Paradyn Parallel Performance Tools

Dyninst
Programmer's Guide

Release 12.2
July 2022

Computer Science Department
University of Wisconsin-Madison
Madison, WI 53706

Computer Science Department
University of Maryland
College Park, MD 20742
Email: dyninst-api@cs.wisc.edu
Web: www.dyninst.org
      github.com/dyninst/dyninst

dyninstAPI

1. Introduction

The normal cycle of developing a program is to edit the source code, compile it, and then execute the resulting binary. However, sometimes this cycle can be too restrictive. We may wish to change the program while it is executing or after it has been linked, thus avoiding the process of re-compiling, re-linking, or even re-executing the program to change the binary. At first, this may seem like a bizarre goal, however, there are several practical reasons why we may wish to have such a system. For example, if we are measuring the performance of a program and discover a performance problem, it might be necessary to insert additional instrumentation into the program to understand the problem. Another application is performance steering; for large simulations, computational scientists often find it advantageous to be able to make modifications to the code and data while the simulation is executing.

This document describes an Application Program Interface (API) to permit the insertion of code into a computer application that is either running or on disk. The API for inserting code into a running application, called dynamic instrumentation, shares much of the same structure as the API for inserting code into an executable file or library, known as static instrumentation. The API also permits changing or removing subroutine calls from the application program. Binary code changes are useful to support a variety of applications including debugging, performance monitoring, and to support composing applications out of existing packages. The goal of this API is to provide a machine independent interface to permit the creation of tools and applications that use runtime and static code patching. The API and a simple test application are described in [1]. This API is based on the idea of dynamic instrumentation described in [3].

The key features of this interface are the abilities to:
- Insert and change instrumentation in a running program.
- Insert instrumentation into a binary on disk and write a new copy of that binary back to disk.
- Perform static and dynamic analysis on binaries and processes.

The goal of this API is to keep the interface small and easy to understand. At the same time, it needs to be sufficiently expressive to be useful for a variety of applications. We accomplished this goal by providing a simple set of abstractions and a way to specify which code to insert into the application[1].

---

[1] To generate more complex code, extra (initially un-called) subroutines can be linked into the application program, and calls to these subroutines can be inserted at runtime via this interface.

2.   Abstractions

The DyninstAPI library provides an interface for instrumenting and working with binaries and processes. The user writes a *mutator*, which uses the DyninstAPI library to operate on the application. The process that contains the *mutator* and DyninstAPI library is known as the *mutator process*. The *mutator process* operates on other processes or on-disk binaries, which are known as *mutatees.*

The API is based on abstractions of a program. For dynamic instrumentation, it can be based on the state while in execution. The two primary abstractions in the API are *points* and *snippets*. A *point* is a location in a program where instrumentation can be inserted. A *snippet* is a representation of some executable code to be inserted into a program at a point. For example, if we wished to record the number of times a procedure was invoked, the *point* would be entry point of the procedure, and the *snippets* would be a statement to increment a counter. *Snippets* can include conditionals and function calls.

Mutatees are represented using an *address space* abstraction. For dynamic instrumentation, the *address space* represents a process and includes any dynamic libraries loaded with the process. For static instrumentation, the *address space* includes a disk executable and includes any dynamic library files on which the executable depends. The *address space* abstraction is extended by *process* and *binary* abstractions for dynamic and static instrumentation. The *process* abstraction represents information about a running process such as threads or stack state. The *binary* abstraction represents information about a binary found on disk.

The code and data represented by an *address space* is broken up into *function* and *variable* abstractions. *Function*s contain *points*, which specify locations to insert instrumentation. *Functions* also contain a *control flow graph* abstraction, which contains information about *basic blocks*, *edges*, *loops*, and *instructions*. If the *mutatee* contains debug information, DyninstAPI will also provide abstractions about variable and function *types*, *local variables*, *function parameters*, and *source code line information*. The collection of *functions* and *variables* in a mutatee is represented as an *image*.

The API includes a simple type system based on structural equivalence. If mutatee programs have been compiled with debugging symbols and the symbols are in a format that Dyninst understands, type checking is performed on code to be inserted into the mutatee. See Section 4.28 for a complete description of the type system.

Due to language constructs or compiler optimizations, it may be possible for multiple functions to *overlap* (that is, share part of the same function body) or for a single function to have multiple *entry points*. In practice, it is impossible to determine the difference between multiple overlapping functions and a single function with multiple entry points. The DyninstAPI uses a model where each function (BPatch_function object) has a single entry point, and multiple functions may overlap (share code). We guarantee that instrumentation inserted in a particular function is only executed in the context of that function, even if instrumentation is inserted into a location that exists in multiple functions.

3.	Examples

To illustrate the ideas of the API, we present several short examples that demonstrate how the API can be used. The full details of the interface are presented in the next section. To prevent confusion, we refer to the application process or binary that is being modified as the mutatee, and the program that uses the API to modify the application as the mutator. The mutator is a separate process from the application process.

The examples in this section are simple code snippets, not complete programs. Appendix A - Complete Examples provides several examples of complete Dyninst programs.

3.1	Instrumenting a function

A mutator program must create a single instance of the class `BPatch`. This object is used to access functions and information that are global to the library. It must not be destroyed until the mutator has completely finished using the library. For this example, we assume that the mutator program has declared a global variable called `bpatch` of class `BPatch`.

All instrumentation is done with a `BPatch_addressSpace` object, which allows us to write codes that work for both dynamic and static instrumentation. During initialization we use either `BPatch_process` to attach to or create a process, or `BPatch_binaryEdit` to open a file on disk. When instrumentation is completed, we will either run the `BPatch_process`, or write the `BPatch_binaryEdit` back onto the disk.

The mutator first needs to identify the application to be modified. If the process is already in execution, this can be done by specifying the executable file name and process id of the application as arguments in order to create an instance of a process object:

```
BPatch_process *appProc = bpatch.processAttach(name, processId);
```

This creates a new instance of the `BPatch_process` class that refers to the existing process. It had no effect on the state of the process (i.e., running or stopped). If the process has not been started, the mutator specifies the pathname and argument list of a program it seeks to execute:

```
BPatch_process *appProc = bpatch.processCreate(pathname, argv);
```

If the mutator is opening a file for static binary rewriting, it executes:

```
BPatch_binaryEdit *appBin = bpatch.openBinary(pathname);
```

The above statements create either a `BPatch_process` object or `BPatch_binaryEdit` object, depending on whether Dyninst is doing dynamic or static instrumentation. The instrumentation and analysis code can be made agnostic towards static or dynamic modes by using a `BPatch_addressSpace` object. Both `BPatch_process` and `BPatch_binaryEdit` inherit from `BPatch_addressSpace`, so we can use cast operations to move between the two:

```
BPatch_process *appProc = static_cast<BPatch_process *>(appAddrSpace)
-or-
BPatch_binaryEdit *appBin = static_cast<BPatch_binaryEdit *>(appAddrSpace)
```

Similarly, all instrumentation commands can be performed on a `BPatch_addressSpace` object, allowing similar codes to be used between dynamic instrumentation and binary rewriting:

```
BPatch_addressSpace *app = appProc;
-or-
BPatch_addressSpace *app = appBin;
```

Once the address space has been created, the mutator defines the snippet of code to be inserted and identifies where the points should be inserted.

If the mutator wants to instrument the entry point of `InterestingProcedure`, it should get a `BPatch_function` from the application's `BPatch_image`, and get the entry `BPatch_point` from that function:

```
std::vector<BPatch_function *> functions;
std::vector<BPatch_point *> *points;

BPatch_image *appImage = app->getImage();
appImage->findFunction("InterestingProcedure", functions);
points = functions[0]->findPoint(BPatch_locEntry);
```

The mutator also needs to construct the instrumentation that it will insert at the `BPatch_point`. It can do this by allocating an integer in the application to store instrumentation results, and then creating a `BPatch_snippet` to increment that integer:

```
BPatch_variableExpr *intCounter =
    app->malloc(*(appImage->findType("int")));

BPatch_arithExpr addOne(BPatch_assign, *intCounter,
        BPatch_arithExpr(BPatch_plus, *intCounter, BPatch_constExpr(1)));
```

The mutator can set the `BPatch_snippet` to be run at the `BPatch_point` by executing an `insertSnippet` call:

```
app->insertSnippet(addOne, *points);
```

Finally, the mutator should either continue the mutate process and wait for it to finish, or write the resulting binary onto the disk, depending on whether it is doing dynamic or static instrumentation:

```
appProc->continueExecution();
while (!appProc->isTerminated()) {
    bpatch.waitForStatusChange();
}
-or-
appBin->writeFile(newPath);
```

A complete example can be found in Appendix A - Complete Examples.

3.2   Binary Analysis

This example will illustrate how to use Dyninst to iterate over a function's control flow graph and inspect instructions. These are steps that would usually be part of a larger data flow or control flow analysis. Specifically, this example will collect every basic block in a function, iterate over them, and count the number of instructions that access memory.

Unlike the previous instrumentation example, this example will analyze a binary file on disk. Bear in mind, these techniques can also be applied when working with processes. This example makes use of InstructionAPI, details of which can be found in the InstructionAPI Reference Manual.

Similar to the above example, the mutator will start by creating a BPatch object and opening a file to operate on:

```
BPatch bpatch;
BPatch_binaryEdit *binedit = bpatch.openFile(pathname);
```

The mutator needs to get a handle to a function to do analysis on. This example will look up a function by name; alternatively, it could have iterated over every function in `BPatch_image` or `BPatch_module`:

```
BPatch_image *appImage = binedit->getImage();

std::vector<BPatch_function *> funcs;
image->findFunction("InterestingProcedure", funcs);
```

A function's control flow graph is represented by the `BPatch_flowGraph` class. The `BPatch_flowGraph` contains, among other things, a set of `BPatch_basicBlock` objects connected by `BPatch_edge` objects. This example will simply collect a list of the basic blocks in `BPatch_flowGraph` and iterate over each one:

```
BPatch_flowGraph *fg = funcs[0]->getCFG();

std::set<BPatch_basicBlock *> blocks;
fg->getAllBasicBlocks(blocks);
```

Each basic block has a list of instructions. Each instruction is represented by a `Dyninst::InstructionAPI::Instruction::Ptr` object.

```
std::set<BPatch_basicBlock *>::iterator block_iter;
for (block_iter = blocks.begin(); block_iter != blocks.end(); ++block_iter)
{
    BPatch_basicBlock *block = *block_iter;
    std::vector<Dyninst::InstructionAPI::Instruction::Ptr> insns;
    block->getInstructions(insns);
}
```

Given an `Instruction` object, which is described in the InstructionAPI Reference Manual, we can query for properties of this instruction. InstructionAPI has numerous methods for inspecting the memory accesses, registers, and other properties of an instruction. This example simply checks whether this instruction accesses memory:

```
std::vector<Dyninst::InstructionAPI::Instruction::Ptr>::iterator
        insn_iter;
for (insn_iter = insns.begin(); insn_iter != insns.end(); ++insn_iter)
{
    Dyninst::InstructionAPI::Instruction::Ptr insn = *insn_iter;
    if (insn->readsMemory() || insn->writesMemory()) {
        insns_access_memory++;
    }
}
```

3.3   Instrumenting Memory Accesses

There are two snippets useful for memory access instrumentation: `BPatch_effectiveAddress-Expr` and `BPatch_bytesAccessedExpr`. Both have nullary constructors; the result of the snippet depends on the instrumentation point where the snippet is inserted. `BPatch_effectiveAddressExpr` has type void*, while `BPatch_bytesAccessedExpr` has type int.

These snippets may be used to instrument a given instrumentation point if and only if the point has memory access information attached to it. In this release the only way to create instrumentation points that have memory access information attached is via `BPatch_function.findPoint(const std::set<BPatch_opCode>&)`. For example, to instrument all the loads and stores in a function named `InterestingProcedure` with a call to `printf`, one may write:

```
BPatch_addressSpace *app = ...;
BPatch_image *appImage = proc->getImage();

// We're interested in loads and stores
std::set<BPatch_opCode> axs;
axs.insert(BPatch_opLoad);
axs.insert(BPatch_opStore);

// Scan the function InterestingProcedure and create instrumentation points
std::vector<BPatch_function*> funcs;
appImage->findFunction("InterestingProcedure", funcs);
std::vector<BPatch_point*>* points = funcs[0]->findPoint(axs);

// Create the printf function call snippet
std::vector<BPatch_snippet*> printfArgs;
BPatch_snippet *fmt = new BPatch_constExpr("Access at: %p.\n");
printfArgs.push_back(fmt);
BPatch_snippet *eae = new BPatch_effectiveAddressExpr();
printfArgs.push_back(eae);

// Find the printf function
std::vector<BPatch_function *> printfFuncs;
appImage->findFunction("printf", printfFuncs);

// Construct the function call snippet
BPatch_funcCallExpr printfCall(*(printfFuncs[0]), printfArgs);

// Insert the snippet at the instrumentation points
app->insertSnippet(printfCall, *points);
```

4.   Interface

This section describes functions in the API. The API is organized as a collection of C++ classes.
The primary classes are `BPatch`, `Bpatch_process`, `BPatch_binaryEdit`, `BPatch_thread`,
`BPatch_image`, `BPatch_point`, and `BPatch_snippet`. The API also uses a template class
called `std::vector`. This class is based on the Standard Template Library (STL) vector class.

4.1   Class BPatch

The **BPatch** class represents the entire Dyninst library. There can only be one instance of this
class at a time. This class is used to perform functions and obtain information that is not specific
to a particular thread or image.

std::vector<BPatch_process*> *getProcesses()

> Returns the list of processes that are currently defined. This list includes processes that
> were directly created by calling processCreate/processAttach, and indirectly by the UNIX
> `fork` or the Windows `CreateProcess` system call.   It is up to the user to delete this vec-
> tor when they are done with it.

BPatch_process *processAttach(const char *path, int pid, BPatch_hybridMode mode=BPatch_normalMode)
BPatch_process *processCreate(const char *path, const char *argv[], const char **envp = NULL, int stdin_fd=0, int
        stdout_fd=1, int stderr_fd=2, BPatch_hybridMode mode=BPatch_normalMode)

> Each of these functions returns a pointer to a new instance of the `BPatch_process` class.
> The `path` parameter needed by these functions should be the pathname of the executable
> file   containing   the   process   image.   The   `processAttach`   function   returns   a
> `BPatch_process` associated with an existing process. On Linux platforms the path pa-
> rameter can be `NULL` since the executable image can be derived from the process pid. At-
> taching to a process puts it into the stopped state. The `processCreate` function creates a
> new process and returns a new `BPatch_process` associated with it. The new process is
> put into a stopped state before executing any code.

> The `stdin_fd, stdout_fd`, and `stderr_fd` parameters are used to set the standard in-
> put, output, and error of the child process. The default values of these parameters leave
> the input, output, and error to be the same as the mutator process. To change these val-
> ues, an open UNIX file descriptor (see `open(1)`) can be passed.

> The `mode` parameter is used to select the desired level of code analysis. Activating hybrid
> code analysis causes Dyninst to augment its static analysis of the code with run-time code
> discovery techniques. There are three modes: `BPatch_normalMode`, BPatch_ex-
> ploratoryMode, and BPatch_defensiveMode. Normal mode enables the regular static
> analysis features of Dyninst. Exploratory mode and defensive mode enable addtional dy-
> namic features to correctly analyze programs that contain uncommon code patterns, such
> as malware. Exploratory mode is primarily oriented towards analyzing dynamic control
> transfers, while defensive mode additionally aims to tackle code obfuscation and self-

modifying code. Both of these modes are still experimental and should be used with caution. Defensive mode is only supported on Windows.

Defensive mode has been tested on normal binaries (binaries that run correctly under normal mode), as well as some simple, packed executables (self-decrypting or decompressing). More advanced forms of code obfuscation, such as self-modifying code, have not been tested recently. The traditional Dyninst interface may be used for instrumentation of binaries in defensive mode, but in the case of highly obfuscated code, this interface may prove to be ineffective due to the lack of a complete view of control flow at any given point. Therefore, defensive mode also includes a set of callbacks that enables instrumentation to be performed as new code is discovered. Due to the fact that recent efforts have focused on simpler forms of obfuscation, these callbacks have not been tested in detail. The next release of Dyninst will target more advanced uses of defensive mode.

BPatch_binaryEdit *openBinary(const char *path,
    bool openDependencies = false)

This function opens the executable file or library file pointed to by `path` for binary rewriting. If `openDependencies` is true then Dyninst will also open all shared libraries that `path` depends on. Upon success, this function returns a new instance of a `BPatch_binaryEdit` class that represents the opened file and any dependent shared libraries. This function returns `NULL` in the event of an error.

bool pollForStatusChange()

This is useful for a mutator that needs to periodically check on the status of its managed threads and does not want to check each process individually. It returns `true` if there has been a change in the status of one or more threads that has not yet been reported by either `isStopped` or `isTerminated`.

void setDebugParsing (bool state)

Turn on or off the parsing of debugger information. By default, the debugger information (produced by the –g compiler option) is parsed on those platforms that support it. However, for some applications this information can be quite large. To disable parsing this information, call this method with a value of `false` prior to creating a process.

bool parseDebugInfo()

Return true if debugger information parsing is enabled, or `false` otherwise.

void setTrampRecursive (bool state)

Turn on or off trampoline recursion. By default, any snippets invoked while another snippet is active will not be executed. This is the safest behavior, since recursively-calling snippets can cause a program to take up all available system resources and die. For

example, adding instrumentation code to the start of printf, and then calling printf from that snippet will result in infinite recursion.

This protection operates at the granularity of an instrumentation point. When snippets are first inserted at a point, this flag determines whether code will be created with recursion protection. Changing the flag is **not** retroactive, and inserting more snippets will not change the recursion protection of the point. Recursion protection increases the overhead of instrumentation points, so if there is no way for the snippets to call themselves, calling this method with the parameter `true` will result in a performance gain. The default value of this flag is `false`.

bool isTrampRecursive ()

Return whether trampoline recursion is enabled or not. `True` means that it is enabled.

void setTypeChecking(bool state)

Turn on or off type-checking of snippets. By default type-checking is turned on, and an attempt to create a snippet that contains type conflicts will fail. Any snippet expressions created with type-checking off have the type of their left operand. Turning type-checking off, creating a snippet, and then turning type-checking back on is similar to the type cast operation in the C programming language.

bool isTypeChecked()

Return `true` if type-checking of snippets is enabled, or `false` otherwise.

bool waitForStatusChange()

This function waits until there is a status change to some thread that has not yet been reported by either `isStopped` or `isTerminated`, and then returns true. It is more efficient to call this function than to call `pollForStatusChange` in a loop, because `waitForStatusChange` blocks the mutator process while waiting.

void setDelayedParsing (bool)

Turn on or off delayed parsing. When it is activated Dyninst will initially parse only the symbol table information in any new modules loaded by the program, and will postpone more thorough analysis (instrumentation point analysis, variable analysis, and discovery of new functions in stripped binaries). This analysis will automatically occur when the information is necessary.

