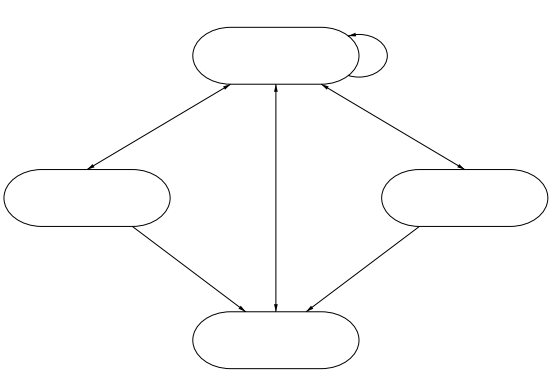
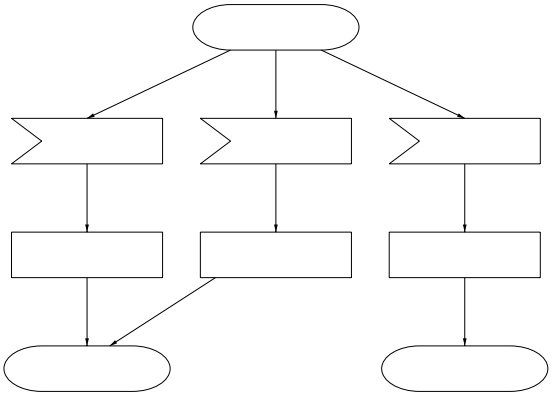
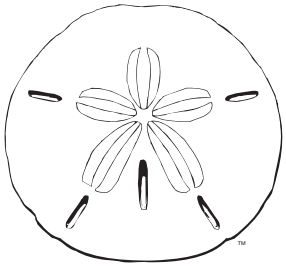
Bayfront CAPE Tools™
User's Guide







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Users Manual
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1. Introduction

Thank you for purchasing Bayfront Technologies Computer Aided Protocol Engineering (CAPE) Tools. This chapter introduces the concept of Computer Aided Protocol Engineering (CAPE) and the structure of the Bayfront CAPE Tools™. If you prefer to immediately install and run the Bayfront tools, please refer to Chapter 2.

1.1. Computer Aided Protocol Engineering (CAPE)

Realtime systems are different from traditional software systems. A traditional software system takes input and goes from an initial state to a final state. Typical examples of traditional software systems are batch, off-line data processing and numerical packages. Realtime systems such as communications systems, operating systems and process control systems never terminate in a final state. These systems maintain a continuous interaction with their environment. They are expected to remain in operation for long periods of time. Protocol systems are a subset of realtime systems. The Bayfront CAPE Tools were created to address the construction of communication protocol systems. These same tools can be used to aid the construction of other realtime systems such as process control systems or client/server systems. Bayfront CAPE Tools:

- are used to automate a significant percent of protocol system implementation, maintenance and documentation
- accept user defined protocols or state machines and generate C code implementations
- automatically generate state transition diagrams, state/event transition diagrams and International Telegraph and Telephone Consultative Committee (CCITT) Specification and Description Language (SDL) diagrams from the input protocol or state machine description.

The figure below illustrates the use of Bayfront CAPE Tools.

