MATFEAP programmer documentation

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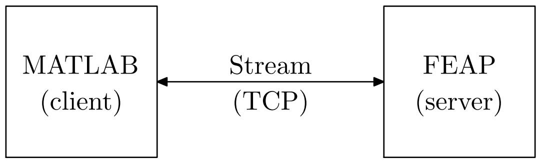
Contents

Chapter 1

MATFEAP basics

1.1 Introduction

MATFEAP is an interface between MATLAB and the finite element analysis program FEAP. MATFEAP is meant to be a successor to FEAPMEX, an earlier interface project which used MATLAB's MEX system for interfacing with external codes. MATFEAP differs from FEAPMEX primarily in that it runs MATLAB and FEAP in different processes which communicate with each other via either a network socket (or optionally a pipe):



There are several advantages to this socket-based architecture:

- The text command interface to FEAP has remained more stable than the internal architecture. By building the communication between MATLAB and FEAP on this text interface, rather than by calling FEAP's internal routines directly from MATLAB, it is less difficult to keep MATFEAP working with multiple FEAP versions than it was to keep FEAPMEX working.
- When debugging problems with FEAP, it is possible to run `gdb`, `valgrind`, and other debugging tools directly on the FEAP server. Also, if FEAP crashes, it will not take MATLAB down with it.
- Because each FEAP simulation runs in a separate process, there are no issues with initializing the global segment (and all the common block variables that FEAP uses) on initialization, nor are there issues with releasing system resources on exit. In contrast, getting the global FEAP initialization and shutdown right was always tricky with FEAPMEX.
- Also because each FEAP simulation runs in a separate process, it is possible to have multiple FEAP simulations open simultaneously.
- The FEAP server does not need to be on the same machine as the MATLAB client. This could be useful for running MATLAB on a laptop or other "front-end" machine and running the FEAP server on a higher-power remote system.
- MATFEAP does not need a MEX component. Therefore, there are no issues of compatibility with the compilers used by the MEX interface. Users can compile the FEAP server using the same compilers and flags that they use to compile FEAP, and the client support code needs only MATLAB and Java.

1.2 Code organization

The server code is made up of three basic modules:

- The server daemon module is responsible for setting up a socket connection on the server side, setting up a new child processes to handle each incoming simulation request, and cleaning up the child processes when simulations are finished. The call to the server module is transparent from the perspective of the FORTRAN code that calls it. When the server module returns control to a child process, that child communicates with the client via its standard input and output streams, just as it would if the client were someone entering commands at the terminal.
- The `feapsrv` module provides a command line interface for accessing FEAP's internal state, and implements the server side of the data transfer protocols used by MATFEAP. This command line interface is invoked at the start of each simulation, and it can be invoked during the simulation through a FEAP user macro.
- There are several FORTRAN support routines called by `feapsrv`. Some of these routines are simple interfaces to ordinary FEAP functions; the rest are modifications to FEAP functions, mostly automatically generated. These FORTRAN routines serve two purposes. First, they let us call a few FEAP routines from `feapsrv` without worrying about proper cross-language binding of FEAP's common block variables. Second, they add synchronization messages to existing routines in order to make it easy for the client to tell when input is expected.

In addition to the FORTRAN support routines, the server is also linked to the standard FEAP library.

The support on the client side consists of two pieces: a Java class that manages the socket connection (there is also an optional MEX library), and a library of MATLAB routines that manage the protocol by which MATLAB communicates with the FEAP server.

The documentation that follows is largely automatically extracted from specially-formatted comments in the MATFEAP source files. The documentation tool we use is available at

`http://www.cims.nyu.edu/~dbindel/code/dsbweb.c`

1.3 Running MATFEAP

To run a MATFEAP simulation, you have to build the `feaps` (FEAP server) executable and run it on the machine where the simulation is to take place. Once the FEAP server is running, start MATLAB and execute the `matfeap_init` script to set the system paths correctly:

```
% matfeap_init.m
% Initializes paths used by the MATFEAP interface

addpath([pwd, '/mlab']);
cd mlab/csock
if exist('csockmex')
  fprintf('Using C socket bindings\n');
  cd ../..
  addpath([pwd, '/mlab/csock']);
  feaps_unix;
else
  fprintf('Using Java socket bindings\n');
  cd ../..
  addpath([pwd, '/mlab/jsock']);
  javaaddpath([pwd, '/mlab/jsock']);
  feaps_pipe;
end
```

This initialization routine should work fine with MATLAB versions 7+, including the student edition. In MATLAB 6.5, the class path used by MATLAB's JVM cannot be dynamically modified, so one has to set that variable in another way – see the Mathworks site for details.

1.4 Simple example

To give the flavor for how MATFEAP works in practice, we give a simple example that uses several of MATFEAP's capabilities.

The `Iblock2` input deck in the example subdirectory describes a square mesh with `n` elements on a side, where the parameter `n` is not defined in the input deck. We start a FEAP simulation with `n = 10`, get the tangent stiffness and residual into MATLAB, solve the linear system and write the results back to FEAP, and then use FEAP's X11 graphics to show the displaced shape. Once the user has finished admiring our deformed block, he can press a key (at which point the FEAP simulation will exit and the graphics will disappear).

```
param.n       = 10;  % Parameter to the FEAP input deck
param.verbose = 1;   % See everything that FEAP sends

p  = feapstart('Iblock2', param);  % Start FEAP simulation

K  = feaptang(p);    % Form the tangent matrix
R  = feapresid(p);   % Form the residual force vector
du = K\R;            % Compute a Newton update
feapsetu(p, du);     % Set the displacement vector

% Plot the results
feapcmd(p, 'plot', 'defo', 'mesh', 'boun', 'load', 'end');

% Quit
disp('Press any key to exit');
pause;
feapquit(p);
```

Chapter 2

Setting up the C server

The `feapserver` routine provides a fairly generic way to turn a console-based FORTRAN program into a UNIX server daemon. From the perspective of the FORTRAN program, very little changes on return from a call to `feapserver`, except that the input and output terminals are now connected to a remote client via a socket. Ordinary FORTRAN `read` and `write` statements directed to the standard output will go over that socket. The caller doesn't need to know anything about the details that turn the program into a network server daemon on this call. However, these details and their implementation are spelled out below.

2.1 Reaping child processes

In UNIX, child processes are not released to the system until after the parent process checks the child process exit status using `wait` or `waitpid`. We install a handler on SIGCHLD events (change of child status) that checks the exit status of any child processes that are finished.

This is a standard piece of most UNIX daemons.

```
static void sigchld_handler(int s)
{
    while (waitpid(-1, NULL, WNOHANG) > 0);
}

static void install_reaper()
{
    struct sigaction sa;
    sa.sa_handler = sigchld_handler;
    sigemptyset(&sa.sa_mask);
    sa.sa_flags = SA_RESTART;
    ec(sigaction(SIGCHLD, &sa, NULL));
}
```

2.2 Receiving TCP socket connections

On the server side, there are two phases to setting up a socket connection. First, we need to set up a socket – create it, give it an address with `bind`, and use `listen` to tell the system that we can receive connections on it. By default, the server listens on `MYPORT` (3490), but this value can be changed by setting the `MATFEAP_PORT` environment variable.

```
static int tcp_socket_setup(int port)
{
    int sockfd;                         /* socket file descriptor */
    struct sockaddr_in my_addr;         /* my address information */
    int yes=1;

    memset(&my_addr, 0, sizeof(my_addr));
    my_addr.sin_family = AF_INET;
    my_addr.sin_port = htons(port);
    my_addr.sin_addr.s_addr = INADDR_ANY;

    ec(sockfd = socket(AF_INET, SOCK_STREAM, 0));
    ec(setsockopt(sockfd, SOL_SOCKET, SO_REUSEADDR, &yes, sizeof(int)));
    ec(bind(sockfd, (struct sockaddr*) &my_addr, sizeof(my_addr)));
    ec(listen(sockfd, BACKLOG));

    printf("Server listening on port %d\n", port);
    return sockfd;
}

static int tcp_handle_connection(int sockfd)
{
    struct sockaddr_in their_addr;
    socklen_t sin_size = sizeof(struct sockaddr_in);
    while (1) {
        int new_fd = accept(sockfd, (struct sockaddr*) &their_addr, &sin_size);
        if (new_fd < 0)
            perror("accept");
        else {
            time_t c = time(NULL);
            printf("Connection from %s -- %s",
                   inet_ntoa(their_addr.sin_addr), ctime(&c));
            return new_fd;
        }
    }
}
```