Users which require small run-time perturbation of a program should not delay parsing; the overhead for analysis may occur at unexpected times if it is triggered by internal Dyninst behavior. Users who desire instrumentation of a small number of functions will benefit from delayed parsing.

bool delayedParsingOn()

>   Return `true` if delayed parsing is enabled, or `false` otherwise.

void setInstrStackFrames(bool)

>   Turn on and off stack frames in instrumentation. When on, Dyninst will create stack frames around instrumentation. A stack frame allows Dyninst or other tools to walk a call stack through instrumentation, but introduces overhead to instrumentation. The default is to not create stack frames.

bool getInstrStackFrames()

>   Return true if instrumentation will create stack frames, or `false` otherwise.

void setMergeTramp (bool)

>   Turn on or off inlined tramps. Setting this value to true will make each base trampoline have all of its mini-trampolines inlined within it. Using inlined mini-tramps may allow instrumentation to execute faster, but inserting and removing instrumentation may take more time. The default setting for this is `true`.

bool isMergeTramp ()

>   This returns the current status of inlined trampolines. A value of `true` indicates that trampolines are inlined.

void setSaveFPR (bool)

>   Turn on or off floating point saves. Setting this value to `false` means that floating point registers will never be saved, which can lead to large performance improvements. The default value is `true`. Setting this flag may cause incorrect program behavior if the instrumentation does clobber floating point registers, so it should only be used when the user is positive this will never happen.

bool isSaveFPROn ()

>   This returns the current status of the floating point saves. `True` means we are saving floating points based on the analysis for the given platform.

void setBaseTrampDeletion(bool)

>   If true, we delete the base tramp when the last corresponding minitramp is deleted. If false, we leave the base tramp in. The default value is `false`.

bool baseTrampDeletion()

>   Return true if base trampolines are set to be deleted, or `false` otherwise.

void setLivenessAnalysis(bool)

>   If true, we perform register liveness analysis around an `instPoint` before inserting instrumentation, and we only save registers that are live at that point. This can lead to

faster run-time speeds, but at the expense of slower instrumentation time. The default value is `true`.

bool livenessAnalysisOn()

Return true if liveness analysis is currently enabled.

void getBPatchVersion(int &major, int &minor, int &subminor)

Return Dyninst's version number. The major version number will be stored in `major`, the minor version number in `minor`, and the subminor version in `subminor`. For example, under Dyninst 5.1.0, this function will return 5 in `major`, 1 in `minor`, and 0 in `subminor`.

int getNotificationFD()

Returns a file descriptor that is suitable for inclusion in a call to `select()`. Dyninst will write data to this file descriptor when it to signal a state change in the process. `BPatch::pollForStatusChange` should then be called so that Dyninst can handle the state change. This is useful for applications where the user does not want to block in `BPatch::waitForStatusChange`. The file descriptor will reset when the user calls `BPatch::pollForStatusChange`.

BPatch_type *createArray(const char *name, BPatch_type *ptr, unsigned int low, unsigned int hi)

Create a new array type. The name of the type is `name`, and the type of each element is `ptr`. The index of the first element of the array is `low`, and the last is `high`. The standard rules of type compatibility, described in Section 4.28, are used with arrays created using this function.

BPatch_type *createEnum(const char *name, std::vector<char *> &elementNames, std::vector<int> &elementIds)
BPatch_type *createEnum(const char *name, std::vector<char *> &elementNames)

Create a new enumerated type. There are two variations of this function. The first one is used to create an enumerated type where the user specifies the identifier (int) for each element. In the second form, the system specifies the identifiers for each element. In both cases, a vector of character arrays is passed to supply the names of the elements of the enumerated type. In the first form of the function, the number of element in the `elementNames` and `elementIds` vectors must be the same, or the type will not be created and this function will return `NULL`. The standard rules of type compatibility, described in Section 4.28, are used with enums created using this function.

BPatch_type *createScalar(const char *name, int size)

Create a new scalar type. The `name` field is used to specify the name of the type, and the `size` parameter is used to specify the size in bytes of each instance of the type. No additional information about this type is supplied. The type is compatible with other scalars with the same name and size.

BPatch_type *createStruct(const char *name, std::vector<char *> &fieldNames, std::vector<BPatch_type *> &fieldTypes)

>Create a new structure type. The name of the structure is specified in the `name` parameter. The `fieldNames` and `fieldTypes` vectors specify fields of the type. These two vectors must have the same number of elements or the function will fail (and return `NULL`). The standard rules of type compatibility, described in Section 4.28, are used with structures created using this function. The size of the structure is the sum of the size of the elements in the `fieldTypes` vector.

BPatch_type *createTypedef(const char *name, BPatch_type *ptr)

>Create a new type called `name` and having the type `ptr`.

BPatch_type *createPointer(const char *name, BPatch_type *ptr)
BPatch_type *createPointer(const char *name, BPatch_type *ptr, int size)

>Create a new type, named `name`, which points to objects of type `ptr`. The first form creates a pointer whose size is equal to `sizeof(void*)`on the target platform where the mutatee is running. In the second form, the size of the pointer is the value passed in the `size` parameter.

BPatch_type *createUnion(const char *name, std::vector<char *> &fieldNames, std::vector<BPatch_type *> &fieldTypes)

>Create a new union type. The name of the union is specified in the `name` parameter. The `fieldNames` and `fieldTypes` vectors specify fields of the type. These two vectors must have the same number of elements or the function will fail (and return `NULL`). The size of the union is the size of the largest element in the `fieldTypes` vector.

4.2   Callbacks

The following functions are intended as a way for API users to be informed when an error or significant event occurs. Each function allows a user to register a handler for an event. The return code for all callback registration functions is the address of the handler that was previously registered (which may be `NULL` if no handler was previously registered). For backwards compatibility reasons, some callbacks may pass a `BPatch_thread` object when a `BPatch_process` may be more appropriate. A `BPatch_thread` may be converted into a `BPatch_process` using `BPatch_thread::getProcess()`.

4.2.1 Asynchronous Callbacks

```
typedef void (*BPatchAsyncThreadEventCallback)(
        BPatch_process *proc, BPatch_thread *thread)
bool registerThreadEventCallback(BPatch_asyncEventType type,
        BPatchAsyncThreadEventCallback cb)
bool removeThreadEventCallback(BPatch_asyncEventType type,
        BPatch_AsyncThreadEventCallback cb)
```

The type parameter can be either one of `BPatch_threadCreateEvent` or `BPatch_threadDestroyEvent`. Different callbacks can be registered for different values of `type`.

4.2.2 Code Discovery Callbacks

```
typedef void (*BPatchCodeDiscoveryCallback)( BPatch_Vector<BPatch_function*> &newFuncs,
        BPatch_Vector<BPatch_function*> &modFuncs)
bool registerCodeDiscoveryCallback(
        BPatchCodeDiscoveryCallback cb)
bool removeCodeDiscoveryCallback(BPatchCodeDiscoveryCallback cb)
```

This callback is invoked whenever previously un-analyzed code is discovered through runtime analysis, and delivers a vector of functions whose analysis have been modified and a vector of functions that are newly discovered.

4.2.3 Code Overwrite Callbacks

```
typedef void (*BPatchCodeOverwriteBeginCallback)(
        BPatch_Vector<BPatch_basicBlock*> &overwriteLoopBlocks);
typedef void (*BPatchCodeOverwriteEndCallback)(
        BPatch_Vector<std::pair<Dyninst::Address,int> > &deadBlocks, BPatch_Vector<BPatch_function*>
        &owFuncs, BPatch_Vector<BPatch_function*> &modFuncs, BPatch_Vector<BPatch_function*>
        &newFuncs)
bool registerCodeOverwriteCallbacks(
        BPatchCodeOverwriteBeginCallback cbBegin, BPatchCodeOverwriteEndCallback cbEnd)
```

Register a callback at the beginning and end of overwrite events. Only invoke if Dyninst's hybrid analysis mode is set to BPatch_defensiveMode.

The `BPatchCodeOverwriteBeginCallback` callback allows the user to remove any instrumentation when the program starts writing to a code page, which may be desirable as instrumentation cannot be removed during the overwrite loop's execution, and any breakpoint instrumentation will dramatically slow the loop's execution.

The `BPatchCodeOverwriteEndCallback` callback delivers the effects of the overwrite loop when it is done executing. In many cases no code will have changed.

4.2.4   Dynamic calls

```
typedef void (*BPatchDynamicCallSiteCallback)(
        BPatch_point *at_point, BPatch_function *called_function);
bool registerDynamicCallCallback(BPatchDynamicCallSiteCallback cb);
bool removeDynamicCallCallback(BPatchDynamicCallSiteCallback cb);
```

> The `registerDynamicCallCallback` interface will not automatically instrument any dynamic call site. To make sure the call back function is called, the user needs to explicitly instrument dynamic call sites. One way to achieve this goal is to first get instrumentation points representing dynamic call sites and then call `BPatch_point::monitorCalls` with a `NULL` input parameter.

4.2.5   Dynamic libraries

```
typedef void (*BPatchDynLibraryCallback)(BPatch_thread *thr,
        BPatch_object *obj, bool loaded);
BPatchDynLibraryCallback registerDynLibraryCallback(
        BPatchDynLibraryCallback func)
```

> Note that in versions previous to 9.1, BPatchDynLibraryCallback's signature took a BPatch_module instead of a BPatch_object.

4.2.6   Errors

```
enum BPatchErrorLevel { BPatchFatal, BPatchSerious, BPatchWarning, BPatchInfo };
typedef void (*BPatchErrorCallback)(BPatchErrorLevel severity, int number, const char * const *params)
BPatchErrorCallback registerErrorCallback(BPatchErrorCallback func)
```

> This function registers the error callback function with the `BPatch` class. The return value is the address of the previous error callback function. Dyninst users can change the error callback during program execution (e.g., one error callback before a GUI is initialized, and a different one after). The `severity` field indicates how important the error is (from fatal to information/status). The `number` is a unique number that identifies this error message. `Params` are the parameters that describe the detail about an error, e.g., the process id where the error occurred. The number and meaning of params depends on the error. However, for a given error number the number of parameters returned will always be the same.

4.2.7   Exec

typedef void (*BPatchExecCallback)(BPatch_thread *thr)
BPatchExecCallback registerExecCallback(
        BPatchExecCallback func) Not implemented on Windows.

4.2.8   Exit

typedef enum BPatch_exitType { NoExit, ExitedNormally, ExitedViaSignal };
typedef void (*BPatchExitCallback)(BPatch_thread *proc, BPatch_exitType exit_type);
BPatchExitCallback registerExitCallback(
        BPatchExitCallback func)

>   Register a function to be called when a process terminates. For a normal process exit, the
>   callback will actually be called just before the process exits, but while its process state
>   still exists. This allows final actions to be taken on the process before it actually exits.
>   The function `BPatch_thread::isTerminated()` will return true in this context even
>   though the process hasn't yet actually exited. In the case of an exit due to a signal, the
>   process will have already exited.

4.2.9   Fork

typedef void (*BPatchForkCallback)(BPatch_thread *parent, BPatch_thread *child);

>   This is the prototype for the pre-`fork` and post-`fork` callbacks. The `parent` parameter is
>   the parent thread, and the `child` parameter is a `BPatch_thread` in the newly created
>   process. When invoked as a pre-`fork` callback, the child is `NULL`.

BPatchForkCallback registerPreForkCallback(
        BPatchForkCallback func) not implemented on Windows
BPatchForkCallback registerPostForkCallback(
        BPatchForkCallback func) not implemented on Windows

>   Register callbacks for pre-fork (before the child is created) and post-fork (immediately
>   after the child is created). When a pre-fork callback is executed the `child` parameter will
>   be `NULL`.

4.2.10   One Time Code

typedef void (*BPatchOneTimeCodeCallback)(Bpatch_thread *thr,
        void *userData, void *returnValue);
BPatchOneTimeCodeCallback registerOneTimeCodeCallback(
        BPatchOneTimeCodeCallback func)

>   The `thr` field contains the thread that executed the `oneTimeCode` (if thread-specific) or an
>   unspecified thread in the process (if process-wide). The `userData` field contains the
>   value passed to the `oneTimeCode` call. The `returnValue` field contains the return result
>   of the `oneTimeCode` snippet.

4.2.11 Signal Handler

typedef void (*BPatchSignalHandlerCallback)(BPatch_point *at_point, long signum, std::vector<Dyninst::Address> *handlers)
bool registerSignalHandlerCallback(BPatchSignalHandlerCallback cb, std::set<long> &signal_numbers)
bool registerSignalHandlerCallback(BPatchSignalHandlerCallback cb, BPatch_Set<long> *signal_numbers)
bool removeSignalHandlerCallback(BPatchSignalHandlerCallback cb);

This function registers the signal handler callback function with the `BPatch` class. The return value indicates success or failure. The `signal_numbers` set contains those signal numbers for which the callback will be invoked.

The `at_point` parameter indicates the point at which the signal/exception was raised, `signum` is the number of the signal/exception that was raised, and the `handlers` vector contains any registered handler(s) for the signal/exception. In Windows this corresponds to the stack of Structured Exception Handlers, while for Unix systems there will be at most one registered exception handler. This functionality is only fully implemented for the Windows platform.

4.2.12 Stopped Threads

typedef void (*BPatchStopThreadCallback)(BPatch_point *at_point, void *returnValue)

This is the prototype for the callback that is associated with the `stopThreadExpr` snippet class (see Section 4.13). Unlike the other callbacks in this section, `stopThreadExpr` callbacks are registered during the creation of the `stopThreadExpr` snippet type. Whenever a `stopThreadExpr` snippet executes in a given thread, the snippet evaluates the `calculation` snippet that `stopThreadExpr` takes as a parameter, stops the thread's execution and invokes this callback. The `at_point` parameter is the `BPatch_point` at which the `stopThreadExpr` snippet was inserted, and `returnValue` contains the computation made by the calculation snippet.

4.2.13 User-triggered callbacks

typedef void (*BPatchUserEventCallback)(BPatch_process *proc, void *buf, unsigned int bufsize);
bool registerUserEventCallback(BPatchUserEventCallback cb)
bool removeUserEventCallback(BPatchUserEventCallback cb)

Register a callback that is executed when the user sends a message from the mutatee using the `DYNINSTuserMessage` function in the runtime library.

4.3 Class BPatch_addressSpace

The **BPatch_addressSpace** class is a superclass of the `BPatch_process` and BPatch_binaryEdit classes. It contains functionality that is common between the two sub classes.

BPatch_image *getImage()

Return a handle to the executable file associated with this `BPatch_process` object.

bool getSourceLines(unsigned long addr, std::vector< BPatch_statement > & lines)

This function returns the line information associated with the mutatee address, `addr`. The vector `lines` contain pairs of filenames and line numbers that are associated with `addr`. In many cases only one filename and line number is associated with an address, but certain compiler optimizations may lead to multiple filenames and lines at an address. This information is only available if the mutatee was compiled with debug information.

This function returns `true` if it was able to find any line information at `addr`, or false otherwise.

bool getAddressRanges(const char * fileName, unsigned int lineNo, std::vector< std::pair< unsigned long, unsigned long > > & ranges)

Given a filename and line number, `fileName` and `lineNo`, this function this function returns the ranges of mutatee addresses that implement the code range in the output parameter `ranges`. In many cases a source code line will only have one address range implementing it. However, compiler optimizations may transform this into multiple disjoint address ranges. This information is only available if the mutatee was compiled with debug information.

This function returns `true` if it was able to find any line information, `false` otherwise.

BPatch_variableExpr *malloc(int n,
        std::string name = std::string(""))

BPatch_variableExpr *malloc(const BPatch_type &type,
        std::string name = std::string(""))

These two functions allocate memory. Memory allocation is from a heap. The heap is not necessarily the same heap used by the application. The available space in the heap may be limited depending on the implementation. The first function, `malloc(int n)`, allocates n bytes of memory from the heap. The second function, `malloc(const BPatch_type& t)`, allocates enough memory to hold an object of the specified type. Using the second version is strongly encouraged because it provides additional information to permit better type checking of the passed code. If a name is specified, Dyninst will assign `var_name` to the variable; otherwise, it will assign an internal name. The returned memory is persistent and will not be released until `BPatch_process::free` is called or the application terminates.

BPatch_variableExpr *createVariable(Dyninst::Address addr,
        BPatch_type *type,
        std::string var_name = std::string(""),
        BPatch_module *in_module = NULL)

This method creates a new variable at the given address `addr` in the module `in_module`. If a name is specified, Dyninst will assign `var_name` to the variable; otherwise, it will assign an internal name. The `type` parameter will become the type for the new variable.

When operating in binary rewriting mode, it is an error for the `in_module` parameter to be `NULL`; it is necessary to specify the module in which the variable will be created. Dyninst will then write the variable back out in the file specified by `in_module`.

bool free(BPatch_variableExpr &ptr)

Free the memory in the passed variable `ptr`. The programmer is responsible for verifying that all code that could reference this memory will not execute again (either by removing all snippets that refer to it, or by analysis of the program). Return true if the free succeeded.

bool getRegisters(std::vector<BPatch_register> &regs)

This function returns a vector of `BPatch_register` objects that represent registers available to snippet code.

BPatchSnippetHandle *insertSnippet(const BPatch_snippet &expr,
        BPatch_point &point,
        BPatch_callWhen when=[BPatch_callBefore| BPatch_callAfter],
        BPatch_snippetOrder order = BPatch_firstSnippet)

BPatchSnippetHandle *insertSnippet(const BPatch_snippet &expr,
        const std::vector<BPatch_point *> &points,
        BPatch_callWhen when=[BPatch_callBefore| BPatch_callAfter],
        BPatch_snippetOrder order = BPatch_firstSnippet)

Insert a snippet of code at the specified `point`. If a list of `points` is supplied, insert the code snippet at each point in the list. The optional `when` argument specifies when the snippet is to be called; a value of `BPatch_callBefore` indicates that the snippet should be inserted just before the specified `point` or `points` in the code, and a value of `BPatch_callAfter` indicates that it should be inserted just after them.

The `order` argument specifies where the snippet is to be inserted relative to any other snippets previously inserted at the same point. The values `BPatch_firstSnippet` and `BPatch_lastSnippet` indicate that the snippet should be inserted before or after all snippets, respectively.

It is illegal to use `BPatch_callAfter` with a `BPatch_entry` point. Use `BPatch_callBefore` when instrumenting entry points, which inserts instrumentation before the first instruction in a subroutine. Likewise, it is illegal to use `BPatch_callBefore` with a `BPatch_exit` point. Use `BPatch_callAfter` with exit points. `BPatch_callAfter` inserts instrumentation at the last instruction in the subroutine. `insertSnippet` will return `NULL` when used with an illegal pair of points.

bool deleteSnippet(BPatchSnippetHandle *handle)

> Remove the snippet associated with the passed `handle`. If the `handle` is not defined for the process, then `deleteSnippet` will return false.

void beginInsertionSet()

> Normally, a call to `insertSnippet` immediately injects instrumentation into the mutatee. However, users may wish to insert a set of snippets as a single batch operation. This provides two benefits: First, Dyninst may insert instrumentation in a more efficient manner. Second, multiple snippets may be inserted at multiple points as a single operation, with either all snippets being inserted successfully or none. This batch insertion mode is begun with a call to `beginInsertionSet`; after this call, no snippets are actually inserted until a corresponding call to `finalizeInsertionSet`. Dyninst accumulates all calls to `insertSnippet` during batch mode internally, and the returned `BPatchSnippetHandles` are filled in when `finalizeInsertionSet` is called.

> Insertion sets are unnecessary when doing static binary instrumentation. Dyninst uses an implicit insertion set around all instrumentation to a static binary.

bool finalizeInsertionSet(bool atomic)

> Inserts all snippets accumulated since a call to `beginInsertionSet`. If the `atomic` parameter is `true`, then a failure to insert any snippet results in all snippets being removed; effectively, the insertion is all-or-nothing. If the atomic parameter is `false`, then snippets are inserted individually. This function also fills in the `BPatchSnippetHandle` structures returned by the `insertSnippet` calls comprising this insertion set. It returns `true` on success and `false` if there was an error inserting any snippets.

> Insertion sets are unnecessary when doing static binary instrumentation. Dyninst uses an implicit insertion set around all instrumentation to a static binary.

bool removeFunctionCall(BPatch_point &point)

> Disable the mutatee function call at the specified location. The `point` specified must be a valid call point in the image of the mutatee. The purpose of this routine is to permit tools to alter the semantics of a program by eliminating procedure calls. The mechanism to achieve the removal is platform dependent, but might include branching over the call or replacing it with NOPs. This function only removes a function call; any parameters to the function will still be evaluated.

bool replaceFunction (BPatch_function &old, BPatch_function &new)
bool revertReplaceFunction (BPatch_function &old)

> Replace all calls to user function `old` with calls to `new`. This is done by inserting instrumentation (specifically a `BPatch_funcJumpExpr`) into the beginning of function `old` such that a non-returning jump is made to function `new`. Returns `true` upon success, `false` otherwise.

bool replaceFunctionCall(BPatch_point &point, BPatch_function &newFunc)

> Change the function call at the specified `point` to the function indicated by `newFunc`. The purpose of this routine is to permit runtime steering tools to change the behavior of programs by replacing a call to one procedure by a call to another. `Point` must be a function call point. If the change was successful, the return value is `true`, otherwise `false` will be returned.