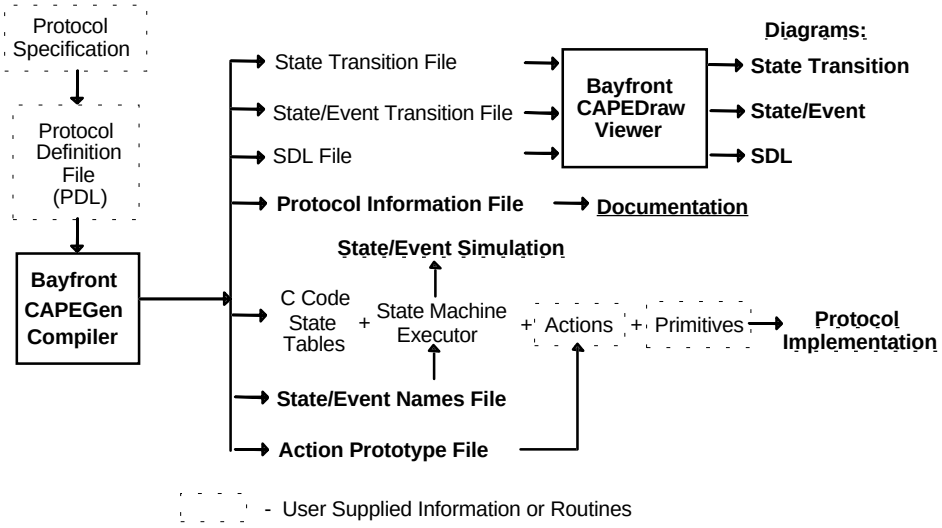


Figure 1. Bayfront CAPE Tools™ Usage

Bayfront's CAPE Tools take a user generated protocol definition language (PDL) file as input. The PDL describes the protocol in terms of protocol-level concepts like states, events and actions. Bayfront's Cape Tools then create several output files depending on the options selected. These files include

- C Code file to implement the protocol

- Action prototype file to assist in the implementation of actions
- Protocol Information file for cross reference
- State and Event names file for debugging purposes
- State Transition Diagram file (pre layout and display format)
- State/Event Transition Diagram file (pre layout and display format)
- System Description Language (SDL) Diagram file (pre layout and display format).

Implementation is only part of the effort in constructing a successful system. The Bayfront CAPE Tools also aid the developer in the important documentation, simulation and validation aspects of system construction. The generation, content, and use of this information is discussed in detail in the remainder of this manual.

1.2. Communication System Architectures

Communication systems are composed of protocols and state machines contained within communicating functional layers. A hierarchical set of layers is called a protocol stack. The International Standards Organization (ISO) Open Systems Interconnection (OSI) model defines seven such functional layers illustrated in the figure below.

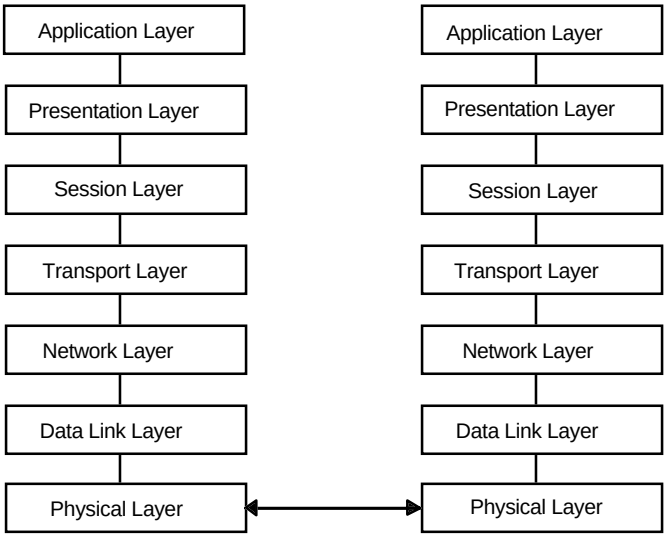


Figure 2 International Standards Organization ISO Model

Each layer consists of communicating protocols or state machines. Interlayer communication occurs through communications channels, queues or mailboxes depending on the operating system and implementation details. The figure below illustrates a general interlayer communication model.

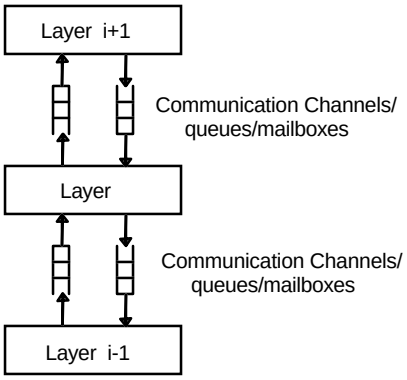


Figure 3. Inter-Layer Communications

Each functional layer contains one or more communicating state machines. These state machines are driven by a layer event processor and typically react to an incoming event such as a received message or a timeout. The figure below illustrates a general layer composed of four state machines and an event processor.

