS** and **HIT** events shall indicate the amount of data read from the cache line for the particular cache hit or cache miss.

The **n_lines** argument of the **GASP_UPC_CACHE_MISS** event shall indicate the number of bytes brought into the cache as a result of the miss (in most cases, the line size of the cache).

The `n_dirty` argument of the `GASP_UPC_CACHE_INVALIDATE` shall indicate the number of dirty cache lines that were written back to shared memory due to a cache line invalidation.

5.4.8 Collective communication events

Table 10 shows events related to collective communication.

Symbolic name	Event type	vararg arguments
<code>GASP_UPC_ALL_BROADCAST</code>	Start, End	<code>gasp_upc_PTS_t *dst,</code> <code>gasp_upc_PTS_t *src,</code> <code>size_t nbytes,</code> int <code>upc_flags</code>
<code>GASP_UPC_ALL_SCATTER</code>	Start, End	<code>gasp_upc_PTS_t *dst,</code> <code>gasp_upc_PTS_t *src,</code> <code>size_t nbytes,</code> int <code>upc_flags</code>
<code>GASP_UPC_ALL_GATHER</code>	Start, End	<code>gasp_upc_PTS_t *dst,</code> <code>gasp_upc_PTS_t *src,</code> <code>size_t nbytes,</code> int <code>upc_flags</code>
<code>GASP_UPC_ALL_GATHER_ALL</code>	Start, End	<code>gasp_upc_PTS_t *dst,</code> <code>gasp_upc_PTS_t *src,</code> <code>size_t nbytes,</code> int <code>upc_flags</code>
<code>GASP_UPC_ALL_EXCHANGE</code>	Start, End	<code>gasp_upc_PTS_t *dst,</code> <code>gasp_upc_PTS_t *src,</code> <code>size_t nbytes,</code> int <code>upc_flags</code>
<code>GASP_UPC_ALL_PERMUTE</code>	Start, End	<code>gasp_upc_PTS_t *dst,</code> <code>gasp_upc_PTS_t *src,</code> <code>gasp_upc_PTS_t *perm,</code> <code>size_t nbytes,</code> int <code>upc_flags</code>
<code>GASP_UPC_ALL_REDUCE</code>	Start, End	<code>gasp_upc_PTS_t *dst,</code> <code>gasp_upc_PTS_t *src,</code> int <code>upc_op,</code> <code>size_t nelems,</code> <code>size_t blk_size,</code> void <code>*func,</code> int <code>upc_flags,</code> <code>gasp_upc_reduction_t type</code>
<code>GASP_UPC_ALL_PREFIX_REDUCE</code>	Start, End	<code>gasp_upc_PTS_t *dst,</code> <code>gasp_upc_PTS_t *src,</code> int <code>upc_op,</code> <code>size_t nelems,</code> <code>size_t blk_size,</code> void <code>*func,</code> int <code>upc_flags,</code> <code>gasp_upc_reduction_t type</code>

Table 10: Collective communication events

The events in Table 10 stem directly from the UPC collective library functions defined in the UPC specification. The `vararg` arguments for each event callback mirror those defined in the UPC language specification.

For the reduction functions, the `gasp_upc_reduction_t` enum shall be provided by a UPC implementation and shall be defined as follows:

```
typedef enum {
    GASP_UPC_REDUCTION_C,
    GASP_UPC_REDUCTION_UC,
    GASP_UPC_REDUCTION_S,
    GASP_UPC_REDUCTION_US,
    GASP_UPC_REDUCTION_I,
    GASP_UPC_REDUCTION_UI,
    GASP_UPC_REDUCTION_L,
    GASP_UPC_REDUCTION_UL,
    GASP_UPC_REDUCTION_F,
    GASP_UPC_REDUCTION_D,
    GASP_UPC_REDUCTION_LD
} gasp_upc_reduction_t;
```

where the suffix to GASP_UPC_REDUCTION denotes the same type as specified in the UPC specification.

5.5 Header files

UPC compilers shall distribute a `pupc.h` C header file with their GAS language implementations that contains function prototypes for the functions defined in Sections 5.2 and 5.3. The `pupc.h` file shall be installed in a directory that is included in the UPC compiler's default search path.

All supported system events and associated `gasp_upc_*` types shall be defined in a `gasp_upc.h` file located in the same directory as the `gasp.h` file. System events not supported by an implementation shall not be included in the `gasp_upc.h` file. The `gasp_upc.h` header file may include definitions for implementation-specific events, along with brief documentation embedded in source code comments.

Compilers shall define a compiler-specific integral `GASP_UPC_VERSION` version number in `gasp_upc.h` that may be incremented when new implementation-specific events are added. Compiler developers are encouraged to use the `GASP_X_Y` naming convention for all implementation-specific events, where X is an abbreviation for their compilation system (such as BUPC) and Y is a short, descriptive name for each event.

Compilers that implement the `pupc` interface shall predefine the feature macro `__UPC_PUPC__` to the value 1. The macro should be predefined whenever applications may safely `#include <pupc.h>`, invoke the functions it defines and use the `#pragma pupc` directives, without causing any translation errors. The feature macro does not guarantee that GASP instrumentation is actually enabled for a given compilation, as some of the features might have no effect in non-instrumenting compilations.

6 Other models

Event sets for additional models (SHMEM, Titanium, CAF, MPI, etc.) will be defined in a future revision of this specification.