> *WARNING: Care must be used when replacing functions. In particular if the compiler has performed inter-procedural register allocation between the original caller/callee pair, the replacement may not be safe since the replaced function may clobber registers the compiler thought the callee left untouched. Also the signatures of the both the function being replaced and the new function must be compatible.*

bool wrapFunction(BPatch_function *old, BPatch_function *new, Dyninst::SymtabAPI::Symbol *sym)
bool revertWrapFunction(BPatch_function *old)

> Replaces all calls to function `old` with calls to function `new`. Unlike replaceFunction above, the old function can still be reached via the name specified by the provided symbol `sym`. Function wrapping allows existing code to be extended by new code. Consider the following code that implements a fast memory allocator for a particular size of memory allocation, but falls back to the original memory allocator (referenced by `origMalloc`) for all others.

```
void *origMalloc(unsigned long size);

void *fastMalloc(unsigned long size) {
    if (size == 1024) {
            unsigned long ret = fastPool;
            fastPool += 1024;
            return ret;
    }
    else {
            return origMalloc(size);
    }
}
```

> The symbol `sym` is provided by the user and must exist in the program; the easiest way to ensure it is created is to use an undefined function as shown above with the definition of `origMalloc`.

> The following code wraps malloc with `fastMalloc`, while allowing functions to still access the original malloc function by calling `origMalloc`. It makes use of the `new` convert interface described in Section 5..

```
using namespace Dyninst;
using namespace SymtabAPI;
BPatch_function *malloc = appImage->findFunction(...);
BPatch_function *fastMalloc = appImage->findFunction(...);
Symtab *symtab = SymtabAPI::convert(fastMalloc->getModule());
```

```
    std::vector<Symbol *> syms;
    symtab->findSymbol(syms, "origMalloc",
                            Symbol::ST_UNKNOWN, // Don't specify type
                            mangledName, // Look for raw symbol name
                            false, // Not regular expression
                            false, // Don't check case
                            true); // Include undefined symbols
    app->wrapFunction(malloc, fastMalloc, syms[0]);
```

For a full, executable example, see Appendix A - Complete Examples.

bool replaceCode(BPatch_point *point, BPatch_snippet *snippet)

This function has been removed; users interested in replacing code should instead use the PatchAPI code modification interface described in the PatchAPI manual. For information on accessing PatchAPI abstractions from DyninstAPI abstractions, see Section 5..

BPatch_module * loadLibrary(const char *libname, bool reload=false)

For dynamic rewriting, this function loads a dynamically linked library into the process's address space. For static rewriting, this function adds a library as a library dependency in the rewritten file. In both cases Dyninst creates a new `BPatch_module` to represent this library.

The `libname` parameter identifies the file name of the library to be loaded, in the standard way that dynamically linked libraries are specified on the operating system on which the API is running. This function returns a handle to the loaded library. The `reload` parameter is ignored and only remains for backwards compatibility.

bool isStaticExecutable()

This function returns `true` if the original file opened with this `BPatch_addressSpace` is a statically linked executable, or false otherwise.

processType getType()

This function returns a processType that reflects whether this address space is a BPatch_process or a BPatch_binaryEdit.

4.4   Class BPatch_process

The **BPatch_process** class represents a running process, which includes one or more threads of execution and an address space.

bool stopExecution()
bool continueExecution()
bool terminateExecution()

> These three functions change the running state of the process. `stopExecution` puts the process into a stopped state. Depending on the operating system, stopping one process may stop all threads associated with a process. `continueExecution` continues execution of the process. `terminateExecution` terminates execution of the process and will invoke the exit callback if one is registered. Each function returns true on success, or false for failure. Stopping or continuing a terminated thread will fail and these functions will return false.

bool isStopped()
int stopSignal()
bool isTerminated()

> These three functions query the status of a process. `isStopped` returns `true` if the process is currently stopped. If the process is stopped (as indicated by `isStopped`), then `stopSignal` can be called to find out what signal caused the process to stop. `isTerminated` returns true if the process has exited. Any of these functions may be called multiple times, and calling them will not affect the state of the process.

BPatch_variableExpr *getInheritedVariable(BPatch_variableExpr &parentVar)

> Retrieve a new handle to an existing variable (such as one created by `BPatch_process::malloc`) that was created in a parent process and now exists in a forked child process. When a process forks all existing `BPatch_variableExpr`s are copied to the child process, but the Dyninst handles for these objects are not valid in the child `BPatch_process`. This function is invoked on the child process' `BPatch_process`, `parentVar` is a variable from the parent process, and a handle to a variable in the child process is returned. If `parentVar` was not allocated in the parent process, then `NULL` is returned.

BPatchSnippetHandle *getInheritedSnippet(BPatchSnippetHandle &parentSnippet)

> This function is similar to `getInheritedVariable`, but operates on `BPatchSnippetHandles`. Given a child process that was created via fork and a `BPatchSnippetHandle`, `parentSnippet`, from the parent process, this function will return a handle to `parentSnippet` that is valid in the child process. If it is determined that `parentSnippet` is not associated with the parent process, then `NULL` is returned.

void detach(bool cont)

> Detach from the process. The process must be stopped to call this function. Instrumentation and other changes to the process will remain active in the detached copy. The `cont` parameter is used to indicate if the process should be continued as a result of detaching.

Linux does not support detaching from a process while leaving it stopped. All processes are continued after detach on Linux.

int getPid()

Return the system id for the mutatee process. On UNIX based systems this is a PID. On Windows this is the HANDLE object for a process.

typedef enum BPatch_exitType { NoExit, ExitedNormally, ExitedViaSignal };

BPatch_exitType terminationStatus()

If the process has exited, `terminationStatus` will indicate whether the process exited normally or because of a signal. If the process has not exited, `NoExit` will be returned. On AIX, the reason why a process exited will not be available if the process was not a child of the Dyninst mutator; in this case, `ExitedNormally` will be returned in both normal and signal exit cases.

int getExitCode()

If the process exited in a normal way, `getExitCode` will return the associated exit code. Prior to Dyninst 8.2, `getExitCode` would return the argument passed to `exit` or the value returned by `main`; in Dyninst 8.2 and later, it returns the actual exit code as provided by the debug interface and seen by the parent process. In particular, on Linux, this means that exit codes are normalized to the range 0-255.

int getExitSignal()

If the process exited because of a received signal, `getExitSignal` will return the associated signal number.

void oneTimeCode(const BPatch_snippet &expr)

Cause the snippet `expr` to be executed by the mutatee immediately. If the process is multithreaded, the snippet is run on a thread chosen by Dyninst. If the user requires the snippet to be run on a particular thread, use the `BPatch_thread` version of this function instead. The process must be stopped to call this function. The behavior is synchronous; `oneTimeCode` will not return until after the snippet has been run in the application.

bool oneTimeCodeAsync(const BPatch_snippet &expr,
        void *userData = NULL)

This function sets up a snippet to be evaluated by the process at the next available opportunity. When the snippet finishes running Dyninst will callback any function registered through `BPatch::registerOneTimeCodeCallback`, with `userData` passed as a parameter. This function return `true` on success and `false` if it could not post the `oneTimeCode`.

dyninstAPI

If the process is multithreaded, the snippet is run on a thread chosen by Dyninst. If the user requires the snippet to be run on a particular thread, use the `BPatch_thread` version of this function instead. The behavior is asynchronous; `oneTimeCodeAsync` returns before the snippet is executed.

If the process is running when `oneTimeCodeAsync` is called, `expr` will be run immediately. If the process is stopped, then `expr` will be run when the process is continued.

void getThreads(std::vector<BPatch_thread *> &thrds)

Get the list of threads in the process.

bool isMultithreaded()
bool isMultithreadCapable()

The former returns true if the process contains multiple threads; the latter returns true if the process can create threads (e.g., it contains a threading library) even if it has not yet.

4.5   Class BPatch_thread

The **BPatch_thread** class represents and controls a thread of execution that is running in a process.

void getCallStack(std::vector<BPatch_frame>& stack)

This function fills the given vector with current information about the call stack of the thread. Each stack frame is represented by a `BPatch_frame` (see section 4.24 for information about this class).

dynthread_t getTid()

This function returns a platform-specific identifier for this thread. This is the identifier that is used by the threading library. For example, on pthread applications this function will return the thread's `pthread_t` value.

Dyninst::LWP getLWP()

This function returns a platform-specific identifier that the operating system uses to identify this thread. For example, on UNIX platforms this returns the LWP id. On Windows this returns a HANDLE object for the thread.

unsigned getBPatchID()

This function returns a Dyninst-specific identifier for this thread. These ID's apply only to running threads, the BPatch ID of an already terminated thread my be repeated in a new thread.

BPatch_function *getInitialFunc()

> Return the function that was used by the application to start this thread. For example, on pthread applications this will return the initial function that was passed to `pthread_cre-ate.`

unsigned long getStackTopAddr()

> Returns the base address for this thread's stack.

bool isDeadOnArrival()

> This function returns true if this thread terminated execution before Dyninst was able to attach to it. Since Dyninst performs new thread detection asynchronously, it is possible for a thread to be created and destroyed before Dyninst can attach to it. When this happens, a new `BPatch_thread` is created, but `isDeadOnArrival` always returns true for this thread. It is illegal to perform any thread-level operations on a dead on arrival thread.

BPatch_process *getProcess()

> Return the `BPatch_process` that contains this thread.

void *oneTimeCode(const BPatch_snippet &expr, bool *err = NULL)

> Cause the snippet `expr` to be evaluated by the process immediately. This is similar to the BPatch_process::oneTimeCode function, except that the snippet is guaranteed to run only on this thread. The process must be stopped to call this function. The behavior is synchronous; `oneTimeCode` will not return until after the snippet has been run in the application.

bool oneTimeCodeAsync(const BPatch_snippet &expr,
                                     void *userData = NULL,
                                     BpatchOneTimeCodeCallback cb = NULL)

> This function sets up the snippet `expr` to be evaluated by this thread at the next available opportunity. When the snippet finishes running, Dyninst will callback any function registered through `BPatch::registerOneTimeCodeCallback`, with `userData` passed as a parameter. This function returns `true` if `expr` was posted or false otherwise.

> This is similar to the `BPatch_process::oneTimeCodeAsync` function, except that the snippet is guaranteed to run only on this thread. The process must be stopped to call this function. The behavior is asynchronous; `oneTimeCodeAsync` returns before the snippet is executed.

4.6   Class BPatch_binaryEdit

The BPatch_binaryEdit class represents a set of executable files and library files for binary rewriting. BPatch_binaryEdit inherits from the BPatch_addressSpace class, where most functionality for binary rewriting is found.

bool writeFile(const char *outFile)

> Rewrite a `BPatch_binaryEdit` to disk. The original file opened with this `BPatch_binaryEdit` is written to the current working directory with the name `outFile`. If any dependent libraries were also opened and have instrumentation or other modifications, then those libraries will be written to disk in the current working directory under their original names.

> A rewritten dependency library should only be used with the original file that was opened for rewriting. For example, if the file `a.out` and its dependent library `libfoo.so` were opened for rewriting, and both had instrumentation inserted, then the rewritten `libfoo.so` should not be used without the rewritten `a.out`. To build a rewritten `libfoo.so` that can load into any process, `libfoo.so` must be the original file opened by `BPatch::openBinary.`

> This function returns `true` if it successfully wrote a file, or false otherwise.

4.7   Class BPatch_sourceObj

The BPatch_sourceObj class is the C++ superclass for the BPatch_function, BPatch_module, and BPatch_image classes. It provides a set of common methods for all three classes. In addition, it can be used to build a "generic" source navigator using the `getObjParent` and `getSourceObj` methods to get parents and children of a given level (i.e. the parent of a module is an image, and the children will be the functions).

enum BPatchErrorLevel { BPatchFatal, BPatchSerious, BPatchWarning, BPatchInfo };

enum BPatch_sourceType {
        BPatch_sourceUnknown,
        BPatch_sourceProgram,
        BPatch_sourceModule,
        BPatch_sourceFunction,
        BPatch_sourceOuterLoop,
        BPatch_sourceLoop,
        BPatch_sourceStatement };

BPatch_sourceType getSrcType()

> Returns the type of the current source object.

void getSourceObj(std::vector<BPatch_sourceObj *> &objs)

> Returns the child source objects of the current source object. For example, when called on a `BPatch_sourceProgram` object this will return objects of type `BPatch_source-Function`. When called on a `BPatch_sourceFunction` object it may return `BPatch_sourceOuterLoop` and `BPatch_sourceStatement` objects.

BPatch_sourceObj *getObjParent()

> Return the parent source object of the current source object. The parent of a `BPatch_im-age` is `NULL`.

```
typedef enum BPatch_language {
  BPatch_c,
  BPatch_cPlusPlus,
  BPatch_fortran,
  BPatch_fortran77,
  BPatch_fortran90,
  BPatch_f90_demangled_stabstr,
  BPatch_fortran95,
  BPatch_assembly,
  BPatch_mixed,
  BPatch_hpf,
  BPatch_java,
  BPatch_unknownLanguage
} BPatch_language;
```

BPatch_language getLanguage()

> Return the source language of the current `BPatch_sourceObject`. For programs that are written in more than one language, `BPatch_mixed` will be returned. If there is insufficient information to determine the language, `BPatch_unknownLanguage` will be returned.

4.8   Class BPatch_function

An object of this class represents a function in the application. A `BPatch_image` object (see description below) can be used to retrieve a `BPatch_function` object representing a given function.

```
std::string getName();
std::string getDemangledName();
std::string getMangledName();
std::string getTypedName();
void getNames(std::vector<std::string> &names);
void getDemangledNames(std::vector<std::string> &names);
void getMangledNames(std::vector<std::string> &names);
void getTypedNames(std::vector<std::string> &names);
```

> Return name(s) of the function. The `getName` functions return the primary name; this is typically the first symbol we encounter while parsing the program; `getName` is an alias

for `getDemangledName`. The `getNames` functions return all known names for the func-
tion, including any names specified by weak symbols.

bool getAddressRange(Dyninst::Address &start,
                                    Dyninst::Address &end)

Returns the bounds of the function; for non-contiguous functions, this is the lowest and
highest address of code that the function includes.

std::vector<BPatch_localVar *> *getParams()

Return a vector of `BPatch_localVar` snippets that refer to the parameters of this func-
tion. The position in the vector corresponds to the position in the parameter list (starting
from zero). The returned local variables can be used to check the types of functions, and
can be used in snippet expressions.

BPatch_type *getReturnType()

Return the type of the return value for this function.

BPatch_variableExpr *getFunctionRef()

For platforms with complex function pointers (e.g., 64-bit PPC) this constructs and re-
turns the appropriate descriptor.

std::vector<BPatch_localVar *> *getVars()

Returns a vector of `BPatch_localVar` objects that contain the local variables in this
function. These `BPatch_localVar`s can be used as parts of snippets in instrumentation.
This function requires debug information to be present in the mutatee. If Dyninst was un-
able to find any local variables, this function will return an empty vector. It is up to the
user to free the vector returned by this function.

bool isInstrumentable()

Return `true` if the function can be instrumented, and `false` if it cannot. Various condi-
tions can cause a function to be uninstrumentable. For example, there exists a platform-
specific minimum function size beyond which a function cannot be instrumented.

bool isSharedLib()

This function returns `true` if the function is defined in a shared library.

BPatch_module *getModule()

Return the module that contains this function. Depending on whether the program was
compiled for debugging or the symbol table stripped, this information may not be avail-
able. This function returns `NULL` if module information was not found.

char *getModuleName(char *name, int maxLen)

Copies the name of the module that contains this function into the buffer pointed to by
`name`. Copies at most `maxLen` characters and returns a pointer to `name`.

```
enum BPatch_procedureLocation {
        BPatch_entry,
        BPatch_exit,
        BPatch_subroutine,
        BPatch_locInstruction,
        BPatch_locBasicBlockEntry,
        BPatch_locLoopEntry,
        BPatch_locLoopExit,
        BPatch_locLoopStartIter,
        BPatch_locLoopStartExit,
        BPatch_allLocations }
```
const std::vector<BPatch_point *> *findPoint(const BPatch_procedureLocation loc)

> Return the BPatch_point or list of BPatch_points associated with the procedure. It is
> used to select which type of points associated with the procedure will be returned.
> BPatch_entry and BPatch_exit request respectively the entry and exit points of the
> subroutine. BPatch_subroutine returns the list of points where the procedure calls other
> procedures. If the lookup fails to locate any points of the requested type, NULL is returned.

enum BPatch_opCode { BPatch_opLoad, BPatch_opStore, BPatch_opPrefetch }
std::vector<BPatch_point *> *findPoint(const std::set<BPatch_opCode>& ops)
std::vector<BPatch_point *> *findPoint(const BPatch_Set<BPatch_opCode>& ops)

> Return the vector of BPatch_points corresponding to the set of machine instruction
> types described by the argument. This version is used primarily for memory access in-
> strumentation. The BPatch_opCode is an enumeration of instruction types that may be re-
> quested: BPatch_opLoad, BPatch_opStore, and BPatch_opPrefetch. Any combination
> of these may be requested by passing an appropriate argument set containing the desired
> types. The instrumentation points created by this function have additional memory access
> information attached to them. This allows such points to be used for memory access spe-
> cific snippets (e.g. effective address). The memory access information attached is de-
> scribed under Memory Access classes in section 4.27.1.

BPatch_localVar *findLocalVar(const char *name)

> Search the function's local variable collection for name. This returns a pointer to the lo-
> cal variable if a match is found. This function returns NULL if it fails to find any vari-
> ables.

std::vector<BPatch_variableExpr *> *findVariable(const char * name)
bool findVariable(const char *name, std::vector<BPatch_variableExpr> &vars)

> Return a set of variables matching name at the scope of this function. If no variables
> match in the local scope, then the global scope will be searched for matches. This func-
> tion returns NULL if it fails to find any variables.

BPatch_localVar *findLocalParam(const char *name)

> Search the function's parameters for a given name. A BPatch_localVar * pointer is re-
> turned if a match is found, and NULL is returned otherwise.

void *getBaseAddr()

> Return the starting address of the function in the mutatee's address space.

BPatch_flowGraph *getCFG()

> Return the control flow graph for the function, or `NULL` if this information is not available. The `BPatch_flowGraph` is described in section 4.16.

bool findOverlapping(std::vector<BPatch_function *> &funcs)

> Determine which functions overlap with the current function (see Section 2.). Return `true` if other functions overlap the current function; the overlapping functions are added to the `funcs` vector. Return `false` if no other functions overlap the current function.

bool addMods(std::set<StackMod *> mods)
>   implemented on x86 and x86-64

> Apply stack modifications in `mods` to the current function; the `StackMod` class is described in section 4.25. Perform error checking, handle stack alignment requirements, and generate any modifications required for cleanup at function exit. `addMods` atomically adds all modifications in `mods`; if any mod is found to be unsafe, none of the modifications in `mods` will be applied.

> `addMods` can only be used in binary rewriting mode.

> Returns `false` if the stack modifications are unsafe or if Dyninst is unable to perform the analysis required to guarantee safety.

4.9   Class BPatch_point

An object of this class represents a location in an application's code at which the library can insert instrumentation. A `BPatch_image` object (see section 4.10) is used to retrieve a `BPatch_point` representing a desired point in the application.

```
enum  BPatch_procedureLocation  {  BPatch_entry,  BPatch_exit,
     BPatch_subroutine, BPatch_address }
```

BPatch_procedureLocation getPointType()

> Return the type of the point.

BPatch_function *getCalledFunction()

> Return a `BPatch_function` representing the function that is called at the point. If the point is not a function call site or the target of the call cannot be determined, then this function returns `NULL`.

std::string getCalledFunctionName()

>   Returns the name of the function called at this point. This method is similar to `getCalledFunction()->getName()`, except in cases where DyninstAPI is running in binary rewriting mode and the called function resides in a library or object file that DyninstAPI has not opened. In these cases, Dyninst is able to determine the name of the called function, but is unable to construct a `BPatch_function` object.