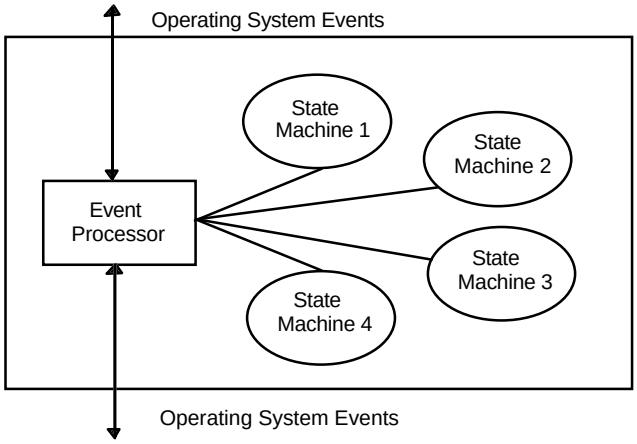


Figure 4. Communicating State Machines within a Layer

The layer event processor determines the set of state machines needed to respond to an event. It then applies the event to those state machines.

1.3. Client/Server System Architectures

Client/Server systems are composed of two different types of processes: clients who request services and servers who are service providers. This system has the advantage of modularizing function and well defined interfaces. Newer operating systems such as Microsoft's Windows NT as well as certain features of Microsoft's Windows OS are based on this model. The figure below illustrates the Windows NT Client/Server Structure.

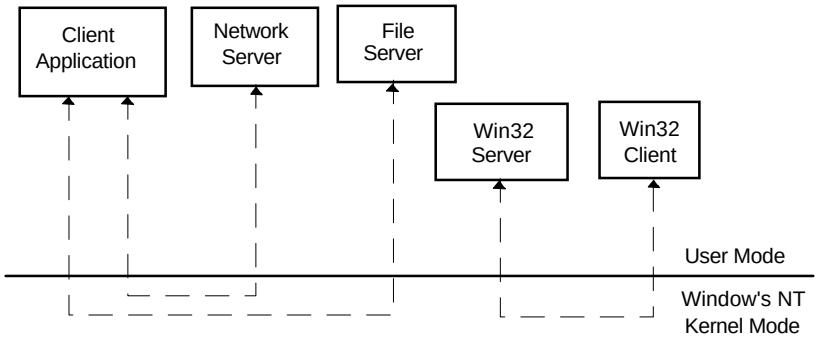


Figure 5. Microsoft's Windows NT Client/Server Model

Present in the Windows NT environment are servers that provide a specific functionality with a well defined interface protocol. For example the network server acts on connection, data transfer and disconnection requests from client applications. The network server must detect clients who violate the server protocol (e.g. a client who transfers data or disconnects before connecting).

The figure below illustrates Microsoft's Windows Dynamic Data Exchange (DDE) protocol messages.

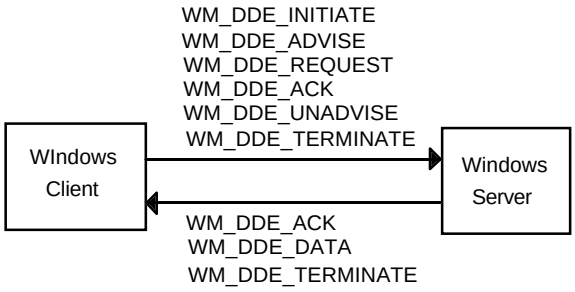


Figure 6. Microsoft's Windows DDE Client/Server Model

The Windows Client and the Windows Server exchange numerous messages. Not all messages are valid at any one time. Both the Client and Server implement a protocol or state machine that defines the rules for message transfer. The protocol allows the Server to detect faulty Client communications and assists the Client in the orderly connection and data transfer with the Server. The Bayfront generated state/event transition diagram for the DDE Client/Server protocol is illustrated in the diagram below.