2.3 Receiving local socket connections

In addition to TCP socket connections, we allow the server to use UNIX domain socket connections. UNIX domain sockets are used in various other system servers as well, including X11. The primary advantage of UNIX-domain sockets over TCP sockets is performance: if you're going to run both the client and the server on the same machine and you use a UNIX-domain socket, then the operating system can handle context switches a little more intelligently. The disadvantage of using UNIX domain sockets is that Java doesn't know about them at this time – you have to use the MEX-based socket infrastructure to connect to the UNIX domain server.

UNIX domain sockets differ from TCP sockets primarily in the setup phase – afterward, everything works the same. The location of a UNIX domain socket is specified as a filesystem location rather than a port number. We use the existence of a port name to tell MATFEAP to listen on a UNIX domain socket.

```
static int local_socket_setup(const char* sockname)
{
    int sockfd;                           /* socket file descriptor */
    struct sockaddr_un my_addr;           /* my address information */
    int len;

    /* Remove any previous socket */
    unlink(sockname);

    memset(&my_addr, 0, sizeof(my_addr));
    my_addr.sun_family = AF_UNIX;
    strcpy(my_addr.sun_path, sockname);
    len = sizeof(my_addr.sun_family) + strlen(my_addr.sun_path) + 1;

    ec(sockfd = socket(AF_UNIX, SOCK_STREAM, 0));
    ec(bind(sockfd, (struct sockaddr*) &my_addr, len));
    ec(listen(sockfd, BACKLOG));

    printf("Server listening on local socket %s\n", sockname);
    return sockfd;
}

static int local_handle_connection(int sockfd)
{
    struct sockaddr_un their_addr;
    socklen_t sin_size = sizeof(struct sockaddr_un);
    while (1) {
        int new_fd = accept(sockfd, (struct sockaddr*) &their_addr, &sin_size);
        if (new_fd < 0)
            perror("accept");
        else {
            time_t c = time(NULL);
            printf("Connection -- %s", ctime(&c));
            return new_fd;
        }
    }
}
```

2.4 Deciding on a socket connections

We decide whether to use TCP or UNIX domain sockets based on the setting of the environment variables. If `MATFEAP_SOCKNAME` is set, we use that as the address for a local UNIX-domain socket. Otherwise, if `MATFEAP_PORT` is set, we use that as the port number for a TCP-based socket. If no relevant environment variable is set, then we default to a TCP-based server listening on port 3490.

```
static int feapsock_local_socket;

static int socket_setup()
{
    int port = MYPORT;
    char* port_env = getenv(PORT_ENV_VAR);
    char* sockname = getenv(SOCKNAME_ENV_VAR);
    if (port_env)
        port = atoi(port_env);

    feapsock_local_socket = (sockname != 0);
    if (feapsock_local_socket)
        return local_socket_setup(sockname);
    else
        return tcp_socket_setup(port);
}

static int handle_connection(int sockfd)
{
    if (feapsock_local_socket)
        return local_handle_connection(sockfd);
    else
        return tcp_handle_connection(sockfd);
}
```

2.5 Redirecting I/O streams

UNIX treats socket file descriptors like any other file descriptors. That means the socket input and output streams can be connected to `stdin` (fd 0) and `stdout` (fd 1) using the `dup` or `dup2` system calls. I leave `stderr` alone so that the FEAP server can send debugging information to the terminal without breaking the protocol used to communicate between the server and the client.

```
static void send_std_to_socket(int new_fd)
{
    dup2(new_fd, 0);
    dup2(new_fd, 1);
    /*dup2(new_fd, 2);*/
    close(new_fd);
}
```

2.6 The main daemon

The main loop is a Fortran-callable routine that accepts incoming socket connections from clients and assigns to each a simulation process. The call to `feapserver` in the original process never exits. In child processes created to handle incoming connections, `feapserver` returns control to the calling routine, allowing FEAP to continue running as it usually would.

```
int feapserver_()
{
    int sockfd = socket_setup();
    install_reaper();

    while (1) {
        int new_fd = handle_connection(sockfd);
        if (!fork()) {  /* This is the child process */
            close(sockfd);
            send_std_to_socket(new_fd);
            return 0;
        }
        close(new_fd);  /* Parent doesn't need this */
    }

    exit(0);
}
```

Chapter 3

The `feapsrv` interface

When running `feapsrv`, the client can access most MATFEAP-specific functions using a text-based command interface. These include things like changing the working directory, setting FEAP parameters, and sending or receiving FEAP's internal arrays and common block entries. The C code is in the driver's seat when `feapsrv` is active, though there are frequent calls back into the FORTRAN code.

3.1 Synchronization

In order to communicate over a socket, we need some protocol for telling who is writing and who is reading. Otherwise, it's easy to get into a deadlock, where the client is trying to send a command while the server is itself blocked on a send. The `feapsync` function sends a string that can be used as a synchronization point by the client, so that (for example) the client won't send one command until the previous command has finished. This isn't a perfect solution, but it is a useful primitive.

Synchronization messages are accompanied by an integer label – 0 is a sort of don't care label, and is what we use for all the synchronization messages that aren't explicitly requested by the client.

The `feapsync` routine is called in four places:

1. During file name entry, the server sends a synchronization message just before waiting on each read. This is mostly so that I don't have to recognize what constitutes a prompt for a filename (the prompts changed between FEAP 7.x and 8.0).
2. Just before requesting input during a `tinput` call, the server sends a synchronization message. Like the previous class of messages, these messages are mainly to prevent me from having to understand what constitutes a prompt.
3. The last message sent by the server before exit is a synchronization message. We use this to keep the client from closing the connection too soon – in a well-behaved shutdown, the client shouldn't close the connection until that last message says that the server is ready.
4. The client can explicitly request a labeled synchronization message via the FEAP user macro `serv`.

```
int feapsync_(int* marker)
{
    printf("\nMATFEAP SYNC %d\n", *marker);
    fflush(stdout);
    return 0;
}
```

3.2 Type conversion

Even on a single machine, we need to convert all binary data transfered to wire format. This is because the Java input functions assume wire format independent of what architecture we use. The `hton[sl]` and `ntoh[ls]` functions convert between host and network long (32-bit) and short (16-bit) integers, but there is no such standard function for double precision floating point data. This is what `ntohd` and `htond` are for.

```
double ntohd(double x)
{
    double one = 1;
    if (*((char*) &one) == 0) {
        double tmp;
        char* src = (char*) &x;
        char* dst = (char*) &tmp;
        dst[0] = src[7];
        dst[1] = src[6];
        dst[2] = src[5];
        dst[3] = src[4];
        dst[4] = src[3];
        dst[5] = src[2];
        dst[6] = src[1];
        dst[7] = src[0];
        return tmp;
    } else {
        return x;
    }
}

double htond(double x)
{
    return ntohd(x);
}
```

3.3 Sending parameter values

FEAP has a routine `pconst()` that reads in parameter values, but it turns out not to be optimal for MATFEAP for two reasons. First, if the parameter happens to be invalid, FEAP crashes – not exactly the ideal behavior. Second, `pconst()` sends a prompt to the standard output, and that prompt can screw up the message synchronization used by MATFEAP.

```
void feapsrv_param(const char* var, double val)
{
    extern int servparam_(int*, int*, double*);
    int i1;
    int i2;

    if (var[0] >= 'A' && var[0] <= 'Z')
       i1 = 1+var[0]-'A';
    else if (var[0] >= 'a' && var[0] <= 'z')
       i1 = 1+var[0]-'a';
    else
```

```
        return;  /* Invalid name */

    if (var[1] == '\0')
        i2 = 0;
    else if (var[1] >= 'A' && var[1] <= 'Z')
        i2 = 1+(var[1]-'A');
    else if (var[1] >= 'a' && var[1] <= 'z')
        i2 = 1+(var[1]-'a');
    else if (var[1] >= '0' && var[1] <= '9')
        i2 = 27+(var[1]-'0');
    else
        return;  /* Invalid name */

    servparam_(&i1, &i2, &val);
}
```

3.4 Sending binary arrays

To send an array to the client, we use the following protocol.