BPatch_function *getFunction()

>   Returns a `BPatch_function` representing the function in which this point is contained.

BPatch_basicBlockLoop *getLoop()

>   Returns the containing `BPatch_basicBlockLoop` if this point is part of loop instrumentation. Returns `NULL` otherwise.

void *getAddress()

>   Return the address of the first instruction at this point.

bool usesTrap_NP()

>   Return `true` if inserting instrumentation at this point requires using a trap. On the x86 architecture, because instructions are of variable size, the instruction at a point may be too small for Dyninst to replace it with the normal code sequence used to call instrumentation. Also, when instrumentation is placed at points other than subroutine entry, exit, or call points, traps may be used to ensure the instrumentation fits. In this case, Dyninst replaces the instruction with a single-byte instruction that generates a trap. A trap handler then calls the appropriate instrumentation code. Since this technique is used only on some platforms, on other platforms this function always returns `false`.

const BPatch_memoryAccess* getMemoryAccess()

>   Returns the memory access object associated with this point. Memory access points are described in section 4.27.1.

const std::vector<BPatchSnippetHandle *> getCurrentSnippets()
const std::vector<BPatchSnippetHandle *>
            getCurrentSnippets(BPatch_callWhen when)

>   Return the `BPatchSnippetHandles` for the `BPatch_snippets` that are associated with the point. If argument `when` is `BPatch_callBefore`, then `BPatchSnippetHandles` for snippets installed immediately before this point will be returned. Alternatively, if when is `BPatch_callAfter`, then `BPatchSnippetHandles` for snippets installed immediately after this point will be returned.

bool getLiveRegisters(std::vector<BPatch_register> &regs)

>   Fill `regs` with the registers that are live before this point (e.g., `BPatch_callBefore`). Currently returns only general purpose registers (GPRs).

bool isDynamic()

> This call returns `true` if this is a dynamic call site (e.g. a call site where the function call is made via a function pointer).

void* monitorCalls(BPatch_function* func)

> For a dynamic call site, this call instruments the call site represented by this instrumentation point with a function call. If input parameter `func` is not `NULL`, `func` is called at the call site as the instrumentation. If `func` is `NULL`, the callback function registered with `BPatch::registerDynamicCallCallback` is used for instrumentation. Under both cases, this call returns a pointer to the called function. If the instrumentation point does not represent a dynamic call site, this call returns `NULL`.

bool stopMonitoring()

> This call returns `true` if this instrumentation point is a dynamic call site and its instrumentation is successfully removed. Otherwise, it returns `false`.

Dyninst::InstructionAPI::Instruction::Ptr getInstructionAtPoint()

> On implemented platforms, this function returns a shared pointer to an InstructionAPI Instruction object representing the first machine instruction at this point's address. On unimplemented platforms, returns a `NULL` shared pointer.

4.10   Class BPatch_image

This class defines a program image (the executable associated with a process). The only way to get a handle to a BPatch_image is via the BPatch_process member function `getImage`.

const BPatch_point *createInstPointAtAddr (caddr_t address)

> This function has been removed because it is not safe to use. Instead, use `findPoints`:

bool findPoints(Dyninst::Address addr,
        std::vector<BPatch_point *> &points);

> Returns a vector of `BPatch_points` that correspond with the provided address, one per function that includes an instruction at that address. There will be one element if there is not overlapping code.

std::vector<BPatch_variableExpr *> *getGlobalVariables()

> Return a vector of global variables that are defined in this image.

BPatch_process *getProcess()

> Returns the `BPatch_process` associated with this image.

char *getProgramFileName(char *name, unsigned int len)

>   Fills provided buffer `name` with the program's file name up to `len` characters. The file-name may include path information.

bool getSourceObj(std::vector<BPatch_sourceObj *> &sources)

>   Fill `sources` with the source objects (see section 4.6) that belong to this image. If there are no source objects, the function returns `false`. Otherwise, it returns `true`.

std::vector<BPatch_function *> *getProcedures(
        bool incUninstrumentable = false)

>   Return a vector of the functions in the image. If the `incUninstrumentable` flag is set, the returned table of procedures will include uninstrumentable functions. The default behavior is to omit these functions.

void getObjects(std::vector<BPatch_object *> &objs)

>   Fill in a vector of objects in the image.

std::vector<BPatch_module *> *getModules()

>   Return a vector of the modules in the image.

bool getVariables(std::vector<BPatch_variableExpr *> &vars)

>   Fills `vars` with the global variables defined in this image. If there are no variable, the function returns `false`. Otherwise, it returns `true`.

std::vector<BPatch_function*> *findFunction(
        const char *name,
        std::vector<BPatch_function*> &funcs,
        bool showError = true,
        bool regex_case_sensitive = true,
        bool incUninstrumentable = false)

>   Return a vector of `BPatch_functions` corresponding to `name`, or `NULL` if the function does not exist. If `name` contains a POSIX-extended regular expression, and `dont_use_regex` is `false`, a regular expression search will be performed on function names and matching `BPatch_functions` returned. If `showError` is true, then Dyninst will report an error via the `BPatch::registerErrorCallback` if no function is found.

>   If the `incUninstrumentable` flag is set, the returned table of procedures will include uninstrumentable functions. The default behavior is to omit these functions.

>   [**NOTE**: If `name` is not found to match any demangled function names in the module, the search is repeated as if `name` is a mangled function name. If this second search succeeds, functions with mangled names matching `name` are returned instead.]

```
std::vector<BPatch_function*> *findFunction(
        std::vector<BPatch_function*> &funcs,
        BPatchFunctionNameSieve bpsieve,
        void *sieve_data = NULL,
        int showError = 0,
        bool incUninstrumentable = false)
```

Return a vector of `BPatch_functions` according to the generalized user-specified filter function `bpsieve`. This permits users to easily build sets of functions according to their own specific criteria. Internally, for each `BPatch_function` f in the image, this method makes a call to `bpsieve(f.getName(), sieve_data)`. The user-specified function `bpsieve` is responsible for taking the `name` argument and determining if it belongs in the output vector, possibly by using extra user-provided information stored in `sieve_data`. If the name argument matches the desired criteria, `bpsieve` should return `true`. If it does not, `bpsieve` should return `false`.

The function `bpsieve` should be defined in accordance with the typedef:

```
bool (*BPatchFunctionNameSieve) (const char *name, void* sieve_data);
```

If the `incUninstrumentable` flag is set, the returned table of procedures will include uninstrumentable functions. The default behavior is to omit these functions.

```
bool findFunction(Dyninst::Address addr, std::vector<BPatch_function *> &funcs)
```

Find all functions that have code at the given address, `addr`. Dyninst supports functions that share code, so this method may return more than one `BPatch_function`. These functions are returned via the `funcs` output parameter. This function returns `true` if it finds any functions, `false` otherwise.

```
BPatch_variableExpr *findVariable(const char *name,
    bool showError = true)
BPatch_variableExpr *findVariable(BPatch_point &scope,
        const char *name) second form of this method is not implemented on Windows.
```

Performs a lookup and returns a handle to the named variable. The first form of the function looks up only variables of global scope, and the second form uses the passed `BPatch_point` as the scope of the variable. The returned `BPatch_variableExpr` can be used to create references (uses) of the variable in subsequent snippets. The scoping rules used will be those of the source language. If the image was not compiled with debugging symbols, this function will fail even if the variable is defined in the passed scope.

```
BPatch_type *findType(const char *name)
```

Performs a lookup and returns a handle to the named type. The handle can be used as an argument to `BPatch_addressSpace::malloc` to create new variables of the corresponding type.

BPatch_module *findModule(const char *name,
        bool substring_match = false)

> Returns a module named `name` if present in the image. If the match fails, `NULL` is re-turned. If `substring_match` is `true`, the first module that has `name` as a substring of its name is returned (e.g. to find `libpthread.so.1`, search for `libpthread` with `sub-string_match` set to `true`).

bool getSourceLines(unsigned long addr,
   std::vector<BPatch_statement> & lines)

> Given an address `addr`, this function returns a vector of pairs of filenames and line num-bers at that address. This function is an alias for `BPatch_process::getSourceLines` (see section 4.4).

bool getAddressRanges(const char * fileName, unsigned int lineNo, std::vector< std::pair< unsigned long, unsigned
        long > > & ranges)

> Given a file name and line number, `fileName` and `lineNo`, this function returns a list of address ranges that this source line was compiled into. This function is an alias for `BPatch_process::getAddressRanges` (see section 4.4).

bool parseNewFunctions(std::vector<BPatch_module*> &newModules, const std::vector<Dyninst::Address>
        &funcEntryAddrs)

> This function takes as input a list of function entry points indicated by the `funcEntryAd-drs` vector, which are used to seed parsing in whatever modules they are found. All af-fected modules are placed in the `newModules` vector, which includes any existing mod-ules in which new functions are found, as well as modules corresponding to new regions of the binary, for which new `BPatch_modules` are created. The return value is `true` in the event that at least one previously unknown function was identified, or `false` other-wise.

4.11   Class BPatch_object

An object of this class represents the original executable or a library. It serves as a container of BPatch_module objects.

std::string name()
std::string pathName()

> Return the name of this file; either just the file name or the fully path-qualified name.

Dyninst::Address fileOffsetToAddr(Dyninst::Offset offset)

> Convert the provided offset into the file into a full address in memory.

```
struct Region {
        typedef enum { UNKNOWN, CODE, DATA } type_t;
        Dyninst::Address base;
        unsigned long size;
        type_t type;
};
void regions(std::vector<Region> &regions)
```

Returns information about the address ranges occupied by this object in memory.

```
void modules(std::vector<BPatch_module *> &modules)
```

Returns the modules contained in this object.

```
std::vector<BPatch_function*> *findFunction(
        const char *name,
        std::vector<BPatch_function*> &funcs,
        bool showError = true,
        bool regex_case_sensitive = true,
        bool incUninstrumentable = false)
```

Return a vector of `BPatch_functions` corresponding to `name`, or `NULL` if the function does not exist. If `name` contains a POSIX-extended regular expression, and `dont_use_regex` is `false`, a regular expression search will be performed on function names and matching `BPatch_functions` returned. If `showError` is true, then Dyninst will report an error via the `BPatch::registerErrorCallback` if no function is found.

If the `incUninstrumentable` flag is set, the returned table of procedures will include uninstrumentable functions. The default behavior is to omit these functions.

[**NOTE**: If `name` is not found to match any demangled function names in the module, the search is repeated as if `name` is a mangled function name. If this second search succeeds, functions with mangled names matching `name` are returned instead.]

```
bool findPoints(Dyninst::Address addr,
        std::vector<BPatch_point *> &points);
```

Return a vector of `BPatch_points` that correspond with the provided address, one per function that includes an instruction at that address. There will be one element if there is not overlapping code.

```
std::vector<BPatch_function*> *findFunction(
        const char *name,
        std::vector<BPatch_function*> &funcs,
        bool notify_on_failure = true,
        bool regex_case_sensitive = true,
        bool incUninstrumentable = false)
```

Return a vector of `BPatch_functions` matching `name`, or `NULL` if the function does not exist. If `name` contains a POSIX-extended regular expression, a regex search will be performed on function names, and matching `BPatch_functions` returned. [**NOTE**: The `std::vector` argument `funcs` must be declared fully by the user before calling this function. Passing in an uninitialized reference will result in undefined behavior.]

If the `incUninstrumentable` flag is set, the returned table of procedures will include uninstrumentable functions. The default behavior is to omit these functions.

[**NOTE**: If `name` is not found to match any demangled function names in the BPatch_object, the search is repeated as if `name` is a mangled function name. If this second search succeeds, functions with mangled names matching `name` are returned instead.]

4.12   Class BPatch_module

An object of this class represents a program module, which is part of a program's executable image. A BPatch_module represents a source file in either an executable or a shared library. Dyninst automatically creates a module called `DEFAULT_MODULE` in each executable to hold any objects that it cannot match to a source file. BPatch_module objects are obtained by calling the `BPatch_image` member function `getModules`.

```
std::vector<BPatch_function*> *findFunction(
        const char *name,
        std::vector<BPatch_function*> &funcs,
        bool notify_on_failure = true,
        bool regex_case_sensitive = true,
        bool incUninstrumentable = false)
```

Return a vector of `BPatch_functions` matching `name`, or `NULL` if the function does not exist. If `name` contains a POSIX-extended regular expression, a regex search will be performed on function names, and matching `BPatch_functions` returned. [**NOTE**: The `std::vector` argument `funcs` must be declared fully by the user before calling this function. Passing in an uninitialized reference will result in undefined behavior.]

If the `incUninstrumentable` flag is set, the returned table of procedures will include uninstrumentable functions. The default behavior is to omit these functions.

[**NOTE**: If `name` is not found to match any demangled function names in the module, the search is repeated as if `name` is a mangled function name. If this second search succeeds, functions with mangled names matching `name` are returned instead.]

```
BPatch_Vector<BPatch_function *> *findFunctionByAddress(
        void *addr,
        BPatch_Vector<BPatch_function *> &funcs,
        bool notify_on_failure = true,
        bool incUninstrumentable = false)
```

Return a vector of `BPatch_functions` that contains `addr`, or `NULL` if the function does not exist. [**NOTE**: The `std::vector` argument `funcs` must be declared fully by the user before calling this function. Passing in an uninitialized reference will result in undefined behavior.]

If the `incUninstrumentable` flag is set, the returned table of procedures will include uninstrumentable functions. The default behavior is to omit these functions.

BPatch_function *findFunctionByEntry(Dyninst::Address addr)

> Returns the function that begins at the specified address `addr`.

BPatch_function *findFunctionByMangled(
>   const char *mangled_name,
>   bool incUninstrumentable = false)

> Return a `BPatch_function` for the mangled function `name` defined in the module corresponding to the invoking `BPatch_module`, or `NULL` if it does not define the function.

> If the `incUninstrumentable` flag is set, the functions searched will include uninstrumentable functions. The default behavior is to omit these functions.

bool getAddressRanges(char * fileName, unsigned int lineNo, std::vector< std::pair< unsigned long, unsigned long > > & ranges)

> Given a filename and line number, `fileName` and `lineNo`, this function this function returns the ranges of mutatee addresses that implement the code range in the output parameter `ranges`. In many cases a source code line will only have one address range implementing it. However, compiler optimizations may turn this into multiple, disjoint address ranges. This information is only available if the mutatee was compiled with debug information.

> This function may be more efficient than the `BPatch_process` version of this function. Calling `BPatch_process::getAddressRange` will cause Dyninst to parse line information for all modules in a process. If `BPatch_module::getAddressRange` is called then only the debug information in this module will be parsed.

> This function returns `true` if it was able to find any line information, `false` otherwise.

size_t getAddressWidth()

> Return the size (in bytes) of a pointer in this module. On 32-bit systems this function will return 4, and on 64-bit systems this function will return 8.

void *getBaseAddr()

> Return the base address of the module. This address is defined as the start of the first function in the module.

std::vector<BPatch_function *>
*getProcedures(bool incUninstrumentable = false)

> Return a vector containing the functions in the module.

char *getFullName(char *buffer, int length)

> Fills `buffer` with the full path name of a module, up to `length` characters when this information is available.

BPatch_hybridMode getHybridMode()

>Return the mutator's analysis mode for the mutate; the default mode is the normal mode.

char *getName(char *buffer, int len)

>This function copies the filename of the module into buffer, up to len characters. It returns the value of the buffer parameter.

unsigned long getSize()

>Return the size of the module. The size is defined as the end of the last function minus the start of the first function.

bool getSourceLines(unsigned long addr, std::vector<BPatch_statement> & lines)

>This function returns the line information associated with the mutatee address addr. The vector lines contain pairs of filenames and line numbers that are associated with addr. In many cases only one filename and line number is associated with an address, but certain compiler optimizations may lead to multiple filenames and lines at an address. This information is only available if the mutatee was compiled with debug information.

>This function may be more efficient than the BPatch_process version of this function. Calling BPatch_process::getSourceLines will cause Dyninst to parse line information for all modules in a process. If BPatch_module::getSourceLines is called then only the debug information in this module will be parsed.

>This function returns true if it was able to find any line information at addr, or false otherwise.

char *getUniqueString(char *buffer, int length)

>Performs a lookup and returns a unique string for this image. Returns a string the can be compared (via strcmp) to indicate if two images refer to the same underlying object file (i.e., executable or library). The contents of the string are implementation specific and defined to have no semantic meaning.

bool getVariables(std::vector<BPatch_variableExpr *> &vars)

>Fill the vector vars with the global variables that are specified in this module. Returns false if no results are found and true otherwise.

BpatchSnippetHandle* insertInitCallback(Bpatch_snippet& callback)

>This function inserts the snippet callback at the entry point of this module's init function (creating a new init function/section if necessary).

BpatchSnippetHandle* insertFiniCallback(Bpatch_snippet& callback)

>This function inserts the snippet callback at the exit point of this module's fini function (creating a new fini function/section if necessary).

bool isExploratoryModeOn()

> This function returns `true` if the mutator's analysis mode sets to the defensive mode or the exploratory mode.

bool isMutatee()

> This function returns `true` if the module is the mutatee.

bool isSharedLib()

> This function returns `true` if the module is part of a shared library.

4.13   Class BPatch_snippet

A snippet is an abstract representation of code to insert into a program. Snippets are defined by creating a new instance of the correct subclass of a snippet. For example, to create a snippet to call a function, create a new instance of the class `BPatch_funcCallExpr`. Creating a snippet does not result in code being inserted into an application. Code is generated when a request is made to insert a snippet at a specific point in a program. Sub-snippets may be shared by different snippets (i.e, a handle to a snippet may be passed as an argument to create two different snippets), but whether the generated code is shared (or replicated) between two snippets is implementation dependent.

BPatch_type *getType()

> Return the type of the snippet.   The `BPatch_type` system is described in section 4.14.

float getCost()

> Returns an estimate of the number of seconds it would take to execute the snippet. The problems with accurately estimating the cost of executing code are numerous and out of the scope of this document[2]. It is important to realize that the returned cost value is, at best, an estimate.

The rest of the classes are derived classes of the class `BPatch_snippet`.

BPatch_actualAddressExpr()

> This snippet results in an expression that evaluates to the actual address of the instrumentation. To access the original address where instrumentation was inserted, use `BPatch_originalAddressExpr`. Note that this actual address is highly dependent on a number of internal variables and has no relation to the original address.

BPatch_arithExpr(BPatch_binOp op, const BPatch_snippet &lOperand,
        const BPatch_snippet &rOperand)

> Perform the required binary operation. The available binary operators are:

Operator	Description
BPatch_assign	assign the value of `rOperand` to `lOperand`
BPatch_plus	add `lOperand` and `rOperand`
BPatch_minus	subtract `rOperand` from `lOperand`
BPatch_divide	divide `rOperand` by `lOperand`
BPatch_times	multiply `rOperand` by `lOperand`
BPatch_ref	Array reference of the form `lOperand[rOperand]`
BPatch_seq	Define a sequence of two expressions (similar to comma in C)

BPatch_arithExpr(BPatch_unOp, const BPatch_snippet &operand)

> Define a snippet consisting of a unary operator.   The unary operators are:

Operator	Description
BPatch_negate	Returns the negation of an integer
BPatch_addr	Returns a pointer to a BPatch_variableExpr
BPatch_deref	Dereferences a pointer

BPatch_boolExpr(BPatch_relOp op, const BPatch_snippet &lOperand,
        const BPatch_snippet &rOperand)

> Define a relational snippet. The available operators are:

Operator	Function
BPatch_lt	Return `lOperand` < `rOperand`
BPatch_eq	Return `lOperand` == `rOperand`
BPatch_gt	Return `lOperand` > `rOperand`
BPatch_le	Return `lOperand` <= `rOperand`
BPatch_ne	Return `lOperand` != `rOperand`
BPatch_ge	Return `lOperand` >= `rOperand`
BPatch_and	Return `lOperand` && `rOperand` (Boolean and)
BPatch_or	Return `lOperand` || `rOperand` (Boolean or)

> The type of the returned snippet is boolean, and the operands are type checked.