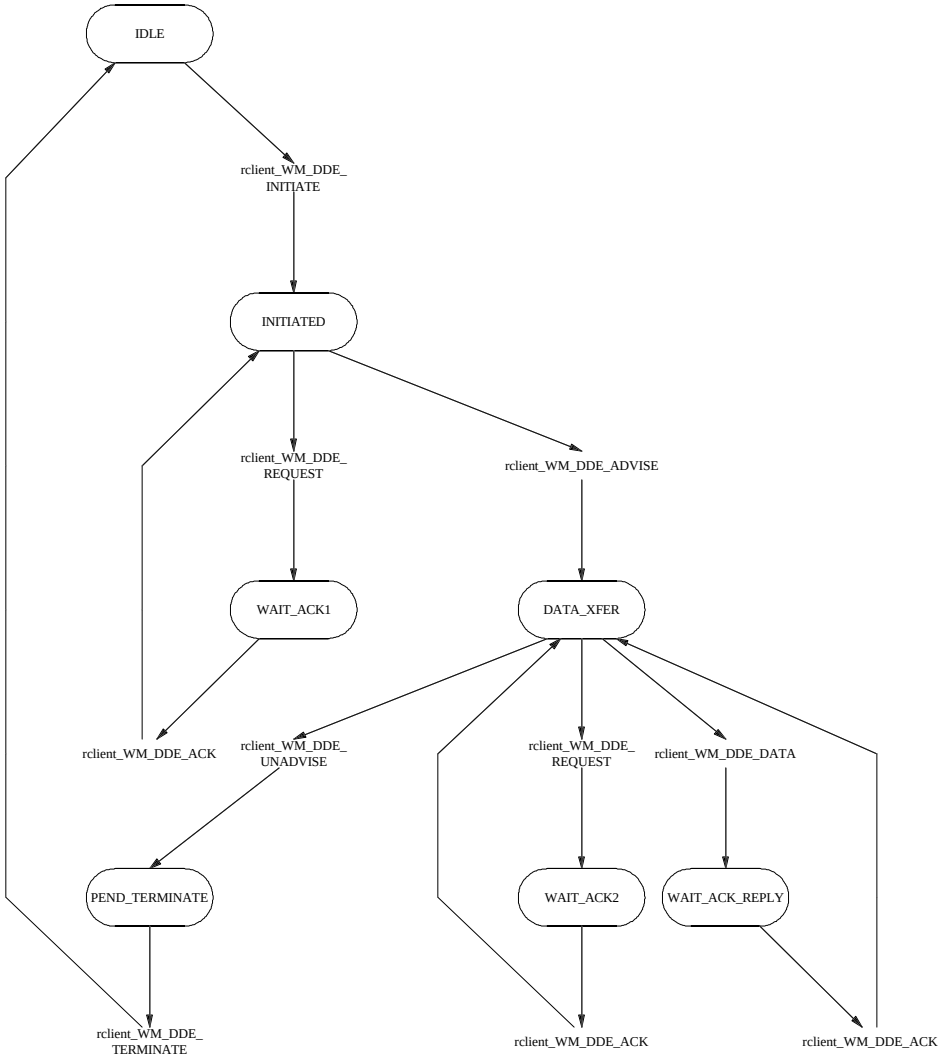


Figure 7. DDE Server State/Event Transition Diagram

Microsoft has itself realized the complexity of the client/server DDE protocol and implemented an application interface layer on top to try to simplify and make consistent the interface. Microsoft calls this the Dynamic Data Exchange Management Library (DDEML).

Bayfront's CAPE Tools assist in the design of client/server systems by abstracting and formalizing the client/server protocols into specific states, events and actions.

1.4. Realtime System Architectures

Realtime system architectures are composed of separate processes which are mutually dependent. The action of one process may start or stop the activity of other processes. These interdependent activities between processes must be synchronized. Processes synchronize by exchanging information through channels, mailboxes or queues. This information exchange is usually performed according to a protocol or state machine.

The figure below illustrates a high level architecture of an Aircraft Heads Up Display (HUD) realtime system.

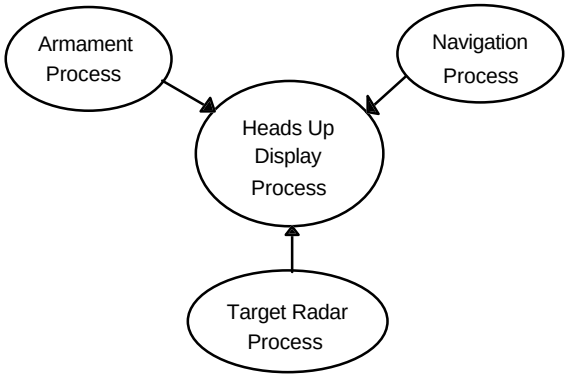


Figure 8. Heads Up Display Realtime System

The architecture of the Heads Up Display system consists of the interaction of mutually dependent processes (e.g. armament, navigation, target radar and heads up display processes). These processes communicate through protocols which define specific states, events and actions. Bayfront's CAPE Tools provide the realtime developer with a formalism to design the inter- and intra- process communications.