1. Server sends: `Send` *type count*, where *type* is `i` (integer) or `d` (double), and *count* is an integer indicating the number of values to be sent.
2. Client sends: `text` or `binary` or `cancel`.
3. Server sends: nothing if the client requested `cancel`; a stream of 32-bit integers or 64-bit doubles in wire format if the client requested `binary`; or ordinary text representations of the array data, printed one per line, if the client requested `text`.

All this assumes that the array was found – if not, the server would send `Not found` instead of sending a `Send` line, and the interaction would stop there.

```
int fmsendint_(int* data, int* len)
{
    char buf[256];
    char* token;
    int i;

    printf("Send int %d\n", *len);
    fflush(stdout);
    if (fgets(buf, sizeof(buf), stdin) == NULL)
        return 0;

    token = strtok(buf, " \t\r\n");
    if (strcmp(token, "text") == 0) {
        for (i = 0; i < *len; ++i)
            printf("%d\n", data[i]);
    } else if (strcmp(token, "binary") == 0) {
        for (i = 0; i < *len; ++i) {
            int32_t datum = htonl(data[i]);
            fwrite(&datum, sizeof(int32_t), 1, stdout);
        }
    }
    fflush(stdout);

    return 0;
}

int fmsenddbl_(double* data, int* len)
{
    char buf[256];
    char* token;
    int i;

    printf("Send double %d\n", *len);
    fflush(stdout);
    if (fgets(buf, sizeof(buf), stdin) == NULL)
        return 0;

    token = strtok(buf, " \t\r\n");
    if (strcmp(token, "text") == 0) {
        for (i = 0; i < *len; ++i)
            printf("%g\n", data[i]);
    } else if (strcmp(token, "binary") == 0) {
        for (i = 0; i < *len; ++i) {
            double datum = htond(data[i]);
            fwrite(&datum, sizeof(double), 1, stdout);
        }
    }
    fflush(stdout);

    return 0;
}
```

3.5 Receiving binary arrays

To receive an array to the client, we use a protocol very similar to the one used for sending:

1. Server sends: `Recv` *type count*, where *type* is `i` (integer) or `d` (double), and *count* is an integer indicating the number of values to be sent.
2. Client sends: `text` or `binary` or `cancel`.
3. Client sends: nothing if the client requested `cancel`; a stream of 32-bit integers or 64-bit doubles in wire format if the client requested `binary`; or ordinary text representations of the array data, printed one per line, if the client requested `text`.

All this assumes that the array was found – if not, the server would send `Not found` instead of sending a `Send` line, and the interaction would stop there.

It is much more likely that a receive request will be canceled than that a send request will be canceled. When the client wants to receive some data, it dynamically allocates as much space as needed to hold the response; but when the client wants to send data, it has to send exactly as much as the FEAP array wants.

```
int fmrecvint_(int* data, int* len)
{
    char buf[256];
    char* token;
    int i;

    printf("Recv int %d\n", *len);
    fflush(stdout);
    if (fgets(buf, sizeof(buf), stdin) == NULL)
        return 0;

    token = strtok(buf, " \t\r\n");
    if (strcmp(token, "text") == 0) {
        for (i = 0; i < *len; ++i)
            scanf("%d", &(data[i]));
    } else if (strcmp(token, "binary") == 0) {
        for (i = 0; i < *len; ++i) {
            int32_t datum;
            fread(&datum, sizeof(int32_t), 1, stdin);
            data[i] = ntohl(datum);
        }
    }

    return 0;
}

int fmrecvdbl_(double* data, int* len)
{
    char buf[256];
    char* token;
    int i;

    printf("Recv double %d\n", *len);
    fflush(stdout);
    if (fgets(buf, sizeof(buf), stdin) == NULL)
        return 0;

    token = strtok(buf, " \t\r\n");
    if (strcmp(token, "text") == 0) {
        for (i = 0; i < *len; ++i)
            scanf("%lg", &(data[i]));
    } else if (strcmp(token, "binary") == 0) {
        for (i = 0; i < *len; ++i) {
            double datum;
            fread(&datum, sizeof(double), 1, stdin);
            data[i] = ntohd(datum);
        }
    }

    return 0;
}
```

3.6 Sending sparse arrays

Sparse arrays are sent from FEAP to MATLAB in coordinate form. Transfer from MATLAB back to FEAP is currently not supported. There was already a FORTRAN routine in place to print various FEAP sparse matrices to a file for later retrieval in MATLAB; I adapted that routine for use in MATFEAP by changing all the file I/O routines into calls to `writeaij` (below). Sending an array consists of two steps:

1. A call to `matspew` to accumulate a count of the number of nonzero coordinates to be sent during the data transfer. After making the count, we send a message `nnz` *count* to the client.
2. A second call to `matspew` to send the data. For the binary version of the protocol, the data is sent in triplets: `i, j, Aij`, where `i` and `j` are 32-bit integers in wire format and `Aij` is a wire format double. For text versions of the protocol, the data is sent with one triple per line.

```
int writeaij_(int* i, int* j, double* aij, int* count)
{
    /* Cases:
     *  count >=  0 -- accumulate count
     *  count == -1 -- output as text
     *  count == -2 -- output as binary
     */
    if (*count >= 0) {
        ++(*count);
    } else if (*count == -1) {
        printf("%d %d %lg\n", *i, *j, *aij);
    } else if (*count == -2) {
        double coord[3];
        coord[0] = htond(*i);
        coord[1] = htond(*j);
        coord[2] = htond(*aij);
        fwrite(coord, sizeof(double), 3, stdout);
    }
    return 0;
}

void sparse_write(char* types, char* var)
{
    extern int matspew_(char* var, int* cnt);
    int type = 0;
    if (strcmp(types, "text") == 0)
        type = -1;
    else if (strcmp(types, "binary") == 0)
        type = -2;
    if (type && var) {
        int cnt = 0;
        matspew_(var, &cnt);
        printf("nnz %d\n", cnt);
        cnt = type;
        matspew_(var, &cnt);
    }
}
```