BPatch_breakPointExpr()

> Define a snippet that stops a process when executed by it. The stop can be detected using the `isStopped` member function of `BPatch_process`, and the program's execution can be resumed by calling the `continueExecution` member function of `BPatch_process`.

BPatch_bytesAccessedExpr()

> This expression returns the number of bytes accessed by a memory operation. For most load/store architecture machines it is a constant expression returning the number of bytes

for the particular style of load or store. This snippet is only valid at a memory operation instrumentation point.

BPatch_constExpr(signed int value)
BPatch_constExpr(unsigned int value)
BPatch_constExpr(signed long value)
BPatch_constExpr(unsigned long value)
BPatch_constExpr(const char *value)
BPatch_constExpr(const void *value)
BPatch_constExpr(long long value)

Define a constant snippet of the appropriate type. The `char*` form of the constructor creates a constant string; the null-terminated string beginning at the location pointed to by the parameter is copied into the application's address space, and the `BPatch_constExpr` that is created refers to the location to which the string was copied.

BPatch_dynamicTargetExpr()

This snippet calculates the target of a control flow instruction with a dynamically determined target. It can handle dynamic calls, jumps, and return statements.

BPatch_effectiveAddressExpr()

Define an expression that contains the effective address of a memory operation. For a multi-word memory operation (i.e. more than the "natural" operation size of the machine), the effective address is the base address of the operation.

BPatch_funcCallExpr(const BPatch_function& func,
        const std::vector<BPatch_snippet*> &args)

Define a call to a function. The passed function must be valid for the current code region. `Args` is a list of arguments to pass to the function; the maximum number of arguments varies by platform and is summarized below. If type checking is enabled, the types of the passed arguments are checked against the function to be called. Availability of type checking depends on the source language of the application and program being compiled for debugging.

Platform	Maximum number of arguments
AMD64/EMT-64	No limit
IA-32	No limit
POWER	8 arguments

BPatch_funcJumpExpr (const BPatch_function &func)

This snippet has been removed; use `BPatch_addressSpace::wrapFunction` instead.

BPatch_ifExpr(const BPatch_boolExpr &conditional,
          const BPatch_snippet &tClause,
          const BPatch_snippet &fClause)
BPatch_ifExpr(const BPatch_boolExpr &conditional,
          const BPatch_snippet &tClause)

> This constructor creates an if statement. The first argument, `conditional`, should be a
> Boolean expression that will be evaluated to decide which clause should be executed. The
> second argument, `tClause`, is the snippet to execute if the conditional evaluates to
> `true`. The third argument, `fClause`, is the snippet to execute if the conditional evalu-
> ates to `false`. This third argument is optional. Else-if statements, can be constructed by
> making the `fClause` of an if statement another if statement.

BPatch_insnExpr(BPatch_instruction *insn) implemented on x86-64

> This constructor creates a snippet that allows the user to mimic the effect of an existing
> instruction. In effect, the snippet "wraps" the instruction and provides a handle to particu-
> lar components of instruction behavior. This is currently implemented for memory opera-
> tions, and provides two override methods: `overrideLoadAddress` and `overrideStore-`
> `Address`. Both methods take a `BPatch_snippet` as an argument. Unlike other snippets,
> this snippet should be installed via a call to `BPatch_process::replaceCode` (to replace
> the original instruction). For example:

```
// Assume that access is of type BPatch_memoryAccess, as
// provided by a call to BPatch_point->getMemoryAccess. A
// BPatch_memoryAccess is a child of BPatch_instruction, and
// is a valid source of a BPatch_insnExpr.

BPatch_insnExpr insn(access);

// This example will modify a store by increasing the target
// address by 16.

BPatch_arithExpr newStoreAddr(BPatch_plus,
                              BPatch_effectiveAddressExpr(),
                              BPatch_constExpr(16));

// now override the original store address

insn.overrideStoreAddress(newStoreAddr)

//  now replace the original instruction with the new one.
// Point is a BPatch_point corresponding to the desired location, and
// process is a BPatch_process.

process.replaceCode(point, insn);
```

BPatch_nullExpr()

> Define a null snippet. This snippet contains no executable statements.

BPatch_originalAddressExpr()

> This snippet results in an expression that evaluates to the original address of the point where the snippet was inserted. To access the actual address where instrumentation is executed, use `BPatch_actualAddressExpr`.

BPatch_paramExpr(int paramNum)

> This constructor creates an expression whose value is a parameter being passed to a function. `ParamNum` specifies the number of the parameter to return, starting at 0. Since the contents of parameters may change during subroutine execution, this snippet type is only valid at points that are entries to subroutines, or when inserted at a call point with the `when` parameter set to `BPatch_callBefore.`

BPatch_registerExpr(BPatch_register reg)
BPatch_registerExpr(Dyninst::MachRegister reg)

> This snippet results in an expression whose value is the value in the register at the point of instrumentation.

BPatch_retExpr()

> This snippet results in an expression that evaluates to the return value of a subroutine. This snippet type is only valid at `BPatch_exit` points, or at a call point with the `when` parameter set to `BPatch_callAfter.`

BPatch_scrambleRegistersExpr()

> This snippet sets all General Purpose Registers to the flag value.

BPatch_sequence(const std::vector<BPatch_snippet*> &items)

> Define a sequence of snippets. The passed snippets will be executed in the order in which they appear in `items`.

BPatch_shadowExpr(bool entry,
        const BPatchStopThreadCallback &cb,
        const BPatch_snippet &calculation,
        bool useCache = false,
        BPatch_stInterpret interp = BPatch_noInterp)

> This snippet creates a shadow copy of the snippet `BPatch_stopThreadExpr`.

BPatch_stopThreadExpr(const BPatchStopThreadCallback &cb,
     const BPatch_snippet &calculation,
     bool useCache = false,
     BPatch_stInterpret interp = BPatch_noInterp)

>This snippet stops the thread that executes it. It evaluates a calculation snippet and triggers a callback to the user program with the result of the calculation and a pointer to the BPatch_point at which the snippet was inserted.

BPatch_threadIndexExpr()

>This snippet returns an integer expression that contains the thread index of the thread that is executing this snippet. The thread index is the same value that is returned on the mutator side by `BPatch_thread::getBPatchID`.

BPatch_tidExpr(BPatch_process *proc)

>This snippet results in an integer expression that contains the tid of the thread that is executing this snippet. This can be used to record the threadId, or to filter instrumentation so that it only executes for a specific thread.

BPatch_variableExpr(char *in_name,
     BPatch_addressSpace *in_addSpace,
     AddressSpace *as,
     AstNodePtr ast_wrapper_,
     BPatch_type *type, void* in_address)
BPatch_variableExpr(BPatch_addressSpace *in_addSpace,
     AddressSpace *as,
     void *in_address,
     int in_register,
     BPatch_type *type,
     BPatch_storageClass storage = BPatch_storageAddr,
     BPatch_point *scp = NULL)
BPatch_variableExpr(BPatch_addressSpace *in_addSpace,
     AddressSpace *as,
     BPatch_localVar *lv,
     BPatch_type *type,
     BPatch_point *scp)
BPatch_variableExpr(BPatch_addressSpace *in_addSpace,
     AddressSpace *ll_addSpace,
     int_variable *iv,
     BPatch_type *type)

>Define a variable snippet of the appropriate type. The first constructor is used to get function pointers; the second is used to get forked copies of variable expression, used by malloc; the third is used for local variables; and the last is used by `BPatch_addressSpace::findOrCreateVariable()`.

BPatch_whileExpr(const BPatch_snippet &condition,
        const BPatch_snippet &body)

> This constructor creates a while statement. The first argument, `condition`, should be a Boolean expression that will be evaluated to decide whether `body` should be executed. The second argument, `body`, is the snippet to execute if the condition evaluates to `true`.

4.14   Class BPatch_type

The class BPatch_type is used to describe the types of variables, parameters, return values, and functions. Instances of the class can represent language predefined types (e.g. int, float), mutatee defined types (e.g., structures compiled into the mutatee application), or mutator defined types (created using the `create*` methods of the `BPatch` class).

std::vector<BPatch_field *> *getComponents()

> Return a vector of the types of the fields in a `BPatch_struct` or `BPatch_union`. If this method is invoked on a type whose `BPatch_dataClass` is not `BPatch_struct` or `BPatch_union`, `NULL` is returned.

std::vector<BPatch_cblock *> *getCblocks()

> Return the common block classes for the type. The methods of the `BPatch_cblock` can be used to access information about the member of a common block. Since the same named (or anonymous) common block can be defined with different members in different functions, a given common block may have multiple definitions. The vector returned by this function contains one instance of `BPatch_cblock` for each unique definition of the common block. If this method is invoked on a type whose `BPatch_dataClass` is not `BPatch_common`, `NULL` will be returned.

BPatch_type *getConstituentType()

> Return the type of the base type. For a `BPatch_array` this is the type of each element, for a `BPatch_pointer` this is the type of the object the pointer points to. For `BPatch_typedef` types, this is the original type. For all other types, NULL is returned.

```
enum BPatch_dataClass {
     BPatch_dataScalar,        BPatch_dataEnumerated,
     BPatch_dataTypeClass,    BPatch_dataStructure,
     BPatch_dataUnion,        BPatch_dataArray,    BPatch_data-
Pointer,        BPatch_dataReference,    BPatch_dataFunction,
     BPatch_dataTypeAttrib,    BPatch_dataUnknownType,
     BPatch_dataMethod, BPatch_dataCommon,        BPatch_dat-
aPrimitive,    BPatch_dataTypeNumber,    BPatch_dataTypeDefine,
     BPatch_dataNullType  }
```

BPatch_dataClass getDataClass()

> Return one of the above data classes for this type.

unsigned long getLow()
unsigned long getHigh()

> Return the upper and lower bound of an array. Calling these two methods on non-array types produces an undefined result.

const char *getName()

> Return the name of the type.

bool isCompatible(const BPatch_type &otype)

> Return true if `otype` is type compatible with this type. The rules for type compatibility are given in Section 4.28. If the two types are not type compatible, the error reporting callback function will be invoked one or more times with additional information about why the types are not compatible.

4.15   Class BPatch_variableExpr

The **BPatch_variableExpr** class is another class derived from `BPatch_snippet`. It represents a variable or area of memory in a process's address space. A `BPatch_variableExpr` can be obtained from a `BPatch_process` using the `malloc` member function, or from a `BPatch_image` using the `findVariable` member function.

Some `BPatch_variableExpr` have an associated `BPatch_type`, which can be accessed by functions inherited from `BPatch_snippet`. `BPatch_variableExpr` objects will have an associated `BPatch_type` if they originate from binaries with sufficient debug information that describes types, or if they were provided with a `BPatch_type` when created by Dyninst.

BPatch_variableExpr provides several member functions not provided by other types of snippets:

void readValue(void *dst)
void readValue(void *dst, int size)

> Read the value of the variable in an application's address space that is represented by this `BPatch_variableExpr`. The `dst` parameter is assumed to point to a buffer large enough to hold a value of the variable's type. If the `size` parameter is supplied, then the number of bytes it specifies will be read. For the first version of this method, if the size of the variable is unknown (i.e., no type information), no data is copied and the method returns false.

void writeValue(void *src)
void writeValue(void *src, int size)

> Change the value of the variable in an application's address space that is represented by this `BPatch_variableExpr`. The `src` parameter should point to a value of the variable's type. If the `size` parameter is supplied, then the number of bytes it specifies will be written. For the first version of this method, if the size of the variable is unknown (i.e., no type information), no data is copied and the method returns false.

void *getBaseAddr()

> Return the base address of the variable. This is designed to let users who wish to access elements of arrays or fields in structures do so. It can also be used to obtain the address of a variable to pass a point to that variable as a parameter to a procedure call. It is similar to the ampersand (&) operator in C.

std::vector<BPatch_variableExpr *> *getComponents()

> Return a pointer to a vector containing the components of a struct or union. Each element of the vector is one field of the composite type, and contains a variable expression for accessing it.

4.16   Class BPatch_flowGraph

The **BPatch_flowGraph** class represents the control flow graph of a function. It provides methods for discovering the basic blocks and loops within the function (using which a caller can navigate the graph). A `BPatch_flowGraph` object can be obtained by calling the `getCFG` method of a `BPatch_function` object.

bool containsDynamicCallsites()

> Return true if the control flow graph contains any dynamic call sites (e.g., calls through a function pointer).

void getAllBasicBlocks(std::set<BPatch_basicBlock*>&)
void getAllBasicBlocks(BPatch_Set<BPatch_basicBlock*>&)

> Fill the given set with pointers to all basic blocks in the control flow graph. `BPatch_basicBlock` is described in section 4.17.

void getEntryBasicBlock(std::vector<BPatch_basicBlock*>&)

> Fill the given vector with pointers to all basic blocks that are entry points to the function. `BPatch_basicBlock` is described in section 4.17.

void getExitBasicBlock(std::vector<BPatch_basicBlock*>&)

> Fill the given vector with pointers to all basic blocks that are exit points of the function. `BPatch_basicBlock` is described in section 4.17.

void getLoops(std::vector<BPatch_basicBlockLoop*>&)

> Fill the given vector with a list of all natural (single entry) loops in the control flow graph.

void getOuterLoops(std::vector<BPatch_basicBlockLoop*>&)

> Fill the given vector with a list of all natural (single entry) outer loops in the control flow graph.

BPatch_loopTreeNode *getLoopTree()

> Return the root node of the tree of loops in this flow graph.

enum BPatch_procedureLocation { BPatch_locLoopEntry, BPatch_locLoopExit, BPatch_locLoopStartIter, BPatch_locLoopEndIter }

std::vector<BPatch_point*> *findLoopInstPoints(const BPatch_procedureLocation loc, BPatch_basicBlockLoop *loop);

> Find instrumentation points for the given loop that correspond to the given location: loop entry, loop exit, the start of a loop iteration and the end of a loop iteration. `BPatch_locLoopEntry` and `BPatch_locLoopExit` instrumentation points respectively execute once before the first iteration of a loop and after the last iteration. `BPatch_locLoopStartIter` and `BPatch_locLoopEndIter` respectively execute at the beginning and end of each loop iteration.

BPatch_basicBlock* findBlockByAddr(Dyninst::Address addr);

> Find the basic block within this flow graph that contains `addr`. Returns `NULL` on failure. This method is inefficient but guaranteed to succeed if addr is present in any block in this CFG.

[**NOTE:** Dyninst is not always able to generate a correct flow graph in the presence of indirect jumps. If a function has a case statement or indirect jump instructions, the targets of the jumps are found by searching instruction patterns (peep-hole). The instruction patterns generated are compiler specific and the control flow graph analyses include only the ones we have seen. During the control flow graph generation, if a pattern that is not handled is used for case statement or multi-jump instructions in the function address space, the generated control flow graph may not be complete.]

4.17   Class BPatch_basicBlock

The **BPatch_basicBlock** class represents a basic block in the application being instrumented. Objects of this class representing the blocks within a function can be obtained using the `BPatch_flowGraph` object for the function. `BPatch_basicBlock` includes methods for navigating through the control flow graph of the containing function.

void getSources(std::vector<BPatch_basicBlock*>&)

> Fills the given vector with the list of predecessors for this basic block (i.e, basic blocks that have an outgoing edge in the control flow graph leading to this block).

void getTargets(std::vector<BPatch_basicBlock*>&)

> Fills the given vector with the list of successors for this basic block (i.e, basic blocks that are the destinations of outgoing edges from this block in the control flow graph).

void getOutgoingEdges(std::vector<BPatch_edge *> &out)

> Fill out with all of the control flow edges that leave this basic block.

void getIncomingEdges(std::vector<BPatch_edge *> &inc)

> Fills inc with all of the control flow edges that point to this basic block.

bool getInstructions(std::vector
<Dyninst::InstructionAPI::Instruction>&)

bool getInstructions(std::vector <
    std::pair<Dyninst::InstructionAPI::Instruction,
        Address> >&)

> Fills the given vector with InstructionAPI Instruction objects representing the instructions in this basic block, and returns true if successful. See the InstructionAPI Programmer's Guide for details. The second call also returns the address each instruction starts at.

bool dominates(BPatch_basicBlock*)

> This function returns true if the argument is pre-dominated in the control flow graph by this block, and false if it is not.

BPatch_basicBlock* getImmediateDominator()

> Return the basic block that immediately pre-dominates this block in the control flow graph.

void getImmediateDominates(std::vector<BPatch_basicBlock*>&)

> Fill the given vector with a list of pointers to the basic blocks that are immediately dominated by this basic block in the control flow graph.

void getAllDominates(std::set<BPatch_basicBlock*>&)
void getAllDominates(BPatch_Set<BPatch_basicBlock*>&)

> Fill the given set with pointers to all basic blocks that are dominated by this basic block in the control flow graph.

bool getSourceBlocks(std::vector<BPatch_sourceBlock*>&)

> Fill the given vector with pointers to the source blocks contributing to this basic block's instruction sequence.

int getBlockNumber()

> Return the ID number of this basic block. The ID numbers are consecutive from 0 to *n-1,* where *n* is the number of basic blocks in the flow graph to which this basic block belongs.

std::vector<BPatch_point *> findPoint(const std::set<BPatch_opCode> &ops)
std::vector<BPatch_point *> findPoint(const BPatch_Set<BPatch_opCode> &ops)

> Find all points in the basic block that match the given operation.

BPatch_point *findEntryPoint()
BPatch_point *findExitPoint()

> Find the entry or exit point of the block.

unsigned long getStartAddress()

> This function returns the starting address of the basic block. The address returned is an absolute address.

unsigned long getEndAddress()

> This function returns the end address of the basic block. The address returned is an absolute address.

unsigned long getLastInsnAddress()

> Return the address of the last instruction in a basic block.

bool isEntryBlock()

> This function returns `true` if this basic block is an entry block into a function.

bool isExitBlock()

> This function returns `true` if this basic block is an exit block of a function.

unsigned size()

> Return the size of a basic block. The size is defined as the difference between the end address and the start address of the basic block.

4.18   Class BPatch_edge

The **BPatch_edge** class represents a control flow edge in a `BPatch_flowGraph`.

BPatch_point *getPoint()

> Return an instrumentation point for this edge. This point can be passed to `BPatch_process::insertSnippet` to instrument the edge.

```
enum BPatch_edgeType { CondJumpTaken, CondJumpNottaken,
     UncondJump, NonJump }
```

```
BPatch_edgeType getType()
```

> Return a type describing this edge. A `CondJumpTaken` edge is found after a conditional branch, along the edge that is taken when the condition is true. A `CondJumpNottaken` edge follows the path when the condition is not taken. `UncondJump` is used along an edge that flows out of an unconditional branch that is always taken. `NonJump` is an edge that flows out of a basic block that does not end in a jump, but falls through into the next basic block.

```
BPatch_basicBlock *getSource()
```

      Return the source `BPatch_basicBlock` that this edge flows from.

```
BPatch_basicBlock *getTarget()
```

      Return the target `BPatch_basicBlock` that this edge flows to.

BPatch_flowGraph *getFlowGraph()

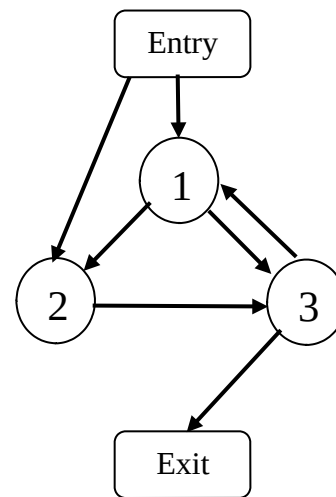   Returns the CFG that contains the edge.