1.5. Bayfront CAPE Architectural Model

Bayfront CAPE Tools support an architectural model that views an individual communications layer, realtime process or client/server protocol as composed of an event processor, a state machine executor, specific protocol state tables and their supporting actions and primitives.

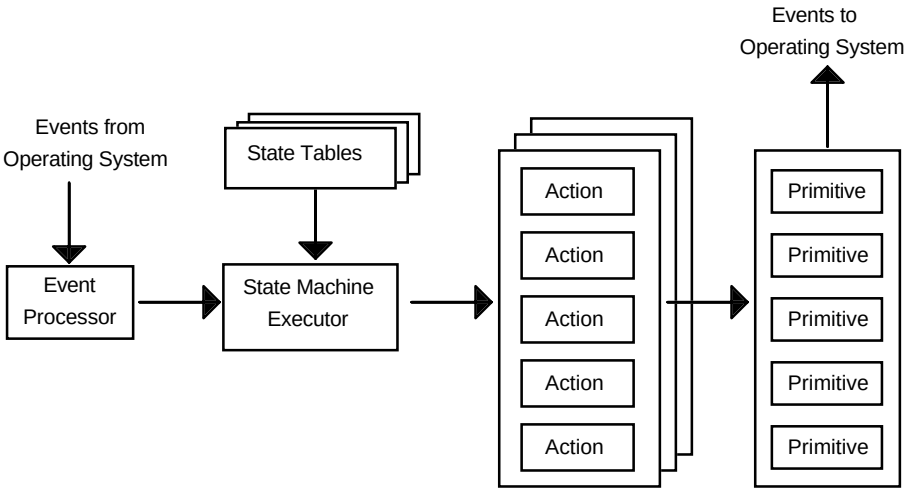


Figure 9. Protocol Layer Architectural Model

Because protocol systems are intimately involved with hardware and operating environments *the event processor, actions, and primitives are all programmed by the user of Bayfront CAPE Tools.* Bayfront supplies the state machine executor (`sm_exec.c`) in source form and example event processors. The Bayfront CAPEGen Compiler produces the state tables and action function prototypes from a Protocol Definition Language (PDL) file. Since a layer can consist of multiple interacting state machines there are state tables and action prototypes for each state machine. Each state machine is described in a separate PDL file. **The benefit of the Bayfront CAPE Tools is in the analysis, documentation and maintenance of the protocol in protocol-oriented PDL terms. The error prone alternative is to maintain the state table structures by hand, hand simulate the states, and hand draw the documentation.**

Communications layers are combined using the operating environment communication mechanisms of streams, queues, communication channels, or mailboxes. This is shown in the figure below.