3.7 The `feapsrv` dispatcher

The `feapsrv` routine is called both at the beginning of the MATFEAP run and whenever the user macro `serv` is invoked. This routine provides a common interface for receiving and dispatching most of the commands used by MATFEAP. In order to keep me honest – and in order to aid debugging – I have tried to make it possible to use the `feapsrv` subcommands as an ordinary user at a terminal interface. This means, among other things, that there is a help string.

```
char* FEAPSRV_HELP =
    "Commands are:\n"
    "  start           - Start / resume ordinary FEAP interaction\n"
    "  quit            - Terminate this FEAP process\n"
    "  help            - Get this message\n"
    "  cd DIR          - Change to directory DIR\n"
    "  cd              - Print current working directory\n"
    "  param           - Set FEAP parameters\n"
    "  set VAR         - Set FEAP common block variable\n"
    "  get VAR         - Print FEAP common block variable\n"
    "  getm VAR        - Start get of FEAP array\n"
    "  setm VAR        - Start set FEAP array\n"
    "  sparse FMT VAR  - Get FEAP sparse matrix as binary or text\n"
    "  clear_isformed  - Clear with the 'resid formed' flag\n"
    "\n"
    "You can enter server mode from FEAP using the 'serv' macro.\n"
    "See the source code / documentation for more information on the\n"
    "protocols used to exchange arrays and sparse matrices\n";

int feapsrv_()
{
    char buf[256];
    printf("FEAPSRV>\n");
    fflush(stdout);
    while (fgets(buf, sizeof(buf), stdin) != NULL) {
        char* token = strtok(buf, " \t\r\n");
        if (token == NULL) {
            continue;
        } else if (strcmp(token, "start") == 0) {
            return 0;
        } else if (strcmp(token, "quit") == 0) {
            exit(0);
        } else if (strcmp(token, "help") == 0) {
            printf(FEAPSRV_HELP);
        } else if (strcmp(token, "cd") == 0) {
            token = strtok(NULL, " \t\r\n");
            if (token == NULL)
                printf("PWD: %s\n", getcwd(buf, sizeof(buf)));
            else if (chdir(token) < 0)
                perror("chdir");
        } else if (strcmp(token, "param") == 0) {
            char* name = strtok(NULL, " \t\r\n");
            char* valtok = strtok(NULL, " \t\r\n");
            double val = atof(valtok);
            feapsrv_param(name, val);
        } else if (strcmp(token, "set") == 0) {
            extern int feapget_(char* var, char* mode);
            token = strtok(NULL, " \t\r\n");
            if (token) {
                int n = strlen(token);
                token[n] = ' ';
                feapget_(token, "w");
                token[n] = 0;
            }
        } else if (strcmp(token, "get") == 0) {
            extern int feapget_(char* var, char* mode);
            token = strtok(NULL, " \t\r\n");
            if (token) {
                int n = strlen(token);
                token[n] = ' ';
                feapget_(token, "r");
                token[n] = 0;
            }
        } else if (strcmp(token, "getm") == 0) {
            extern int feapgetm_(char* var, int len);
            token = strtok(NULL, " \t\r\n");
            if (token)
                feapgetm_(token, strlen(token));
        } else if (strcmp(token, "setm") == 0) {
            extern int feapsetm_(char* var, int len);
            token = strtok(NULL, " \t\r\n");
            if (token)
                feapsetm_(token, strlen(token));
        } else if (strcmp(token, "sparse") == 0) {
            char* transfertype = strtok(NULL, " \t\r\n");
            char* varname = strtok(NULL, " \t\r\n");
            if (transfertype && varname)
                sparse_write(transfertype, varname);
        } else if (strcmp(token, "clear_isformed") == 0) {
            extern int feaptformed_();
            feaptformed_();
        } else {
            printf("Unrecognized command: %s\n", token);
        }
        printf("FEAPSRV>\n");
        fflush(stdout);
    }
    return 0;
}
```

Chapter 4

FORTRAN support routines

The FORTRAN support routines really play a secondary role to the C routines. They are almost all either modifications of existing FEAP routines or thin wrappers over top of existing FEAP routines. The main reason that some of these routines exist is that it is *much* easier to access the FORTRAN common block data used by FEAP directly from FORTRAN than it is to access it from C.

4.1 Adding synchronization on input

We have our own version of the input routine `tinput`, which mediates most of the console input in FEAP. Our version calls `feapsync` to allow the client to sync up with the server, then calls `tinput2`, which is generated from the ordinary `tinput` routine in FEAP.

```
logical function tinput(tx,mt,d,nn)

include  'iofile.h'

logical   tinput2
integer   mt,nn,bnum
character tx(*)*15
real*8    d(*)

save

if(ior.lt.0) then
  bnum = 0
  call feapsync(bnum)
end if
tinput = tinput2(tx,mt,d,nn)

end
```

4.2 Getting and setting scalars

The `feapget` routine either reads a common block variable from the standard input or writes a common block variable to the standard output, depending on whether the mode is `r` or `w`. If no such variable is available, the routine doesn't do anything. The data is always sent in text format.

NOTE: The FORTRAN `read` statement is not very smart, so if the client tries to write a double value into an integer variable, the FORTRAN I/O library is likely to complain and abort the program.

```
subroutine feapget(var, mode)
```

4.3 Sending matrices

The `feapgetm(var)` command fetches the named array from FEAP's dynamic memory system using `pgetd`. If the array is found, `feapgetm` calls `feapsendint` or `feapsenddbl` in order to return the data to the client. Otherwise, it prints a "Not found" message.

There are two variants of this routine. The code below works with newer versions of FEAP (8.0+) in which the `p_point.h` header declares an integer variable capable of storing a FEAP pointer. The code in `feapgetm7.f` works with earlier versions of FEAP in which pointers are always represented as 32-bit integers.

```
subroutine feapgetm(var)

implicit  none

include 'comblk.h'
include 'pointer.h'
include 'p_point.h'

character var*(*)
logical flag
integer lengt, prec

save

call pgetd( var, point, lengt, prec, flag )
if(flag) then
  if(prec.eq.1) then
    call fmsendint(mr(point), lengt)
  else
    call fmsenddbl(hr(point), lengt)
  endif
else
  print *, 'Not found'
endif

end
```

4.4 Receiving matrices

The `feapsetm` command is exactly analogous to `feapgetm`, except that it receives data from the client using `feaprecvint` and `feaprecvdbl` where `feapgetm` sends data.

```
subroutine feapsetm(var)
```

4.5 FORTRAN sparse matrix output support

The `matspew` command is based on the sparse matrix output routine available at `www.ce.berkeley.edu/~rlt/feap/umacr3.f` The `matspew` routine differs from the original routine primarily in that it calls a function `writeaij` where the original routine would write a coordinate triple to file. The writeaij routine takes i, j, and Aij, but it also takes an additional argument that controls the precise behavior of the routine – if negative, it tells writeaij to write binary or text data. If the argument is non-negative, writeaij writes no output, but increments the argument with each call in order to compute the number of nonzeroes that would be written.

The routine can output the following matrices:

- Tangent (tang) and unsymmetric tangent(utan)
- Consistent mass (mass or cmas), lumped mass (lmas), or unsymmetric mass (umas)
- Consistent damping (damp or cdam) or unsymmetric damping (udam)

```
      subroutine matspew(lct, cnt)
```

4.6 Clearing the solution flag

The FEAP common block flag fl(8) is used to keep track of whether or not the residual has been formed since the last solv call. If it has already been formed, there's no reason to form it again. But when we do a calculation on MATLAB and directly write to the FEAP vectors containing the current state, whatever residual might be in FEAP's memory is invalidated. We therefore use feaptformed to clear the value of fl(8) so that FEAP will know when such an event has happened.

```
      subroutine feaptformed()

      implicit  none

      include  'fdata.h'

      save

      fl(8) = .false.

      end
```