4.19   Class BPatch_basicBlockLoop

An object of this class represents a loop in the code of the application being instrumented. We detect both natural loops (single-entry loops) and irreducible loops (multi-entry loops). For a natural loop, it has only one entry block and this entry block dominates all blocks in the loop; thus the entry block is also called the head or the header of the loop. However, for an irreducible loop, it has multiple entry blocks and none of them dominates all blocks in the loop; thus there is no head or header for an irreducible loop. The following figure illustrates the difference:
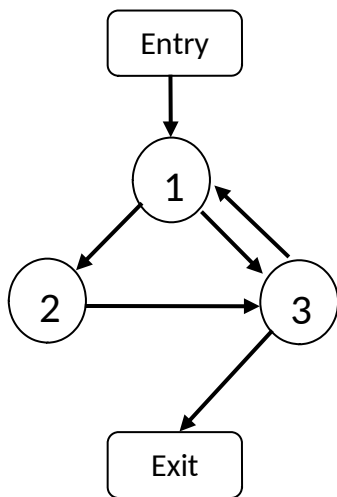
(a) An example of natural loop   (b) An example of irreducible loop

Figure (a) above shows a natural loop, where block 1 represents the single entry and block 1 is the head of the loop. Block 1 dominates block 2 and block 3. Figure (b) above shows an irreducible loop, where block 1 and block 2 are the entries of the loop. Neither block 1 nor block 2 domiantes block 3.

bool containsAddress(unsigned long addr)

      Return true if `addr` is contained within any of the basic blocks that compose this loop, excluding the block of any of its sub-loops.

bool containsAddressInclusive(unsigned long addr)

> Return true if `addr` is contained within any of the basic blocks that compose this loop, or in the blocks of any of its sub-loops.

int getBackEdges(std::vector<BPatch_edge *> &edges)

> Returns the number of back edges in this loop and adds those edges to the `edges` vector. An edge is a back edge if it is from a block in the loop to an entry block of the loop.

int getLoopEntries(std::vector<BPatch_basicBlock *> &entries)

> Returns the number of entry blocks of this loop and adds those blocks to the `entries` vector. An irreducible loop can have multiple entry blocks.

bool getContainedLoops(std::vector<BPatch_basicBlockLoop*>&)

> Fill the given vector with a list of the loops nested within this loop.

BPatch_flowGraph *getFlowGraph()

> Return a pointer to the control flow graph that contains this loop.

bool getOuterLoops(std::vector<BPatch_basicBlockLoop*>&)

> Fill the given vector with a list of the outer loops nested within this loop.

bool getLoopBasicBlocks(std::vector<BPatch_basicBlock*>&)

> Fill the given vector with a list of all basic blocks that are part of this loop.

bool getLoopBasicBlocksExclusive(
        std::vector<BPatch_basicBlock*>&)

> Fill the given vector with a list of all basic blocks that are part of this loop but not its sub-loops.

bool hasAncestor(BPatch_basicBlockLoop*)

> Return true if this loop is nested within the given loop (the given loop is one of its ancestors in the tree of loops).

bool hasBlock(BPatch_basicBlock *b)

> Return true if this loop or any of its sub-loops contain `b`, `false` otherwise.

bool hasBlockExclusive(BPatch_basicBlock *b)

> Return true if this loop, excluding its sub-loops, contains `b`, `false` otherwise.

4.20   Class BPatch_loopTreeNode

The **BPatch_loopTreeNode** class provides a tree interface to a collection of instances of class `BPatch_basicBlockLoop` `contained` in a `BPatch_flowGraph`. The structure of the tree follows the nesting relationship of the loops in a function's flow graph. Each `BPatch_loop-`

`TreeNode` contains a pointer to a loop (represented by `BPatch_basicBlockLoop`), and a set of sub-loops (represented by other `BPatch_loopTreeNode` objects). The root `BPatch_loopTreeNode` instance has a null loop member since a function may contain multiple outer loops. The outer loops are contained in the root instance's vector of children.

Each instance of `BPatch_loopTreeNode` is given a name that indicates its position in the hierarchy of loops. The name of each root loop takes the form of `loop_x`, where x is an integer from 1 to n, where n is the number of outer loops in the function. Each sub-loop has the name of its parent, followed by a `.y`, where y is 1 to `m`, where `m` is the number of sub-loops under the outer loop. For example, consider the following C function:

```
void foo() {
      int x, y, z, i;
      for (x=0; x<10; x++) {
            for (y = 0; y<10; y++)
                   ...
            for (z = 0; z<10; z++)
                    ...
      }
      for (i = 0; i<10; i++) {
            ...
      }
}
```

The foo function will have a root BPatch_loopTreeNode, containing a NULL loop entry and two BPatch_loopTreeNode children representing the functions outer loops. These children would have names loop_1 and loop_2, respectively representing the x and i loops. loop_2 has no children. loop_1 has two child BPatch_loopTreeNode objects, named loop_1.1 and loop_1.2, respectively representing the y and z loops.

BPatch_basicBlockLoop *loop

   A node in the tree that represents a single `BPatch_basicBlockLoop` instance.

std::vector<BPatch_loopTreeNode *> children

   The tree nodes for the loops nested under this loop.

const char *name()

   Return a name for this loop that indicates its position in the hierarchy of loops.

bool getCallees(std::vector<BPatch_function *> &v, BPatch_addressSpace *p)

   This function fills the vector `v` with the list of functions that are called by this loop.

const char *getCalleeName(unsigned int i)

   This function return the name of the ith function called in the loop's body.

unsigned int numCallees()

   Returns the number of callees contained in this loop's body.

BPatch_basicBlockLoop *findLoop(const char *name)

> Finds the loop object for the given canonical loop name.

4.21   Class BPatch_register

A **BPatch_register** represents a single register of the mutatee. The list of `BPatch_registers` can be retrieved with the `BPatch_addressSpace::getRegisters` method.

std::string name()

> This function returns the canonical name of the register.

4.22   Class BPatch_sourceBlock

An object of this class represents a source code level block. Each source block objects consists of a source file and a set of source lines in that source file. This class is used to fill source line information for each basic block in the control flow graph. For each basic block in the control flow graph there is one or more source block object(s) that correspond to the source files and their lines contributing to the instruction sequence of the basic block.

const char* getSourceFile()

> Returns a pointer to the name of the source file in which this source block occurs.

void getSourceLines(std::vector<unsigned short>&)

> Fill the given vector with a list of the lines contained within this source block.

4.23   Class BPatch_cblock

This class is used to access information about a common block.

std::vector<BPatch_field *> *getComponents()

> Return a vector containing the individual variables of the common block.

std::vector<BPatch_function *> *getFunctions()

> Return a vector of the functions that can see this common block with the set of fields described in `getComponents`. However, other functions that define this common block with a different set of variables (or sizes of any variable) will not be returned.

4.24   Class BPatch_frame

A **BPatch_frame** object represents a stack frame. The `getCallStack` member function of `BPatch_thread` returns a vector of `BPatch_frame` objects representing the frames currently on the stack.

BPatch_frameType getFrameType()

Return the type of the stack frame. Possible types are:

Frame Type	Meaning
BPatch_frameNormal	A normal stack frame.
BPatch_frameSignal	A frame that represents a signal invocation.
BPatch_frameTrampoline	A frame the represents a call into instrumentation code.

void *getFP()

Return the frame pointer for the stack frame.

void *getPC()

Returns the program counter associated with the stack frame.

BPatch_function *findFunction()

Returns the function associated with the stack frame.

BPatch_thread *getThread()

Returns the thread associated with the stack frame.

BPatch_point *getPoint()
BPatch_point *findPoint()

For stack frames corresponding to inserted instrumentation, returns the instrumentation point where that instrumentation was inserted. For other frames, returns `NULL`.

bool isSynthesized()

Returns `true` if this frame was artificially created, `false` otherwise.

4.25   Class StackMod

This class defines modifications to the stack frame layout of a function. Stack modifications are basd on the abstraction of stack locations, not the contents of these locations. All stack offsets are with respect to the original stack frame, even if `BPatch_fuction::addMods` is called multiple times for a single function.
implemented on x86 and x86-64

Insert(int low, int high)

This constructor creates a stack modification that inserts stack space in the range [`low`, `high`), where `low` and `high` are stack offsets.

`BPatch_function::addMods` will find this modification unsafe if any instructions in the function access memory that will be non-contiguous after [`low`,`high`) is inserted.

dyninstAPI

Remove(int low, int high)

> This constructor creates a stack modification that removes stack space in the range [low, high), where low and high are stack offsets.
>
> BPatch_function::addMods will find this modification unsafe if any instructions in the function access stack memory in [low,high).

Move(int sLow, int sHigh, int dLow)

> This constructor creates a stack modification that moves stack space [sLow, sHigh) to [dLow, dLow+(sHigh-sLow)).
>
> BPatch_function::addMods will find this modification unsafe if Insert(dLow, dLow+(sHigh-sLow)) or Remove(sLow, sHigh) are unsafe.

Canary()implemented on Linux, GCC only
Canary(BPatch_function* failFunc) implemented on Linux, GCC only

> This constructor creates a stack modification that inserts a stack canary at function entry and a corresponding canary check at function exit(s).
>
> This uses the same canary as GCC's –fstack-protector. If the canary check at function exit fails, failFunc is called. failFunc must be non-returning and take no arguments. If no failFunc is provided, __stack_chk_fail from libc is called; libc must be open in the corresponding BPatch_addressSpace.
>
> This modification will have no effect on functions in which the entry and exit point(s) are the same.
>
> BPatch_function::addMods will find this modification unsafe if another Canary has already been added to the function. Note, however, that this modification can be applied to code compiled with –fstack-protector.

Randomize()
Randomize(int seed)

> This constructor creates a stack modification that rearranges the stack-stored local variables of a function. This modification requires symbol information (e.g., DWARF), and only local variables specified by the symbols will be randomized. If DyninstAPI finds a stack access that is not consistent with a symbol-specified local, that local will not be randomized. Contiguous ranges of local variables are randomized; if there are two or more contiguous ranges of locals within the stack frame, each is randomized separately. More than one local variable is required for randomization.
>
> BPatch_function::addMods will return false if Randomize is added to a function without local variable information, without local variables on the stack, or with only a single local variable.

dyninstAPI

srand is used to generate a new ordering of local variables; if seed is provided, this value is provided to srand as its seed.

BPatch_function::addMods will find this modification unsafe if any other modifications have been applied.

4.26   Container Classes

4.26.1 Class std::vector

The **std::vector** class is a container used to hold other objects used by the API. As of Dyninst 5.0, std::vector is an alias for the C++ Standard Template Library (STL) std::vector.

4.26.2 Class BPatch_Set

BPatch_Set is another container class, similar to the set class in the STL. THIS CLASS HAS BEEN DEPRECATED AND WILL BE REMOVED IN THE NEXT RELEASE. In addition the methods provided by std::set, it provides the following compatibility methods:

BPatch_Set()

A constructor that creates an empty set with the default comparison function.

BPatch_Set(const BPatch_Set<T,Compare>& newBPatch_Set)

Copy constructor.

void remove(const T&)

Remove the given element from the set.

bool contains(const T&)

Return true if the argument is a member of the set, otherwise returns false.

T* elements(T*)
void elements(std::vector<T> &)

Fill an array (or vector) with a list of the elements in the set that are sorted in ascending order according to the comparison function. The input argument should point to an array large enough to hold the elements. This function returns its input argument, unless the set is empty, in which case it returns NULL.

T minimum()

Return the minimum element in the set, as determined by the comparison function. For an empty set, the result is undefined.

T maximum()

Return the maximum element in the set, as determined by the comparison function. For an empty set, the result is undefined.

BPatch_Set<T,Compare>& operator+= (const T&)

Add the given object to the set.

BPatch_Set<T,Compare>& operator|= (const BPatch_Set<T,Compare>&)

Set union operator. Assign the result of the union to the set on the left hand side.

BPatch_Set<T,Compare>& operator&= (const BPatch_Set<T,Compare>&)

Set intersection operator. Assign the result of the intersection to the set on the left hand side.

BPatch_Set<T,Compare>& operator-= (const BPatch_Set<T,Compare>&)

Set difference operator. Assign the difference of the sets to the set on the left hand side.

BPatch_Set<T,Compare> operator| (const BPatch_Set<T,Compare>&)

Set union operator.

BPatch_Set<T,Compare> operator& (const BPatch_Set<T,Compare>&)

Set intersection operator.

BPatch_Set<T,Compare> operator- (const BPatch_Set<T,Compare>&)

Set difference operator.

4.27   Memory Access Classes

Instrumentation points created through findPoint(const std::set<BPatch_opCode>& ops) get memory access information attached to them. This information is used by the memory access snippets, but is also available to the API user. The classes that encapsulate memory access information are contained in the BPatch_memoryAccess_NP.h header.

4.27.1 Class BPatch_memoryAccess

This class encapsulates a memory access abstraction. It contains information that describes the memory access type: read, write, read/write, or prefetch. It also contains information that allows the effective address and the number of bytes transferred to be determined.

bool isALoad()

Return true if the memory access is a load (memory is read into a register).

bool isAStore()

Return true if the memory access is write. Some machine instructions may both load and store.

bool isAPrefetch_NP()

> Return true if memory access is a prefetch (i.e, it has no observable effect on user registers). It this returns true, the instruction is considered neither load nor store. Prefetches are detected only on IA32.

short prefetchType_NP()

> If the memory access is a prefetch, this method returns a platform specific prefetch type.

BPatch_addrSpec_NP getStartAddr_NP()

> Return an address specification that allows the effective address of a memory reference to be computed. For example, on the x86 platform a memory access instruction operand may contain a base register, an index register, a scaling value, and a constant base. The `BPatch_addrSpec_NP` describes each of these values.

BPatch_countSpec_NP getByteCount_NP()

> Return a specification that describes the number of bytes transferred by the memory access.

4.27.2   Class BPatch_addrSpec_NP

This class encapsulates the information required to determine an effective address at runtime. The general representation for an address is a sum of two registers and a constant; this may change in future releases. Some architectures use only certain bits of a register (e.g. bits 25:31 of XER register on the Power chip family); these are represented as pseudo-registers. The numbering scheme for registers and pseudo-registers is implementation dependent and should not be relied upon; it may change in future releases.

int getImm()

> Return the constant offset. This may be positive or negative.

int getReg(unsigned i)

> Return the register number for the ith register in the sum, where $0 \leq i \leq 2$. Register numbers are positive; a value of -1 means no register.

int getScale()

> Returns any scaling factor used in the memory address computation.

4.27.3   Class BPatch_countSpec_NP

This class encapsulates the information required to determine the number of bytes transferred by a memory access.

4.28   Type System

The Dyninst type system is based on the notion of structural equivalence. Structural equivalence
was selected to allow the system the greatest flexibility in allowing users to write mutators that
work with applications compiled both with and without debugging symbols enabled. Using the
`create*` methods of the `BPatch` class, a mutator can construct type definitions for existing muta-
tee structures. This information allows a mutator to read and write complex types even if the ap-
plication program has been compiled without debugging information. However, if the applica-
tion has been compiled with debugging information, Dyninst will verify the type compatibility of
the operations performed by the mutator.

The rules for type computability are that two types must be of the same storage class (i.e. arrays
are only compatible with other arrays) to be type compatible. For each storage class, the follow-
ing additional requirements must be met for two types to be compatible:

Bpatch_dataScalar

Scalars are compatible if their names are the same (as defined by strcmp) and their sizes
are the same.

BPatch_dataPointer

Pointers are compatible if the types they point to are compatible.

BPatch_dataFunc

Functions are compatible if their return types are compatible, they have same number of
parameters, and position by position each element of the parameter list is type compati-
ble.

BPatch_dataArray

Arrays are compatible if they have the same number of elements (regardless of their
lower and upper bounds) and the base element types are type compatible.

BPatch_dataEnumerated

Enumerated types are compatible if they have the same number of elements and the iden-
tifiers of the elements are the same.

BPatch_dataStructure
BPatch_dataUnion

Structures and unions are compatible if they have the same number of constituent parts
(fields) and item by item each field is type compatible with the corresponds field of the
other type.

In addition, if either of the types is the type BPatch_unknownType, then the two types are com-
patible. Variables in mutatee programs that have not been compiled with debugging symbols (or
in the symbols are in a format that the Dyninst library does not recognize) will be of type
BPatch_unknownType.

5.　　　　Using DyninstAPI with the component libraries

In this section, we describe how to access the underlying component library abstractions from corresponding Dyninst abstractions. The component libraries (SymtabAPI, InstructionAPI, ParseAPI, and PatchAPI) often provide greater functionality and cleaner interfaces than Dyninst, and thus users may wish to use a mix of abstractions. In general, users may access component library abstractions via a `convert` function, which is overloaded and namespaced to give consistent behavior. The definitions of all component library abstractions are located in the appropriate documentation.

```
PatchAPI::PatchMgrPtr PatchAPI::convert(BPatch_addressSpace *);

PatchAPI::PatchObject *PatchAPI::convert(BPatch_object *);
ParseAPI::CodeObject *ParseAPI::convert(BPatch_object *);
SymtabAPI::Symtab *SymtabAPI::convert(BPatch_object *);

SymtabAPI::Module *SymtabAPI::convert(BPatch_module *);

PatchAPI::PatchFunction *PatchAPI::convert(BPatch_function *);
ParseAPI::Function *ParseAPI::convert(BPatch_function *);

PatchAPI::PatchBlock *PatchAPI::convert(BPatch_basicBlock *);
ParseAPI::Block *ParseAPI::convert(BPatch_basicBlock *);

PatchAPI::PatchEdge *PatchAPI::convert(BPatch_edge *);
ParseAPI::Edge *ParseAPI::convert(BPatch_edge *);

PatchAPI::Point *PatchAPI::convert(BPatch_point *, BPatch_callWhen);
PatchAPI::SnippetPtr PatchAPI::convert(BPatch_snippet *);

SymtabAPI::Type *SymtabAPI::convert(BPatch_type *);
```

6.   Using the API

In this section, we describe the steps needed to compile your mutator and mutatee programs and to run them. First we give you an overview of the major steps and then we explain each one in detail.

6.1   Overview of Major Steps

To use Dyninst, you have to:

(1) Build and install DyninstAP: DyninstAPI can be installed a package system such as Spack or can be compiled from source. Our github webpage contains detailed instructions for installing Dyninst: https://github.com/dyninst/dyninst.
(2) Create a mutator program (Section 6.2): You need to create a program that will modify some other program. For an example, see the mutator shown in Appendix A.
(3) Set up the mutatee (Section 6.3): On some platforms, you need to link your application with Dyninst's run time instrumentation library. [**NOTE**: This step is only needed in the current release of the API. Future releases will eliminate this restriction.]
(4) *Run the mutator (Section 6.4):* The mutator will either create a new process or attach to an existing one (depending on the whether createProcess or attachProcess is used).

Sections 6.2 through 6.4 explain these steps in more detail.

6.2   Creating a Mutator Program

The first step in using Dyninst is to create a mutator program. The mutator program specifies the mutatee (either by naming an executable to start or by supplying a process ID for an existing process). In addition, your mutator will include the calls to the API library to modify the mutatee. For the rest of this section, we assume that the mutator is the sample program given in Appendix A - Complete Examples.

The following fragment of a Makefile shows how to link your mutator program with the Dyninst library on most platforms:

```
# DYNINST_INCLUDE and DYNINST_LIB should be set to locations
# where Dyninst header and library files were installed, respectively

retee.o: retee.c
$(CC) -c $(CFLAGS) -I$(DYNINST_INCLUDE) retee.c –std=c++11x


retee: retee.o
       $(CC) retee.o -L$(DYNINST_LIB) -ldyninstAPI -o retee –std=c++11x
```

On Linux, the options `-lelf` and `-ldw` may be required at the link step. You will also need to make sure that the `LD_LIBRARY_PATH` environment variable includes the directory that contains the Dyninst shared library.

Since Dyninst uses the C++11x standard, you will also need to enable this option for your compiler. For GCC versions 4.3 and later, this is done by specifying `-std=c++0x`. For GCC versions 4.7 and later, this is done by specifying `-std=c++11`. Some of these libraries, such as libdwarf and libelf, may not be standard on various platforms. Check the README file in dyninst/dyninstAPI for more information on where to find these libraries.