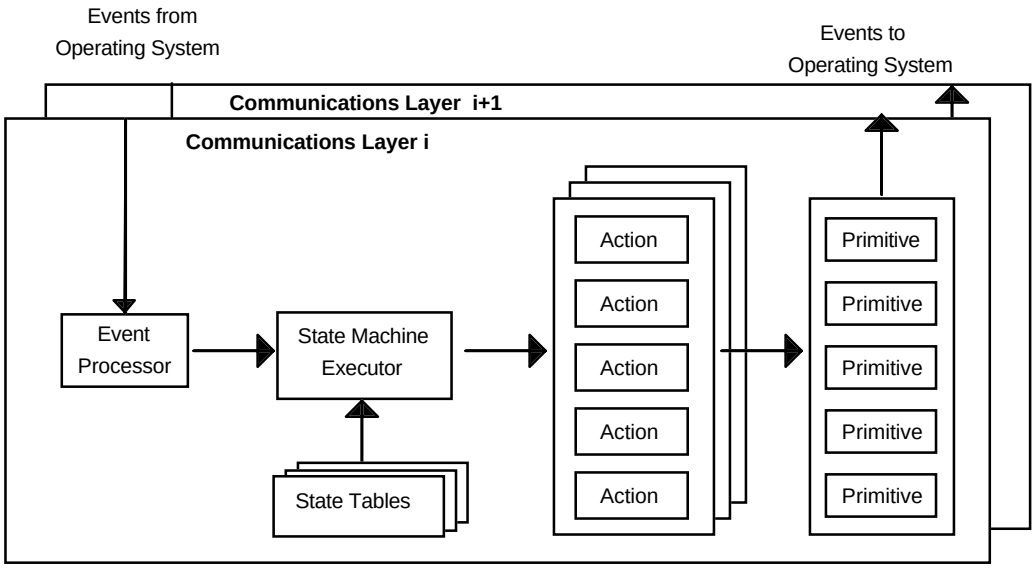


Figure 10. Layered Protocol CAPE Architecture Model

Client/Server systems are composed of a flat architecture of communicating event processors. This is shown in the figure below.

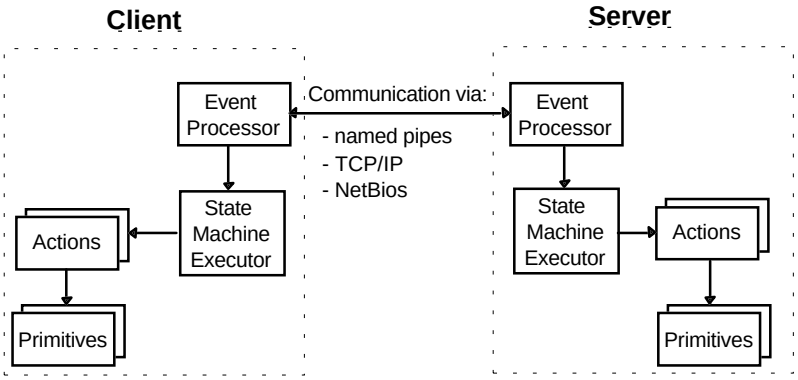


Figure 11. Client/Server CAPE Architecture Model

Realtime systems are also composed of a flat architecture of communicating event processors with a hardware abstraction key to the architecture. This is shown in the figure below.

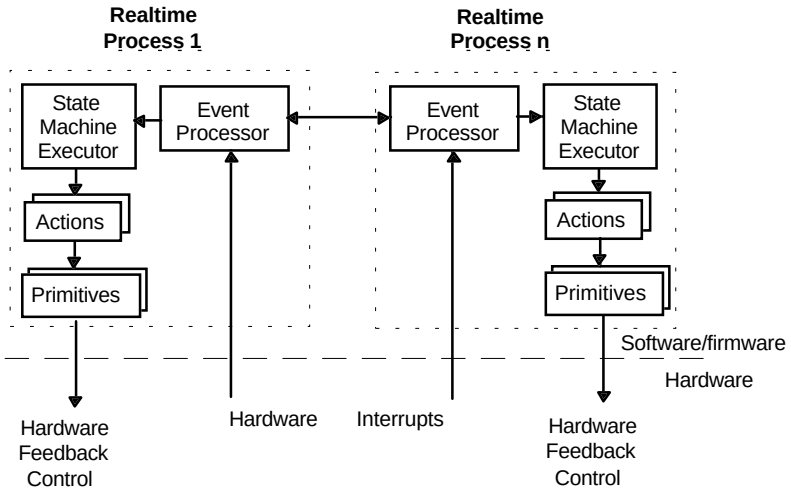


Figure 12. Realtime CAPE Architecture Model

The user supplied event processor interfaces to the operating system specific routines to receive events. These events are either completely handled by the event processor or they are translated into events that are handled by some of the state machines in the layer. These events are defined in the specific protocol state tables produced by the CAPEGen Compiler. The event processor invokes the state machine executor with the current state and event. The state machine executor triggers the execution of actions for the event in the state. The actions depend on supporting user supplied primitive routines that interface to the operating system and the hardware. When all the actions are triggered for the specific state/event pair the state machine executor optionally changes the current state and returns control to the event processor.

The event processor creates a structure called the Event Control Block (ECB) upon the receipt of each event that contains the context and other useful information. The ECB contains all information necessary to act on the current event. This information includes a pointer to the event, a pointer to the specific context of the event, the state machine name and other miscellaneous fields used for implementation optimization. A more concrete example of the event processor and state machine interaction is given in Chapter 5.