4.7 The FEAP dispatch macro

The FEAP user macro serv plays two roles. If called with a positive integer argument (e.g. serv,,1), FEAP will call feapsync to output a string that the MATLAB client can use for synchronization. Otherwise, FEAP will call the feapsrv dispatcher routine, which allows the MATLAB client to access most of the MATFEAP-specific functionality available.

```
      subroutine umacr1(lct,ctl,prt)

c      * * F E A P * * A Finite Element Analysis Program

c....  Copyright (c) 1984-2006: Regents of the University of California
c                               All rights reserved

c-----[--.----+----.----+----.-----------------------------------------]
c     Modification log                                Date (dd/mm/year)
c       Original version                                    01/11/2006
c-----[--.----+----.----+----.-----------------------------------------]
```

```
c      Purpose:  User interface for adding solution command language
c                instructions.

c      Inputs:
c         lct       - Command character parameters
c         ctl(3)    - Command numerical parameters
c         prt       - Flag, output if true

c      Outputs:
c         N.B.  Users are responsible for command actions.  See
c               programmers manual for example.
c-----[--.----+----.----+----.-----------------------------------------]
      implicit  none

      include  'iofile.h'
      include  'umac1.h'

      logical   pcomp,prt
      character lct*15
      real*8    ctl(3)
      integer   ival

      save

c     Set command word

      if(pcomp(uct,'mac1',4)) then      ! Usual    form
        uct = 'serv'                    ! Specify 'name'
      elseif(urest.eq.1) then           ! Read  restart data

      elseif(urest.eq.2) then           ! Write restart data

      else                              ! Perform user operation
        ival = ctl(1)
        if(ival.gt.0) then
          call feapsync(ival)
        else
          call feapsrv()
        endif
      endif

      end
```

4.8 Generated files

We mostly augment FEAP by adding new files, but there are a few minor changes that we have to make to the existing files as well. Because MATFEAP is supposed to work with different versions of FEAP, and because some of the files we need to modify vary between FEAP versions, we automatically rewrite the FEAP sources with scripts, rather than trying to come up with a one or more modified routine that will be compatible with all the relevant versions.

The most obvious change is to the FEAP front-end routine. We add calls to `feapserver` (to start the socket server) and to `feapsrv` (so that the user can set parameters, change directories, etc. before entering filenames and processing the input file.

```
feap.f: $(FEAPMAIN)
        $(AWK) ' \
        /call pstart/ { \
          print "      call feapserver()"; \
          print "      call feapsrv()" } \
        { print }' $(FEAPMAIN) > feap.f
```

FEAP calls the `plstop` routine to close files, clear memory, and otherwise clean up before exiting. It causes problems on some systems to close the socket connection before FEAP finishes writing whatever it will to the standard output, so we add a synchronization call at the very end of `plstop`, just before the true exit.

```
plstop.f: $(PLSTOP)
        $(AWK) ' \
        /^[ ]*stop/ { print "      call feapsync(1)" } \
        { print }' $(PLSTOP) > plstop.f
```

The `filnam` routine, which reads in file names from the standard input, requires four modifications:

1. We need to make sure that `filnam` doesn't decide to use the default file names saved in the `feapname` file (which is what the ordinary FEAP routine does). So we strategically insert the statement `lfil = .false.` (indicating that there's no `feapname` to read) immediately before where FEAP tests `lfil`.
2. We add initialization routines for the various filename variables, fixing a bug in FEAP that would otherwise cause the program to go into a tailspin if we tried to quit rather than entering filenames.
3. We make a call to `cleannam` to turn any carriage returns and line feeds received by FEAP into ordinary spaces (it's unclear to me why these characters show up when I send the data over a socket and not over the terminal, but it seems that they do).
4. We add a call to `feapsync` before each read, so that the client will know when it's supposed to provide input.

```
filnam.f:
        $(AWK) ' \
        /if\(lfil\) then/          { print "      lfil = .false."; init = 1 } \
        init == 1 && /^      else/ { init = 2 } \
        init == 2 && /^[ ]*p/      { print; sub(/ p/, " f") } \
        init == 2 && /^[ ]*end/    { init = 0 } \
        /^[0-9 \t]*read/           { print "      call feapsync(0)" } \
        /.not.pcomp\(filein/       { print "      call cleannam(filein)" }  \
        { print }' $(FEAPHOME)/program/filnam.f > filnam.f
```

The `tinput` routine mediates most (though not all) of FEAP's standard input. Prior to version 8.0, `tinput` was in the program subdirectory. Since 8.0, there has been a special UNIX version of `tinput` that uses a `select` loop to keep X11 plots up to date while waiting for user input at the console. We just need to find the version that's appropriate, copy it to the local directory, and rename it to `tinput2`. We have our own version of `tinput` that will call `tinput2` and then call `feapsync` to allow the client to synchronize with the server.

```
tinput2.f:
        if grep "function tinput" $(FEAPHOME)/program/*.f > /dev/null ; \
                then cp $(FEAPHOME)/program/tinput.f tinput0.f ; \
                else cp $(FEAPHOME)/unix/tinput.f tinput0.f ; \
                fi
        $(AWK) '{ gsub(/tinput/, "tinput2"); print }' tinput0.f > tinput2.f
        rm tinput0.f
```

Chapter 5

MATLAB client

The MATLAB client uses a thin Java client class to manage sending and receiving data over a pipe or TCP socket. There is also a C-language MEX file which can be compiled to send and receive data over a TCP or UNIX-domain socket (this C language MEX file is required to run MATFEAP with Octave). Except when using the `feapsrv` interface, the protocol is that the FEAP server will send a synchronization method whenever it is waiting for input and when it is ready to quit. In this mode, the client does not send data except immediately after receiving a synchronization message from FEAP.

When using the `feapsrv` interface documented previously, the generic protocol is to wait for the `FEAPSRV` prompt, then send a command, then wait for the next `FEAPSRV` prompt. However, there are more elaborate protocols for transferring arrays between FEAP and MATLAB, and these are documented along with the `feapsrv` module.

5.1 Communication performance

Of the three communication models offered by MATFEAP, the TCP socket communication is the most flexible (since it can connect to servers on remote machines). At the same time, for single-machine use, it is the slowest of the methods. On the UNIX and OS X boxes where I have done tests, both the pipe communication mechanism and the UNIX-domain socket mechanism seem to achieve reasonable performance. The default behavior as set in `matfeap_init` is to use UNIX-domain sockets with the C MEX client, and pipes with the Java client.

5.2 Interface to the Java socket helper

The Java socket helper class is a thin layer that lets us use Java stream descriptors and binary I/O routines. We use it to establish socket connections, send an recieve lines of data, etc.

The socket routines are

- `sock_new(hostname,port)` - start a socket connection
- `sock_new(command)` - start a pipe connection
- `sock_close(js)` - close a socket
- `sock_recv(js)` - read a line of data
- `sock_send(js)` - send a line of data
- `sock_readdarray(js, len)` - read `len` 64-bit doubles into an array

- `sock_readiarray(js, len)` - read `len` 32-bit integers into an array
- `sock_senddarray(js, array)` - send an array of 64-bit doubles
- `sock_sendiarray(js, array)` - send an array of 32-bit integers

5.3 Interface to the C socket helper

The C socket library provides a MEX interface to both TCP and UNIX domain sockets. This library can be used with MATLAB as an alternative to the Java socket library; or it can be used with recent versions of Octave.

The C socket routines are identical to the Java socket routines, save for `sock_new`:

- `sock_new(hostname,port)` - start a TCP socket connection
- `sock_new(sockname)` - start a UNIX socket connection

In addition, we provide a routine that queries the environment to figure out an appropriate name for a UNIX-domain socket to the server:

- `sock_default_unix` - return the default UNIX socket name

5.4 Communication setup

These routines are used to specify which of the three communication modes available to MATFEAP should be used.

5.4.1 Setting up pipe communication

The `feaps_pipe` function tells MATFEAP to manage communication over a bidirectional pipe managed by Java. This method is not available in the C interface – there the prefered connection method is a UNIX-domain socket.