Under Windows NT, the mutator also needs to be linked with the `dbghelp` library, which is included in the Microsoft Platform SDK. Below is a fragment from a Makefile for Windows NT:

```
# DYNINST_INCLUDE and DYNINST_LIB should be set to locations
# where Dyninst header and library files were installed, respectively

CC = cl

retee.obj: retee.c
        $(CC) -c $(CFLAGS) -I$(DYNINST_INCLUDE)/h

retee.exe: retee.obj
        link -out:retee.exe retee.obj $(DYNINST_LIB)\libdyninstAPI.lib \
         dbghelp.lib
```

6.3   Setting Up the Application Program (mutatee)

On most platforms, any additional code that your mutator might need to call in the mutatee (for example files containing instrumentation functions that were too complex to write directly using the API) can be put into a dynamically loaded shared library, which your mutator program can load into the mutatee at runtime using the loadLibrary member function of BPatch_process.

To locate the runtime library that Dyninst needs to load into your program, an additional environment variable must be set. The variable `DYNINSTAPI_RT_LIB` should be set to the full pathname of the run time instrumentation library, which should be:

```
NOTE: DYNINST_LIB should be set to the location where Dyninst library
files were installed
```

`$(DYNINST_LIB)/libdyninstAPI_RT.so` (UNIX)

`%DYNINST_LIB/libdyninstAPI_RT.dll` (Windows)

6.4   Running the Mutator

At this point, you should be ready to run your application program with your mutator. For example, to start the sample program shown in Appendix A - Complete Examples:

    % retee foo <pid>

6.5   Optimizing Dyninst Performance

This section describes how to tune Dyninst for optimum performance. During the course of a run, Dyninst will perform several types of analysis on the binary, make safety assumptions about instrumentation that is inserted, and rewrite the binary (perhaps several times). Given some guidance from the user, Dyninst can make assumptions about what work it needs to do and can deliver significant performance improvements.

There are two areas of Dyninst performance users typically care about. First, the time it takes Dyninst to parse and instrument a program. This is typically the time it takes Dyninst to start and analyze a program, and the time it takes to modify the program when putting in instrumentation. Second, many users care about the time instrumentation takes in the modified mutatee. This time is highly dependent on both the amount and type of instrumentation put it, but it is still possible to eliminate some of the Dyninst overhead around the instrumentation.

The following subsections describe techniques for improving the performance of these two areas.

6.5.1 Optimizing Mutator Performance

CPU time in the Dyninst mutator is usually consumed by either parsing or instrumenting binaries. When a new binary is loaded, Dyninst will analyze the code looking for instrumentation points, global variables, and attempting to identify functions in areas of code that may not have symbols. Upon user request, Dyninst will also parse debug information from the binary, which includes local variable, line, and type information.

Since Dyninst 10.0.0, Dyninst supports parsing binaries in parallel, which significantly improve the analysis speed. We typically have about 4X speedup when analyzing binaries with 8 threads. By default, Dyninst will use all the available cores on your system. Please set environment variable `OMP_NUM_THREADS` to the number of desired threads.

Debugging information is lazily parsed separately from the rest of the binary parsing. Accessing line, type, or local variable information will cause Dyninst to parse the debug information for all three of these.

Another common source of mutator time is spent re-writing the mutatee to add instrumentation. When instrumentation is inserted into a function, Dyninst may need to rewrite some or all of the function to fit the instrumentation in. If multiple pieces of instrumentation are being inserted into a function, Dyninst may need to rewrite that function multiple times.

If the user knows that they will be inserting multiple pieces of instrumentation into one function, they can batch the instrumentation into one bundle, so that the function will only be re-written once, using the `BPatch_process::beginInsertionSet` and `BPatch_process::endInsertionSet` functions (see section 4.4). Using these functions can result in a significant performance win when inserting instrumentation in many locations.

To use the insertion set functions, add a call to `beginInsertionSet` before inserting instrumentation. Dyninst will start buffering up all instrumentation insertions. After the last piece of in-

strumentation is inserted, call `finalizeInsertionSet`, and all instrumentation will be atomically inserted into the mutatee, with each function being rewritten at most once.

6.5.2   Optimizing Mutatee Performance

As instrumentation is inserted into a mutatee, it will start to run slower. The slowdown is heavily influenced by three factors: the number of points being instrumented, the instrumentation itself, and the Dyninst overhead around each piece of instrumentation. The Dyninst overhead comes from pieces of protection code (described in more detail below) that do things such as saving/restoring registers around instrumentation, checking for instrumentation recursion, and performing thread safety checks.

The factor by which Dyninst overhead influences mutatee run-time depends on the type of instrumentation being inserted.   When inserting instrumentation that runs a memory cache simulator, the Dyninst overhead may be negligible. On the other-hand, when inserting instrumentation that increments a counter, the Dyninst overhead will dominate the time spent in instrumentation. Remember, optimizing the instrumentation being inserted may sometimes be more important than optimizing the Dyninst overhead. Many users have had success writing tools that make use of Dyninst's ability to dynamically remove instrumentation as a performance improvement.

The instrumentation overhead results from safety and correctness checks inserted by Dyninst around instrumentation. Dyninst will automatically attempt to remove as much of this overhead as possible, however it sometimes must make a conservative decision to leave the overhead in. Given additional, user-provided information Dyninst can make better choices about what safety checks to leave in. An unoptimized post-Dyninst 5.0 instrumentation snippet looks like the following:

Save General Purpose Registers	In order to ensure that instrumentation doesn't corrupt the program, Dyninst saves all live general purpose registers.
Save Floating Point Registers	Dyninst may decide to separately save any floating point registers that may be corrupted by instrumentation.
Generate A Stack Frame	Dyninst builds a stack frame for instrumentation to run under. This provides the illusion to instrumentation that it is running as its own function.
Calculate Thread Index	Calculate an index value that identifies the current thread. This is primarily used as input to the Trampoline Guard.
Test and Set Trampoline Guard	Test to see if we are already recursively executing under instrumentation, and skip the user instrumentation if we are.
Execute User Instrumentation	Execute any `BPatch_snippet` code.
Unset Trampoline Guard	Marks the this thread as no longer being in in-

	strumentation
Clean Stack Frame	Clean the stack frame that was generated for instrumentation.
Restore Floating Point Registers	Restore the floating point registers to their original state.
Restore General Purpose Registers	Restore the general purpose registers to their original state.

Dyninst will attempt to eliminate as much of its overhead as is possible. The Dyninst user can assist Dyninst by doing the following:

• **Write BPatch_snippet code that avoids making function calls.** Dyninst will attempt to perform analysis on the user written instrumentation to determine which general purpose and floating point registers can be saved. It is difficult to analyze function calls that may be nested arbitrarily deep. Dyninst will not analyze any deeper than two levels of function calls before assuming that the instrumentation clobbers all registers and it needs to save everything.

> In addition, not making function calls from instrumentation allows Dyninst to eliminate its tramp guard and thread index calculation. Instrumentation that does not make a function call cannot recursively execute more instrumentation.

• **Call `BPatch::setTrampRecursive(true)` if instrumentation cannot execute recursively.** If instrumentation must make a function call, but will not execute recursively, then enable trampoline recursion. This will cause Dyninst to stop generating a trampoline guard and thread index calculation on all future pieces of instrumentation. An example of instrumentation recursion would be instrumenting a call to `write` with instrumentation that calls `printf`—`write` will start calling `printf` printf will re-call `write`.

• **Call `BPatch::setSaveFPR(false)` if instrumentation will not clobber floating point registers**. This will cause Dyninst to stop saving floating point registers, which can be a significant win on some platforms.

• **Use simple `BPatch_snippet` objects when possible**. Dyninst will attempt to recognize, peep-hole optimize, and simplify frequently used code snippets when it finds them. For example, on x86 based platforms Dyninst will recognize snippets that do operations like 'var = constant' or 'var++' and turn these into optimized assembly instructions that take advantage of CISC machine instructions.

• **Call `BPatch::setInstrStackFrames(false)` before inserting instrumentation that does not need to set up stack frames.** Dyninst allows you to force stack frames to be generated for all instrumentation. This is useful for some applications (e.g., debugging your instrumentation code) but allowing Dyninst to omit stack frames wherever possible will improve performance. This flag is false by default; it should be enabled for as little instrumentation as possible in order to maximize the benefit from optimizing away stack frames.

• **Avoid conditional instrumentation wherever possible.** Conditional logic in your instrumentation makes it more difficult to avoid saving the state of the flags.

• **Avoid unnecessary instrumentation.** Dyninst provides you with all kinds of information that you can use to select only the points of actual interest for instrumentation. Use this information to instrument as selectively as possible. The best way to optimize your instrumentation, ultimately, is to know *a priori* that it was unnecessary and not insert it.

Appendix A - Complete Examples

In this section we show two complete examples: the programs from Section 3 and a complete Dyninst program, retee.

1.1   Instrumenting a function

```c
#include <stdio.h>

#include "BPatch.h"
#include "BPatch_addressSpace.h"
#include "BPatch_process.h"
#include "BPatch_binaryEdit.h"
#include "BPatch_point.h"
#include "BPatch_function.h"

using namespace std;
using namespace Dyninst;

// Create an instance of class BPatch
BPatch bpatch;

// Different ways to perform instrumentation
typedef enum {
    create,
    attach,
    open
} accessType_t;

// Attach, create, or open a file for rewriting
BPatch_addressSpace* startInstrumenting(accessType_t accessType,
        const char* name,
        int pid,
        const char* argv[]) {
    BPatch_addressSpace* handle = NULL;

    switch(accessType) {
        case create:
            handle = bpatch.processCreate(name, argv);
            if (!handle) { fprintf(stderr, "processCreate failed\n"); }
            break;
        case attach:
            handle = bpatch.processAttach(name, pid);
            if (!handle) { fprintf(stderr, "processAttach failed\n"); }
            break;
        case open:
            // Open the binary file and all dependencies
            handle = bpatch.openBinary(name, true);
            if (!handle) { fprintf(stderr, "openBinary failed\n"); }
            break;
    }

    return handle;
}
```

```
   // Find a point at which to insert instrumentation
   std::vector<BPatch_point*>* findPoint(BPatch_addressSpace* app,
           const char* name,
           BPatch_procedureLocation loc) {
       std::vector<BPatch_function*> functions;
       std::vector<BPatch_point*>* points;

       // Scan for functions named "name"
       BPatch_image* appImage = app->getImage();
       appImage->findFunction(name, functions);
       if (functions.size() == 0) {
           fprintf(stderr, "No function %s\n", name);
           return points;
       } else if (functions.size() > 1) {
           fprintf(stderr, "More than one %s; using the first one\n", name);
       }

       // Locate the relevant points
       points = functions[0]->findPoint(loc);
       return points;
   }

   // Create and insert an increment snippet
   bool createAndInsertSnippet(BPatch_addressSpace* app,
           std::vector<BPatch_point*>* points) {
       BPatch_image* appImage = app->getImage();

       // Create an increment snippet
       BPatch_variableExpr* intCounter =
           app->malloc(*(appImage->findType("int")), "myCounter");
       BPatch_arithExpr addOne(BPatch_assign,
                               *intCounter,
                               BPatch_arithExpr(BPatch_plus,
                                   *intCounter,
                                   BPatch_constExpr(1)));

       // Insert the snippet
       if (!app->insertSnippet(addOne, *points)) {
           fprintf(stderr, "insertSnippet failed\n");
           return false;
       }
       return true;
   }

   // Create and insert a printf snippet
   bool createAndInsertSnippet2(BPatch_addressSpace* app,
           std::vector<BPatch_point*>* points) {
       BPatch_image* appImage = app->getImage();

       // Create the printf function call snippet
       std::vector<BPatch_snippet*> printfArgs;
       BPatch_snippet* fmt =
```

```
            new BPatch_constExpr("InterestingProcedure called %d times\n");
        printfArgs.push_back(fmt);

        BPatch_variableExpr* var = appImage->findVariable("myCounter");
        if (!var) {
            fprintf(stderr, "Could not find 'myCounter' variable\n");
            return false;
        } else {
            printfArgs.push_back(var);
        }

        // Find the printf function
        std::vector<BPatch_function*> printfFuncs;
        appImage->findFunction("printf", printfFuncs);
        if (printfFuncs.size() == 0) {
            fprintf(stderr, "Could not find printf\n");
            return false;
        }

        // Construct a function call snippet
        BPatch_funcCallExpr printfCall(*(printfFuncs[0]), printfArgs);

        //  Insert the snippet
        if (!app->insertSnippet(printfCall, *points)) {
            fprintf(stderr, "insertSnippet failed\n");
            return false;
        }
        return true;
    }

    void finishInstrumenting(BPatch_addressSpace* app, const char* newName)
    {
        BPatch_process* appProc = dynamic_cast<BPatch_process*>(app);
        BPatch_binaryEdit* appBin = dynamic_cast<BPatch_binaryEdit*>(app);

        if (appProc) {
            if (!appProc->continueExecution()) {
                fprintf(stderr, "continueExecution failed\n");
            }
            while (!appProc->isTerminated()) {
                bpatch.waitForStatusChange();
            }
        } else if (appBin) {
            if (!appBin->writeFile(newName)) {
                fprintf(stderr, "writeFile failed\n");
            }
        }
    }

    int main() {
        // Set up information about the program to be instrumented
        const char* progName = "InterestingProgram";
        int progPID = 42;
        const char* progArgv[] = {"InterestingProgram", "-h", NULL};
        accessType_t mode = create;
```

dyninstAPI

```
      // Create/attach/open a binary
      BPatch_addressSpace* app =
          startInstrumenting(mode, progName, progPID, progArgv);
      if (!app) {
          fprintf(stderr, "startInstrumenting failed\n");
          exit(1);
      }

      // Find the entry point for function InterestingProcedure
      const char* interestingFuncName = "InterestingProcedure";
      std::vector<BPatch_point*>* entryPoint =
          findPoint(app, interestingFuncName, BPatch_entry);
      if (!entryPoint || entryPoint->size() == 0) {
          fprintf(stderr, "No entry points for %s\n", interestingFuncName);
          exit(1);
      }

      // Create and insert instrumentation snippet
      if (!createAndInsertSnippet(app, entryPoint)) {
          fprintf(stderr, "createAndInsertSnippet failed\n");
          exit(1);
      }

      // Find the exit point of main
      std::vector<BPatch_point*>* exitPoint =
          findPoint(app, "main", BPatch_exit);
      if (!exitPoint || exitPoint->size() == 0) {
          fprintf(stderr, "No exit points for main\n");
          exit(1);
      }

      // Create and insert instrumentation snippet 2
      if (!createAndInsertSnippet2(app, exitPoint)) {
          fprintf(stderr, "createAndInsertSnippet2 failed\n");
          exit(1);
      }
      // Finish instrumentation
      const char* progName2 = "InterestingProgram-rewritten";
      finishInstrumenting(app, progName2);
  }
```

1.2   Binary Analysis

```
  #include <stdio.h>

  #include "BPatch.h"
  #include "BPatch_addressSpace.h"
  #include "BPatch_process.h"
  #include "BPatch_binaryEdit.h"
  #include "BPatch_function.h"
  #include "BPatch_flowGraph.h"

  using namespace std;
  using namespace Dyninst;
```

dyninstAPI

```
    // Create an instance of class BPatch
    BPatch bpatch;

    // Different ways to perform instrumentation
    typedef enum {
        create,
        attach,
        open
    } accessType_t;

    BPatch_addressSpace* startInstrumenting(accessType_t accessType,
            const char* name,
            int pid,
            const char* argv[]) {
        BPatch_addressSpace* handle = NULL;

        switch(accessType) {
            case create:
                handle = bpatch.processCreate(name, argv);
                if (!handle) { fprintf(stderr, "processCreate failed\n"); }
                break;
            case attach:
                handle = bpatch.processAttach(name, pid);
                if (!handle) { fprintf(stderr, "processAttach failed\n"); }
                break;
            case open:
                // Open the binary file and all dependencies
                handle = bpatch.openBinary(name, true);
                if (!handle) { fprintf(stderr, "openBinary failed\n"); }
                break;
        }

        return handle;
    }

    int binaryAnalysis(BPatch_addressSpace* app) {
        BPatch_image* appImage = app->getImage();

        int insns_access_memory = 0;

        std::vector<BPatch_function*> functions;
        appImage->findFunction("InterestingProcedure", functions);

        if (functions.size() == 0) {
            fprintf(stderr, "No function InterestingProcedure\n");
            return insns_access_memory;
        } else if (functions.size() > 1) {
                fprintf(stderr, "More than one InterestingProcedure; using the
    first one\n");
        }

        BPatch_flowGraph* fg = functions[0]->getCFG();

        std::set<BPatch_basicBlock*> blocks;
        fg->getAllBasicBlocks(blocks);
```

dyninstAPI

```
        for (auto block_iter = blocks.begin();
                block_iter != blocks.end();
                ++block_iter) {
            BPatch_basicBlock* block = *block_iter;
            std::vector<InstructionAPI::Instruction::Ptr> insns;
            block->getInstructions(insns);

            for (auto insn_iter = insns.begin();
                    insn_iter != insns.end();
                    ++insn_iter) {
                InstructionAPI::Instruction::Ptr insn = *insn_iter;
                if (insn->readsMemory() || insn->writesMemory()) {
                    insns_access_memory++;
                }
            }
        }

        return insns_access_memory;
    }




    int main() {
        // Set up information about the program to be instrumented
        const char* progName = "InterestingProgram";
        int progPID = 42;
        const char* progArgv[] = {"InterestingProgram", "-h", NULL};
        accessType_t mode = create;

        // Create/attach/open a binary
        BPatch_addressSpace* app =
            startInstrumenting(mode, progName, progPID, progArgv);
        if (!app) {
            fprintf(stderr, "startInstrumenting failed\n");
            exit(1);
        }

        int memAccesses = binaryAnalysis(app);

        fprintf(stderr, "Found %d memory accesses\n", memAccesses);
    }
```

1.3   Instrumenting Memory Accesses

```
    #include <stdio.h>

    #include "BPatch.h"
    #include "BPatch_addressSpace.h"
    #include "BPatch_process.h"
    #include "BPatch_binaryEdit.h"
    #include "BPatch_point.h"
```

dyninstAPI

```
#include "BPatch_function.h"

using namespace std;
using namespace Dyninst;

// Create an instance of class BPatch
BPatch bpatch;

// Different ways to perform instrumentation
typedef enum {
    create,
    attach,
    open
} accessType_t;

// Attach, create, or open a file for rewriting
BPatch_addressSpace* startInstrumenting(accessType_t accessType,
        const char* name,
        int pid,
        const char* argv[]) {
    BPatch_addressSpace* handle = NULL;

    switch(accessType) {
        case create:
            handle = bpatch.processCreate(name, argv);
            if (!handle) { fprintf(stderr, "processCreate failed\n"); }
            break;
        case attach:
            handle = bpatch.processAttach(name, pid);
            if (!handle) { fprintf(stderr, "processAttach failed\n"); }
            break;

          case open:
            // Open the binary file; do not open dependencies
            handle = bpatch.openBinary(name, false);
            if (!handle) { fprintf(stderr, "openBinary failed\n"); }
            break;
    }

    return handle;
}

bool instrumentMemoryAccesses(BPatch_addressSpace* app) {
    BPatch_image* appImage = app->getImage();

    // We're interested in loads and stores
    BPatch_Set<BPatch_opCode> axs;
    axs.insert(BPatch_opLoad);
    axs.insert(BPatch_opStore);

    // Scan the function InterestingProcedure
    // and create instrumentation points
    std::vector<BPatch_function*> functions;
    appImage->findFunction("InterestingProcedure", functions);
    std::vector<BPatch_point*>* points =
```

dyninstAPI

```
            functions[0]->findPoint(axs);
        if (!points) {
            fprintf(stderr, "No load/store points found\n");
            return false;
        }

        // Create the printf function call snippet
        std::vector<BPatch_snippet*> printfArgs;
        BPatch_snippet* fmt = new BPatch_constExpr("Access at: 0x%lx\n");
        printfArgs.push_back(fmt);
        BPatch_snippet* eae = new BPatch_effectiveAddressExpr();
        printfArgs.push_back(eae);

        // Find the printf function
        std::vector<BPatch_function*> printfFuncs;
        appImage->findFunction("printf", printfFuncs);
        if (printfFuncs.size() == 0) {
            fprintf(stderr, "Could not find printf\n");
            return false;
        }

        // Construct a function call snippet
        BPatch_funcCallExpr printfCall(*(printfFuncs[0]), printfArgs);

        // Insert the snippet at the instrumentation points
        if (!app->insertSnippet(printfCall, *points)) {
            fprintf(stderr, "insertSnippet failed\n");
            return false;
        }
        return true;
    }

    void finishInstrumenting(BPatch_addressSpace* app, const char* newName) {
        BPatch_process* appProc = dynamic_cast<BPatch_process*>(app);
        BPatch_binaryEdit* appBin = dynamic_cast<BPatch_binaryEdit*>(app);

        if (appProc) {
            if (!appProc->continueExecution()) {
                fprintf(stderr, "continueExecution failed\n");
            }
            while (!appProc->isTerminated()) {
                bpatch.waitForStatusChange();
            }
        } else if (appBin) {
            if (!appBin->writeFile(newName)) {
                fprintf(stderr, "writeFile failed\n");
            }
        }
    }

    int main() {
        // Set up information about the program to be instrumented
        const char* progName = "InterestingProgram";
        int progPID = 42;
        const char* progArgv[] = {"InterestingProgram", "-h", NULL};
```

dyninstAPI

```
      accessType_t mode = create;

      // Create/attach/open a binary
      BPatch_addressSpace* app =
          startInstrumenting(mode, progName, progPID, progArgv);
      if (!app) {
          fprintf(stderr, "startInstrumenting failed\n");
          exit(1);
      }

      // Instrument memory accesses
      if (!instrumentMemoryAccesses(app)) {
          fprintf(stderr, "instrumentMemoryAccesses failed\n");
          exit(1);
      }

      // Finish instrumentation
      const char* progName2 = "InterestingProgram-rewritten";
      finishInstrumenting(app, progName2);
  }
```