The default location for the FEAP executable used by in pipe mode is *MATFEAP*`/srv/feapp`. The location of the `feaps_pipe.m` file should be *MATFEAP*`/srv/feaps_pipe.m`. Since the latter file is obviously on the MATLAB path, we can get the fully qualified name from MATLAB and extract the location of the MATFEAP home directory from it.

```
function feaps_pipe(cmd)

global matfeap_globals
matfeap_globals.sockname = [];
matfeap_globals.server   = [];
matfeap_globals.port     = [];

if nargin < 1
  s = which('feaps_pipe.m');
  i = strfind(s, 'feaps_pipe.m')-length('mlab/');
  matfeap_globals.command = [s(1:i-1), 'srv/feapp'];
  fprintf('Using FEAP in pipe mode: %s\n', matfeap_globals.command);
elseif isempty(cmd)
  matfeap_globals.command = [];
  fprintf('Turning off FEAP pipe mode\n');
else
```

```
  matfeap_globals.command = cmd;
end
```

5.4.2 Setting up TCP socket communication

The `feaps_tcp` function tells MATFEAP to manage communication over a TCP socket (which may be managed by Java or C). The default location for the server is the local host on port 3490.

```
function feaps_tcp(server, port)

global matfeap_globals
matfeap_globals.command  = [];
matfeap_globals.sockname = [];
matfeap_globals.server   = [];
matfeap_globals.port     = [];

if nargin < 1
  matfeap_globals.server = '127.0.0.1';
  matfeap_globals.port   = 3490;
elseif nargin == 1
  if isempty(server)
    fprintf('Turning off FEAP TCP mode\n');
    return;
  elseif isnumeric(server)
    matfeap_globals.server = '127.0.0.1';
    matfeap_globals.port   = server;
  else
    matfeap_globals.server = server;
    matfeap_globals.port   = 3490;
  end
else
  matfeap_globals.server = server;
  matfeap_globals.port   = port;
end

fprintf('Using FEAP in TCP mode: %s:%d\n', ...
        matfeap_globals.server, matfeap_globals.port);
```

5.4.3 Setting up UNIX socket communication

The `feaps_unix` function tells MATFEAP to manage communication over a UNIX-domain socket. This option is only available with the C interface. UNIX-domain sockets are identified by filesystem locations, typically placed under `/tmp`. For MATFEAP, we use the default name `/tmp/feaps-`*USER*, where *USER* is the user name in the current environment. Because MATLAB doesn't have direct access to the environment, we fetch the default socket name through the wrapper function `sock_default_unix`.

```
function feaps_unix(sockname)

global matfeap_globals
matfeap_globals.command  = [];
matfeap_globals.sockname = [];
matfeap_globals.server   = [];
matfeap_globals.port     = [];

if nargin < 1
  matfeap_globals.sockname = sock_default_unix;
elseif nargin == 1
  if isempty(sockname)
    fprintf('Turning off FEAP UNIX mode\n');
    return;
  else
    matfeap_globals.sockname = sockname;
  end
end

fprintf('Using FEAP on UNIX socket: %s\n', matfeap_globals.sockname);
```

5.5 Starting FEAP

The `feapstart` command is used to launch a new FEAP process:

```
function p = feapstart(fname, params)
```

The file name argument is required. The optional `params` argument plays double duty: a set of special parameters are used to control things about the MATFEAP interface, and the remaining parameters are used to initialize the FEAP variable list before opening the designated input deck.

5.5.1 Merging global parameters

The `matfeap_globals` variable is used to provide default values for the fields in the `params` structure, if explicit values are not otherwise provided.

```
global matfeap_globals;

if isstruct(matfeap_globals)
  if isempty(params)
    params = matfeap_globals;
  else
    pnames = fieldnames(matfeap_globals);
    for k = 1:length(pnames)
      if ~isfield(params, pnames{k})
        pvalue = getfield(matfeap_globals, pnames{k});
        params = setfield(params, pnames{k}, pvalue);
      end
    end
  end
end
```

5.5.2 Special parameters

The special parameters are

- `verbose`: if true, output all the stuff that FEAP sends
- `server` and `port`: the server host name (string) and port number (integer)
- `command`: if defined, this string says how to execute the extended FEAP directly from the command line. Used as an alternative to opening a socket connection.
- `dir`: the starting directory to change to after connecting to the FEAP server. By default we use the client's present working directory.

At the same time we process these parameters, we remove them from the `param` structure. That way, everything remaining in the `param` structure after this step can be interpreted as a FEAP input parameter.

```
verb    = 0;           % Are we in verbose mode?
server  = '127.0.0.1'; % Server where FEAP is located
port    = 3490;        % Port where FEAP is located
dir     = pwd;         % Base directory to use for rel paths
command = [];          % Command string to use with pipe interface
sockname = [];         % UNIX domain socket name

if ~isempty(params)
  if isfield(params, 'verbose')
    verb = params.verbose;
    params = rmfield(params, 'verbose');
  end
  if isfield(params, 'server')
    server = params.server;
    params = rmfield(params, 'server');
  end
  if isfield(params, 'port')
    port = params.port;
    params = rmfield(params, 'port');
  end
  if isfield(params, 'command')
    command = params.command;
    params = rmfield(params, 'command');
  end
  if isfield(params, 'sockname')
    sockname = params.sockname;
    params = rmfield(params, 'sockname');
  end
  if isfield(params, 'dir')
    dir = params.dir;
    params = rmfield(params, 'dir');
  end
end
```

5.5.3 Input deck directory

I assume that the file name does not contain any slashes or backslashes; if those occur in the input deck name, then we'll split the name argument into `pathname` and `fname`.

```
lastslash = max([strfind(fname, '/'), strfind(fname, '\')]);
if ~isempty(lastslash)
  pathname = fname(1:lastslash-1);
  fname = fname(lastslash+1:end);
else
  pathname = [];
end
```

5.5.4 Opening FEAP

If `sockname` is nonempty, then the user has specified a UNIX domain socket to connect to the FEAP server. Otherwise if `command` is nonempty, then the user has specified the name of a command to start the (extended) FEAP. This FEAP executable has the same interface as the socket-based version, but it communicates using the ordinary standard I/O streams, which we will connect to a pipe. Otherwise, we'll try to communicate with the server via TCP. We give the same generic error message in the event of any error – "is the server there?"

Once a connection to the FEAP process has been established, we save the relevant Java helper (or C handle) and the verbosity flag together in a handle structure. This structure is the first argument to all the high-level MATFEAP interface functions.

```
try
  if ~isempty(sockname)
    fd = sock_new(sockname);
  elseif ~isempty(command)
    fd = sock_new(command);
  else
    fd = sock_new(server, port);
  end
catch
  fprintf('Could not open connection -- is the FEAP server running?\n');
  error(lasterr);
end

p = [];
p.fd = fd;
p.verb = verb;
```

5.5.5 Passing parameters

The `param` command in the `feapsrv` interface allows the user to send parameters to FEAP. Parameter assignments have the form "param var val". Invalid assignments are (perhaps suboptimally) simply ignored.

```
feapsrvp(p);
if ~isempty(params)
  pnames = fieldnames(params);
  for k = 1:length(pnames)
    pvar = pnames{k};
    pval = getfield(params, pnames{k});
    if ~isnumeric(pval)
```

```
      fprintf('Ignoring non-numeric parameter %s\n', pvar);
    else
      sock_send(fd, sprintf('param %s %g', pvar, pval));
      feapsrvp(p);
    end
  end
end
```

5.5.6 Setting the current directory

If a home directory was specified via a `dir` special argument, we first change to that directory (by default, we change to the client's present working directory). If a path was specified as part of the input deck name, we then change to that directory. If both `dir` and `pathname` are non-empty and the `pathname` specifies a relative path, we will end up in the path relative to the specified base directory.

The `feapsrv` command to change directories will return a diagnostic message if for any reason the directory change doesn't go through. We ignore said message.

```
if ~isempty(dir)
  sock_send(fd, ['cd ', dir]);
  feapsrvp(p);
end
if ~isempty(pathname)
  sock_send(fd, ['cd ', pathname]);
  feapsrvp(p);
end
```

5.5.7 Sending the file names

Once we've set up the parameter string and changed to the proper directory, we're ready to actually start processing an input deck. The `start` command gets us out of the `feapsrv` interface and into ordinary FEAP interactions. We now need to send to FEAP:

1. The name of the input deck.
2. Blank lines to say "we accept the default names for the auxiliary files." The number of auxiliary files has changed over time, which is why we don't use a counter – we just send a blank line at every synchronization message until we see a string that indicates that we've entered all the desired file names.
3. A string "y" for when we're asked if the file names are correct.

If an error occurs during entering the file name, we send the "quit" string and get out of dodge. In response to a request to quit, FEAP will go through the ordinary shutdown procedure, so we'll wait for the last synchronization message before closing the connection.

```
sock_send(fd, 'start');
feapsync(p);
sock_send(fd, fname);

doneflag = 0;
while 1
  s = sock_recv(fd);
  if strfind(s, '*ERROR*')
    p.verb = 1;
    feapsync(p);
    sock_send(fd, 'quit');
    feapsync(p);
    sock_close(fd);
    p = [];
    return;
  elseif strfind(s, 'Files are set')
    feapdispv(p, s);
    feapsync(p);
    sock_send(fd, 'y')
    feapsync(p);
    return;
  elseif strfind(s, 'MATFEAP SYNC')
    sock_send(fd, '');
  else
    feapdispv(p, s);
  end
end
```

5.6 User commands

These are the main routines in the interface used directly by MATFEAP users.

5.6.1 Invoking FEAP macro commands

The `feapcmd` routine is used to invoke FEAP macro routines. It's up to the user to ensure that after the end of the last command in the list, FEAP is back at a prompt involving a `tinput` command (e.g. the macro prompt or a plot prompt).

The `feapcmd` routine should not be used to quit FEAP; use `feapquit` for that.

```
function feapcmd(p, varargin)

for k = 1:length(varargin)
  sock_send(p.fd, varargin{k});
  feapsync(p);
end
```

5.6.2 Exiting FEAP

The `feapquit` command invokes the quit command, says "n" when asked whether we would like to continue, waits for the sign-off synchronization message, and shuts down the connection. This is the graceful way to exit from FEAP. In contrast, the `feapkill` command should be treated as a last-ditch effort to kill a misbehaving FEAP process.

```
function feapquit(p)

sock_send(p.fd, 'quit');
feapsync(p);
sock_send(p.fd, 'n');
feapsync(p,1);
```

```
sock_close(p.fd);

function feapkill(p)

sock_close(p.fd);
```

5.6.3 Putting MATFEAP into verbose mode

In verbose mode, you can see all the interactions between MATFEAP and FEAP. It's possible to switch to verbose mode by setting the `verbose` field in the parameter structure for `feapstart`, or by setting the `matfeap_globals` structure directly; but I find myself wanting to see verbose output fairly regularly, so it seemed worthwhile to have a special method for it.

```
function feaps_verb

global matfeap_globals;
matfeap_globals.verbose = 1;
```

5.7 Basic getter / setter interfaces

These are the MATLAB interface routines that get and set FEAP matrices, arrays, and scalars.

5.7.1 Getting scalar values

To get a scalar variable, we enter the `feapsrv` interface and issue a `get it varname` request. Either it succeeds, in which case the variable is printed; or it fails, in which case nothing is printed. We silently return an empty array to indicate the latter case. After retrieving the variable, we issue a `start` command to exit the `feapsrv` interface and get back to the FEAP macro prompt.

```
function val = feapget(p, var)

if nargin < 2,   error('Missing required argument');      end
if ~ischar(var), error('Variable name must be a string'); end

sock_send(p.fd, 'serv');
feapsrvp(p);
cmd = sprintf('get %s', lower(var));
feapdispv(p, cmd);
sock_send(p.fd, cmd);

val = [];
resp = sock_recv(p.fd);
if ~strcmp(resp, 'FEAPSRV> ')
  val = sscanf(resp, '%g');
  feapdispv(p, resp);
  feapsrvp(p);
end
sock_send(p.fd, 'start');
feapsync(p);
```

5.7.2 Getting arrays

This routine implements the client side of the array fetch protocol described in the `feapsrv` documentation. We enter the `feapsrv` command interface, issue a request for a matrix, read the server's description of the matrix size and type, and then either start an appropriate binary data transfer or bail if something looks malformed. After all this, we return to the FEAP macro interface.

```
function val = feapgetm(p, var)

if nargin < 2,   error('Missing required argument');      end
if ~ischar(var), error('Variable name must be a string'); end

sock_send(p.fd, 'serv');
feapsrvp(p);
cmd = sprintf('getm %s', upper(var));
feapdispv(p, cmd);
sock_send(p.fd, cmd);

resp = sock_recv(p.fd);
[s, resp] = strtok(resp);
val = [];
if strcmp(s, 'Send')
  [datatype, resp] = strtok(resp);  % Data type (int | double)
  [len,      resp] = strtok(resp);  % Number of entries
  len = str2num(len);
  if strcmp(datatype, 'int')
    feapdispv(p, sprintf('Receive %d ints...', len));
    sock_send(p.fd, 'binary')
    val = sock_recviarray(p.fd, len);
  elseif strcmp(datatype, 'double')
    feapdispv(p, sprintf('Receive %d doubles...', len));
    sock_send(p.fd, 'binary')
    val = sock_recvdarray(p.fd, len);
  else
    feapdispv(p, 'Did not recognize response, bailing');
    sock_send(p.fd, 'cancel')
  end
end

feapsrvp(p);
sock_send(p.fd, 'start')
feapsync(p);
```

5.7.3 Setting arrays

This routine implements the client side of the array set protocol described in the `feapsrv` documentation. It is exactly analogous to `feapgetm`, except that now we have to make sure that we're sending the right amount of data. We should almost certainly advertize more clearly when we've exited because the specified array was the wrong size.

```
function feapsetm(p, var, val)

sock_send(p.fd, 'serv');
```

```
feapsrvp(p);
cmd = sprintf('setm %s', upper(var));
feapdispv(p, cmd);
sock_send(p.fd, cmd);

resp = sock_recv(p.fd);
[s, resp] = strtok(resp);
if strcmp(s, 'Recv')
  [datatype, resp] = strtok(resp);
  [len, resp] = strtok(resp);
  len = str2num(len);
  if len ~= prod(size(val))
    feapdispv(p, sprintf('Expected size %d; bailing', len));
    sock_send(p.fd, 'cancel');
  elseif strcmp(datatype, 'int')
    feapdispv(p, sprintf('Sending %d ints...', len));
    sock_send(p.fd, 'binary')
    sock_sendiarray(p.fd, val);
  elseif strcmp(datatype, 'double')
    feapdispv(p, sprintf('Sending %d doubles...', len));
    sock_send(p.fd, 'binary')
    sock_senddarray(p.fd, val);
  else
    feapdispv(p, 'Did not recognize response, bailing');
    sock_send(p.fd, 'cancel')
  end
end

feapsrvp(p);
sock_send(p.fd, 'start')
feapsync(p);
```

5.7.4 Getting sparse matrices

This routine implements the client side of the sparse matrix fetch protocol described in the `feapsrv` documentation. We start the `feapsrv` command interface, request the array, read the number of nonzero entries, and either fetch a block of binary data and convert it to a sparse matrix, or bail if we saw something unexpected.

```
function val = feapgetsparse(p, var)

if nargin < 2,   error('Wrong number of arguments'); end
if ~ischar(var), error('Variable name must be a string'); end
if length(var) < 1, error('Variable name must be at least one char'); end

sock_send(p.fd, 'serv');
feapsrvp(p);
cmd = sprintf('sparse binary %s', lower(var));
feapdispv(p, cmd);
sock_send(p.fd, cmd);

resp = sock_recv(p.fd);
```

```
[s, resp] = strtok(resp);
val = [];
if strcmp(s, 'nnz')
  [len, resp] = strtok(resp);
  len = str2num(len);
  feapdispv(p, sprintf('Receive %d matrix entries...', len));
  val = sock_recvdarray(p.fd, 3*len);
  val = reshape(val, 3, len);
  val = sparse(val(1,:), val(2,:), val(3,:));
end

feapsrvp(p);
sock_send(p.fd, 'start')
feapsync(p);
```

5.8 Getting stiffness, mass, and damping

These are the high-level interface routines that fetch or write the main FEAP sparse matrices.