1.4   retee

The final example is a program called "re-tee." It takes three arguments: the pathname of an ex-
ecutable program, the process id of a running instance of the same program, and a file name. It
adds code to the running program that copies to the named file all output that the program writes
to its standard output file descriptor. In this way it works like "tee," which passes output along
to its own standard out while also saving it in a file. The motivation for the example program is
that you run a program, and it starts to print copious lines of output to your screen, and you wish
to save that output in a file without having to re-run the program.

```
#include <stdio.h>
#include <fcntl.h>
#include <vector>
#include "BPatch.h"
#include "BPatch_point.h"
#include "BPatch_process.h"
#include "BPatch_function.h"
#include "BPatch_thread.h"

/*
 * retee.C
 *
 * This program (mutator) provides an example of several facets of
 * Dyninst's behavior, and is a good basis for many Dyninst
 * mutators. We want to intercept all output from a target application
 * (the mutatee), duplicating output to a file as well as the
 * original destination (e.g., stdout).
 *
 * This mutator operates in several phases. In brief:
 * 1) Attach to the running process and get a handle (BPatch_process
 *     object)
 * 2) Get a handle for the parsed image of the mutatee for function
 *     lookup (BPatch_image object)
```

dyninstAPI

```
 * 3) Open a file for output
 *    3a) Look up the "open" function
 *    3b) Build a code snippet to call open with the file name.
 *    3c) Run that code snippet via a oneTimeCode, saving the returned
 *        file descriptor
 * 4) Write the returned file descriptor into a memory variable for
 *    mutatee-side use
 * 5) Build a snippet that copies output to the file
 *    5a) Locate the "write" library call
 *    5b) Access its parameters
 *    5c) Build a snippet calling write(fd, parameters)
 *    5d) Insert the snippet at write
 * 6) Add a hook to exit to ensure that we close the file (using
 *    a callback at exit and another oneTimeCode)
 */

void usage() {
    fprintf(stderr, "Usage: retee <process pid> <filename>\n");
     fprintf(stderr, "    note: <filename> is relative to the application
process.\n");
}

// We need to use a callback, and so the things that callback requires
// are made global - this includes the file descriptor snippet (see below)
BPatch_variableExpr *fdVar = NULL;

// Before we add instrumentation, we need to open the file for
// writing. We can do this with a oneTimeCode - a piece of code run at
// a particular time, rather than at a particular location.

int openFileForWrite(BPatch_process *app, BPatch_image *appImage, char *file-
Name) {
    // The code to be generated is:
    // fd = open(argv[2], O_WRONLY|O_CREAT, 0666);

    // (1) Find the open function
    std::vector<BPatch_function *>openFuncs;
    appImage->findFunction("open", openFuncs);
    if (openFuncs.size() == 0) {
        fprintf(stderr, "ERROR: Unable to find function for open()\n");
        return -1;
    }

    // (2) Allocate a vector of snippets for the parameters to open
    std::vector<BPatch_snippet *> openArgs;

    // (3) Create a string constant expression from argv[3]
    BPatch_constExpr fileNameExpr(fileName);

    // (4) Create two more constant expressions _WRONLY|O_CREAT and 0666
    BPatch_constExpr fileFlagsExpr(O_WRONLY|O_CREAT);
    BPatch_constExpr fileModeExpr(0666);

    // (5) Push 3 & 4 onto the list from step 2, push first to last parameter.
    openArgs.push_back(&fileNameExpr);
    openArgs.push_back(&fileFlagsExpr);
```

dyninstAPI

```
    openArgs.push_back(&fileModeExpr);

    // (6) create a procedure call using function found at 1 and
    // parameters from step 5.
    BPatch_funcCallExpr openCall(*openFuncs[0], openArgs);

    // (7) The oneTimeCode returns whatever the return result from
    // the BPatch_snippet is. In this case, the return result of
    // open -> the file descriptor.
    void *openFD = app->oneTimeCode( openCall );

    // oneTimeCode returns a void *, and we want an int file handle
    return (int) (long) openFD;
}

// We have used a oneTimeCode to open the file descriptor. However,
// this returns the file descriptor to the mutator - the mutatee has
// no idea what the descriptor is. We need to allocate a variable in
// the mutatee to hold this value for future use and copy the
// (mutator-side) value into the mutatee variable.

// Note: there are alternatives to this technique. We could have
// allocated the variable before the oneTimeCode and augmented the
// snippet to do the assignment. We could also write the file
// descriptor as a constant into any inserted instrumentation.

BPatch_variableExpr *writeFileDescIntoMutatee(BPatch_process *app,
                                              BPatch_image *appImage,
                                              int fileDescriptor) {
    // (1) Allocate a variable in the mutatee of size (and type) int
    BPatch_variableExpr *fdVar = app->malloc(*appImage->findType("int"));
    if (fdVar == NULL) return NULL;

    // (2) Write the value into the variable
    // Like memcpy, writeValue takes a pointer
    // The third parameter is for functionality called "saveTheWorld",
    // which we don't worry about here (and so is false)
    bool ret = fdVar->writeValue((void *) &fileDescriptor, sizeof(int),
                                 false);
    if (ret == false) return NULL;

    return fdVar;
}

// We now have an open file descriptor in the mutatee. We want to
// instrument write to intercept and copy the output. That happens
// here.

bool interceptAndCloneWrite(BPatch_process *app,
                            BPatch_image *appImage,
                            BPatch_variableExpr *fdVar) {
    // (1) Locate the write call
    std::vector<BPatch_function *> writeFuncs;

    appImage->findFunction("write",
```

dyninstAPI

```
                                writeFuncs);
    if(writeFuncs.size() == 0) {
        fprintf(stderr, "ERROR: Unable to find function for write()\n");
        return false;
    }

    // (2) Build the call to (our) write. Arguments are:
    //   ours: fdVar (file descriptor)
    //   parameter: buffer
    //   parameter: buffer size

    // Declare a vector to hold these.
    std::vector<BPatch_snippet *> writeArgs;
    // Push on the file descriptor
    writeArgs.push_back(fdVar);
    // Well, we need the buffer... but that's a parameter to the
    // function we're implementing. That's not a problem - we can grab
    // it out with a BPatch_paramExpr.
    BPatch_paramExpr buffer(1); // Second (0, 1, 2) argument
    BPatch_paramExpr bufferSize(2);
    writeArgs.push_back(&buffer);
    writeArgs.push_back(&bufferSize);

    // And build the write call
    BPatch_funcCallExpr writeCall(*writeFuncs[0], writeArgs);

    // (3) Identify the BPatch_point for the entry of write. We're
    // instrumenting the function with itself; normally the findPoint
    // call would operate off a different function than the snippet.

    std::vector<BPatch_point *> *points;
    points = writeFuncs[0]->findPoint(BPatch_entry);
    if ((*points).size() == 0) {
        return false;
    }

    // (4) Insert the snippet at the start of write

    return app->insertSnippet(writeCall, *points);

    // Note: we have just instrumented write() with a call to
    // write(). This would ordinarily be a _bad thing_, as there is
    // nothing to stop infinite recursion - write -> instrumentation
    // -> write -> instrumentation....
    // However, Dyninst uses a feature called a "tramp guard" to
    // prevent this, and it's on by default.
}

// This function is called as an exit callback (that is, called
// immediately before the process exits when we can still affect it)
// and thus must match the exit callback signature:
//
// typedef void (*BPatchExitCallback) (BPatch_thread *, BPatch_exitType)
//
// Note that the callback gives us a thread, and we want a process - but
```

```
    // each thread has an up pointer.

    void closeFile(BPatch_thread *thread, BPatch_exitType) {
        fprintf(stderr, "Exit callback called for process...\n");

        // (1) Get the BPatch_process and BPatch_images
        BPatch_process *app = thread->getProcess();
        BPatch_image *appImage = app->getImage();

        // The code to be generated is:
        // close(fd);

        // (2) Find close
        std::vector<BPatch_function *> closeFuncs;
        appImage->findFunction("close", closeFuncs);
        if (closeFuncs.size() == 0) {
            fprintf(stderr, "ERROR: Unable to find function for close()\n");
            return;
        }

        // (3) Allocate a vector of snippets for the parameters to open
        std::vector<BPatch_snippet *> closeArgs;

        // (4) Add the fd snippet - fdVar is global since we can't
        // get it via the callback
        closeArgs.push_back(fdVar);

        // (5) create a procedure call using function found at 1 and
        // parameters from step 3.
        BPatch_funcCallExpr closeCall(*closeFuncs[0], closeArgs);

        // (6) Use a oneTimeCode to close the file
        app->oneTimeCode( closeCall );

        // (7) Tell the app to continue to finish it off.
        app->continueExecution();

        return;
    }

    BPatch bpatch;

    // In main we perform the following operations.
    // 1) Attach to the process and get BPatch_process and BPatch_image
    //    handles
    // 2) Open a file descriptor
    // 3) Instrument write
    // 4) Continue the process and wait for it to terminate

    int main(int argc, char *argv[]) {
        int pid;
        if (argc != 3) {
            usage();
            exit(1);
        }
```

```
    pid = atoi(argv[1]);

    // Attach to the program - we can attach with just a pid; the
    // program name is no longer necessary
    fprintf(stderr, "Attaching to process %d...\n", pid);
    BPatch_process *app = bpatch.processAttach(NULL, pid);

    if (!app) return -1;

    // Read the program's image and get an associated image object
    BPatch_image *appImage = app->getImage();
    std::vector<BPatch_function*> writeFuncs;

    fprintf(stderr, "Opening file %s for write...\n", argv[2]);
    int fileDescriptor = openFileForWrite(app, appImage, argv[2]);

    if (fileDescriptor == -1) {
        fprintf(stderr, "ERROR: opening file %s for write failed\n",
                argv[2]);
        exit(1);
    }

    fprintf(stderr, "Writing returned file descriptor %d into"
                    "mutatee...\n", fileDescriptor);

    // This was defined globally as the exit callback needs it.
    fdVar = writeFileDescIntoMutatee(app, appImage, fileDescriptor);
    if (fdVar == NULL) {
        fprintf(stderr, "ERROR: failed to write mutatee-side variable\n");
        exit(1);
    }

    fprintf(stderr, "Instrumenting write...\n");
    bool ret = interceptAndCloneWrite(app, appImage, fdVar);
    if (!ret) {
        fprintf(stderr, "ERROR: failed to instrument mutatee\n");
        exit(1);
    }

    fprintf(stderr, "Adding exit callback...\n");
    bpatch.registerExitCallback(closeFile);

    // Continue the execution...
    fprintf(stderr, "Continuing execution and waiting for termination\n");
    app->continueExecution();

    while (!app->isTerminated())
        bpatch.waitForStatusChange();

    printf("Done.\n");

    return 0;
}
```

Appendix B - Running the Test Cases

This section describes how to run the Dyninst test cases. The primary purpose of the test cases is to verify that the API has been installed correctly (and for use in regression testing by the developers of the Dyninst library). The code may also be of use to others since it provides a fairly complete example of how to call most of the API methods. The test suite consists of mutator programs and their associated mutatee programs.

To compile the test suite, type `make` in the appropriate platform specific directory under dyninst/testsuite. To run, execute `runTests`. Each test will be executed and the result (PASSED/FAILED/CRASHED) printed.

Test mutators are run by the `test_driver` executable (`test_driver.exe` on Windows). The test_driver loads a mutator test from a shared object and runs it on a test mutatee. A single run of the test_driver may execute multiple tests (depending on parameters passed), and each test may execute multiple times with different parameters and on different mutatees.

Dyninst's test space can be very large. Each mutatee can be run under different tests, compiled by different compilers, and run with different parameters. For example, one point in this space would be the test1 mutatee being run under under test1_13, when compiled with the g++ compiler, and in attach mode. When run without any options, the `test_driver` will run all test combinations that are valid on the current platform. Many of the options that are passed to `test_driver` can be used to limit the test space that it runs in.

In order to prevent a crashing test from stopping the `test_driver` from running subsequent tests, `test_driver` can be run under a wrapper application, `runTests`. The `runTests` wrapper invokes the `test_driver` with the any arguments that were passed to `runTests`. It will watch the `test_driver` process, and if `test_driver` exits with a fault it will print an appropriate error message and restart the `test_driver` on the next test.

It is generally recommended that `runTests` be used when running a large sequence of tests, and `test_driver` be used when debugging issues with a single test.

The `test_driver` and `runTests` applications can be invoked with the following list of arguments. Most arguments are used to limit the space of tests that the testsuite will run. For example, to run the above test1_13 example, you could use the following command line:

```
test_driver –run test1_13 –mutatee test1.mutatee_g++ -attach
```

-attach

> Only run tests that attach to the mutatees.

-create

> Only run tests that create mutatees.

-rewriter

> Only run tests that rewrite mutatees.

-staticlink

> Run rewriter tests that use statically linked mutatees.

-dynamiclink

> Run rewriter tests that use dynamically linked mutatees.

-allmode

> Run tests for all modes (create, attach, rewriter on statically linked binaries, rewriter on dynamically linked binaries).

-gcc, -g++, -pgcc, -pgCC, -icc, -icpc

> Run tests on mutatees built with the specified compiler.

-noclean

> Don't remove rewritten mutatees after running rewriter tests.

-all

> Run tests for all possible combinations of unoptimized mutatees.

-none, -low, -high, -max

> Only run tests for mutatees of the given optimization level.

-allopt

> Run tests for all mutatee optimization levels.

-full

> Run tests for all possible combinations of mutatees, including all optimization levels. Requires `make all` to build the optimized mutatees.

-dyninst, -symtab, -instruction, -proccontrol, -stackwalker

> Only run tests for the specified component.

-allcomp

> Run tests for all components.

-32, -64

> Only run tests for 32-bit or 64-bit mutatees. This option is only valid on platforms such as AMD64/Linux and PowerPC/Linux where both 32-bit and 64-bit build environments are available.

-pic

> Only run tests for mutatees compiled as position-independent code. Default is non-PIC mutatees. –all and –full include both.

-sp, -mp, -st, -mt

> ProcControl-specific: run tests in single process, multiprocess, single thread, multithread modes, respectively.

-j n

> This option spawns up to n test_driver instances from a given runTests invocation. This option is highly recommended for large test runs.

-hosts host1 [host2 ... host*n*]

> In conjunction with the –j option above, will distribute tests over the hosts *host1…host*n. The hosts must share a filesystem with the machine from which runTests is being run, and ssh must be configured to allow password-less authentication to those hosts. Note that –j controls the total number of test_driver instances, not the number per host, so you will need to use a –j N at least equal to the number of hosts you wish to use.

-mutatee <mutatee_name>

> Only run tests that use the specified mutatee name. Only certain mutatees can be run with certain tests. The primary test number specifies which mutatees it can be run with. For example, all of the test1_* tests can be run with the test1.mutatee_* mutatees, and all of the test2_* tests can be run with the test2.mutatee_* mutatees.

-run <subtest> <subtest> …

> Only runs the specific sub-tests listed. For example, to run sub-test case 4 of test2 you would enter `test_driver –run test2_4`.

-test

> Alias for `–run`.

-log

> Print more detailed output, including messages generated by the tests. Without this option the testsuite will capture and hide any messages printed by the test, only showing a summary of whether the test passed or failed. By default, output is sent to `stdout`.

-logfile <filename>

> Send output from the `–log` option to the given filename rather than to `stdout`.

-verbose

> Enables test suite debugging output. This is useful when trying to track down issues in the test suite or tests.

dyninstAPI

Appendix C - Common pitfalls

This appendix is designed to point out some common pitfalls that users have reported when using the Dyninst system. Many of these are either due to limitations in the current implementations, or reflect design decisions that may not produce the expected behavior from the system.

Attach followed by detach

If a mutator attaches to a mutatee, and immediately exits, the current behavior is that the mutatee is left suspended. To make sure the application continues, call detach with the appropriate flags.

Attaching to a program that has already been modified by Dyninst

If a mutator attaches to a program that has already been modified by a previous mutator, a warning message will be issued. We are working to fix this problem, but the correct semantics are still being specified. Currently, a message is printed to indicate that this has been attempted, and the attach will fail.

Dyninst is event-driven

Dyninst must sometimes handle events that take place in the mutatee, for instance when a new shared library is loaded, or when the mutatee executes a fork or exec. Dyninst handles events when it checks the status of the mutatee, so to allow this the mutator should periodically call one of the functions `BPatch::pollForStatusChange`, `BPatch::waitForStatusChange`, `BPatch_thread::isStopped`, or `BPatch_thread::isTerminated`.

Missing or out-of-date DbgHelp DLL (Windows)

Dyninst requires an up-to-date DbgHelp library on Windows. See the section on Windows-specific architectural issues for details.

Portland Compiler Group – missing debug symbols

The Portland Group compiler (pgcc) on Linux produces debug symbols that are not read correctly by Dyninst. The binaries produced by the compiler do not contain the source file information necessary for Dyninst to assign the debug symbols to the correct module.

References

1.   B. Buck and J. K. Hollingsworth, "An API for Runtime Code Patching," *Journal of Supercomputing Applications (to appear)*, 2000.
2.   J. K. Hollingsworth and B. P. Miller, "Using Cost to Control Instrumentation Overhead," *Theoretical Computer Science*, **196**(1-2), 1998, pp. 241-258.
3.   J. K. Hollingsworth, B. P. Miller, and J. Cargille, "Dynamic Program Instrumentation for Scalable Performance Tools," *1994 Scalable High-Performance Computing Conf.*, Knoxville, Tenn., pp. 841-850.
4.   J. K. Hollingsworth, B. P. Miller, M. J. R. Goncalves, O. Naim, Z. Xu, and L. Zheng, "MDL: A Language and Compiler for Dynamic Program Instrumentation," *International Conference on Parallel Architectures and Compilation Techniques (PACT)*. Nov. 1997, San Francisco, pp. 201-212.
5.   J. R. Larus and E. Schnarr, "EEL: Machine-Independent Executable Editing," *PLDI*. June 18-21, 1995, La Jolla, CA, ACM, pp. 291-300.