5.8.1 Tangent matrix

The `feaptang` and `feaputan` routines call FEAP macros to form the tangent stiffness matrix (symmetric or unsymmetric) without factoring it, and then retrieve the matrix into MATLAB.

```
function K = feaptang(p)

feapcmd(p, 'tang,,-1');
K = feapgetsparse(p, 'tang');
```

```
function K = feaputan(p)

feapcmd(p, 'utan,,-1');
K = feapgetsparse(p, 'utan');
```

5.8.2 Mass matrix

The `feapmass` and `feapumass` routines call FEAP macros to form the mass (symmetric or unsymmetric), and then retrieve the matrix into MATLAB. This high-level interface only allows you to get the consistent mass, and not the lumped mass.

```
function M = feapmass(p)

feapcmd(p, 'mass');
M = feapgetsparse(p, 'mass');
```

```
function M = feapumass(p)

feapcmd(p, 'mass,unsy');
M = feapgetsparse(p, 'umas');
```

5.8.3 Damping matrix

The `feapdamp` and `feapudamp` routines call FEAP macros to form the damping (symmetric or unsymmetric), and then retrieve the matrix into MATLAB.

```
function D = feapdamp(p)

feapcmd(p, 'damp');
D = feapgetsparse(p, 'damp');
```

```
function D = feapudamp(p)

feapcmd(p, 'damp,unsy');
D = feapgetsparse(p, 'damp');
```

5.9 Getting and setting `X`, `U`, and `F` vectors

These are the high-level interface routines that fetch or write the node position, displacement, and residual vectors.

5.9.1 Getting the displacement

The `feapgetu` command retrieves the full displacement array `U` and returns some subset of it. By default, we extract the active degrees of freedom in the reduced order, using `map2full` to retrieve the appropriate reindexing vector.

```
function u = feapgetu(p, id)

if nargin < 2, id = map2full(p); end
u = feapgetm(p, 'u');
u = u(id);
```

5.9.2 Setting the displacement

The `feapsetu` command sets some subset of the displacement array `U` (by default, we set the active degrees of freedom). If we don't provide a vector to write out, then the assumption is that we want to clear the displacement vector to zero, save for any essential boundary conditions (which FEAP keeps in the second part of the `F` array).

```
function feapsetu(p,u, id)

if nargin < 3, [id, bc_id] = map2full(p); end
u1 = feapgetm(p,'u');

if nargin < 2
  nneq        = feapget(p,'nneq');
  f           = feapgetm(p,'f');
  u1(bc_id)   = f(bc_id + nneq);
end

u1(id) = u;
feapsetm(p, 'u', u1);
```

5.9.3 Getting the nodal positions

The `feapgetx` command gets the nodal position matrix `X` and, optionally, a parallel matrix of displacements. These displacements can be extracted from a displacement vector passed in as an argument, or they can be retrieved from the FEAP `U` array.

```
function [xx, uu] = feapgetx(p,u)

% Get mesh parameters
nnp  = feapget(p,'numnp'); % Number of nodal points
nneq = feapget(p,'nneq');  % Number of unreduced dof
neq  = feapget(p,'neq');   % Number of dof
ndm  = feapget(p,'ndm');   % Number of spatial dimensions
ndf  = feapget(p,'ndf');   % Maximum dof per node

% Get node coordinates from FEAP
xx = feapgetm(p,'x');
xx = reshape(xx, ndm, length(xx)/ndm);

if nargout > 1

  % Extract u if not provided
  if nargin < 1, u = feapgetu(p); end

  % Find out how to map reduced to full dof set
  id   = feapgetm(p,'id');
  id   = reshape(id(1:nneq), ndf, nnp);
  idnz = find(id > 0);

  % Get full dof set
  uu       = zeros(ndf, nnp);
  uu(idnz) = u(id(idnz));

end
```

5.9.4 Getting the residual

The `feapresid` function forms the residual and fetches it from FEAP memory. If the user provides a reduced displacement vector `u` as an argument, then that vector will be written to FEAP's array of nodal unknowns before evaluating the residual.

The one thing that's a little tricky about `feapresid` has to do with an optimization in FEAP. Usually, calls to the FEAP macro to form the residual don't do anything unless there has been a solve step since the previous request for a residual form. But when we modify the displacements and boundary conditions behind FEAP's back, we typically invalidate the current residual, whatever it may be. So before requesting that FEAP form a new residual, we use the `feapsrv` interface to clear the flag that says that the residual has already been formed.

```
function R = feapresid(p, u, id)

if nargin == 2
  feapsetu(p,u);
elseif nargin == 3
  feapsetu(p,u, id);
```

```
end

sock_send(p.fd,'serv');
feapsrvp(p);
feapdispv(p, 'clear_isformed');
sock_send(p.fd, 'clear_isformed');
feapsrvp(p);
sock_send(p.fd, 'start');
feapsync(p);

feapcmd(p,'form');
R = feapgetm(p,'dr');
R = R(1:feapget(p,'neq'));
```

5.10 Utility commands

These are low-level routines that should generally be invisible to the user.

5.10.1 Waiting for synchronization

The `feapsync` command is used to wait for a synchronization message sent by the server. For the moment, we don't use the synchronization labels.

```
function feapsync(p, barriernum)

if nargin == 1, barriernum = 0; end

while 1
  s = sock_recv(p.fd);
  if strfind(s, 'MATFEAP SYNC')
    if barriernum == 0
      break;
    elseif strcmp(s, sprintf('MATFEAP SYNC %d', barriernum))
      break
    else
      feapdispv(p, 'Unexpected barrier');
      feapdispv(p, s);
    end
  else
    feapdispv(p, s);
  end
end
```

5.10.2 Waiting for FEAPSRV

The `feapsrvp` command is used to wait for the server to send a `FEAPSRV` prompt when using the `feapsrv` command interface.

```
function s = feapsrvp(p, prompt)

while 1
  s = sock_recv(p.fd);
  feapdispv(p, s);
  if strfind(s, 'FEAPSRV>'), break; end
end
```

5.10.3 Verbose output

The `feapdispv` routine is used to write messages to the standard output conditioned on the FEAP server being in verbose mode. This is useful if you want to look at the output of FEAP for debugging purposes.

```
function feapdispv(p, msg)

if p.verb
  if length(msg) == 0, msg = ' '; end
  disp(msg);
end
```

5.10.4 Index mapping

The `ID` array in FEAP is used to keep track of which nodal variables are active and which are determined by some boundary condition. We return the relevant portion of the `ID` array along with:

1. The indices of all active degrees of freedom (`full_id`).
2. The indices of all variables subject to BCs (`bc_id`).
3. An array to map the indices of the active degrees of freedom in the full vector to indices in a reduced vector (`reduced_id`).

```
function [full_id, bc_id, reduced_id, id] = map2full(p)

% Get mesh parameters
nneq  = feapget(p, 'nneq');  % Number of unreduced dof
numnp = feapget(p, 'numnp'); % Number of dof
ndf   = feapget(p, 'ndf');   % Maximum dof per node

% Get the index map
id = feapgetm(p, 'id');
id = reshape(id(1:nneq), ndf, numnp);

% Find the index set for free vars in full and reduced vectors
full_id    = find(id >  0);
bc_id      = find(id <= 0);
reduced_id = id(full_id);
```