1.6. Communicating Your Results

The Bayfront CAPEDraw Viewer produces high and low level diagrams of your protocols so that they may be communicated to others. These graphic representations of your work are useful both

to the development team and as end-user documentation. The diagrams can be **automatically** produced from the same PDL definition used to generate the implementation so there is never a reason for a diagram to be out of date with the implementation. Three kinds of diagrams are available; state transition diagrams, state/event transition diagrams, and CCITT Specification and Description Language (SDL) diagrams.

1.6.1. State Transition Diagram

The state transition diagram shows the possible transitions between the states of the protocol. It is the highest level diagram of the protocol state machine. The state transition diagram displays the initial state at the top of the page with all the state interconnections below.

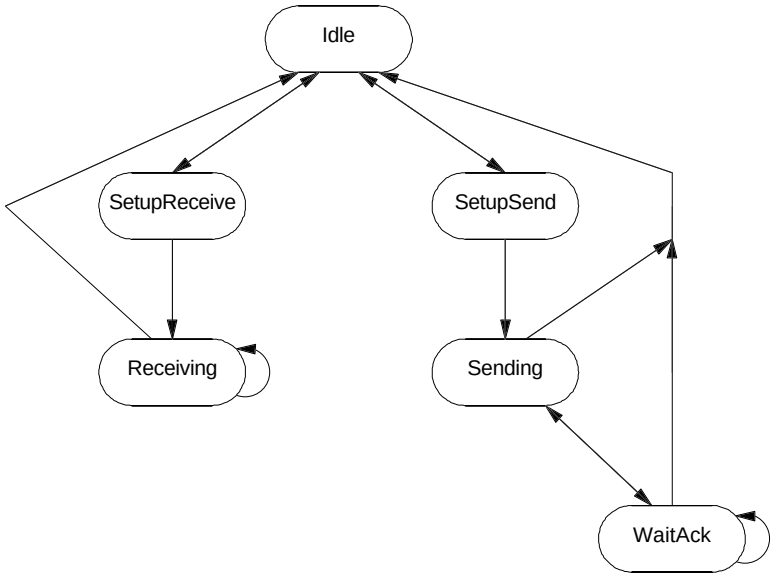


Figure 13. Data transfer protocol State Transition Diagram

The figure above shows the state transition diagram for the data transfer protocol (this protocol can be found in the examples directory). Some of the transitions have arrowheads on only one end indicating one way transitions. Transitions with arrowheads on both ends imply the protocol can bounce back and forth between the two states. Some states like `Receiving` and `WaitAck` have transitions to themselves. This indicates that some events are handled in that state without making a transition to another state.

1.6.2. State/Event Transition Diagram

The state/event transition diagram augments the same transitions shown in the state transition diagram with the events that cause the transitions. This shows how external events may move the protocol state machine through its states. The state/event transition diagram displays the initial state at the top of the page with all states and events below.

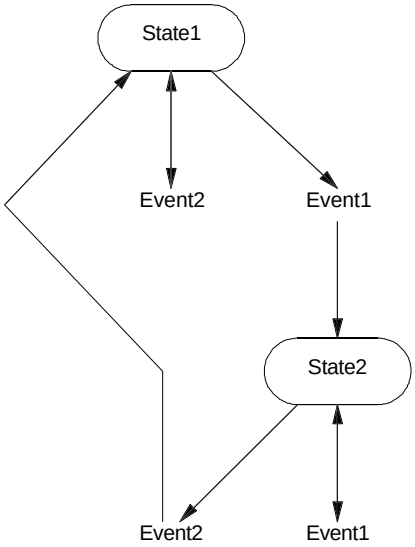


Figure 14. Example State/Event Transition Diagram

The state transition diagram above tells us that `Event1` from `State1` causes a transition to `State2`.

Note: The state displayed at the top of the diagram is the first state listed in the PDL (after the InitialState statement). This allows the user to customize the look of the diagram depending on the state/event connectivity. For example if the initial state is highly connected compared to other states the diagram will be less complex if the first state is not displayed at the top.

1.6.3. SDL Diagram

The SDL diagrams are the lowest level diagrams of the protocol state machine. There is one SDL diagram for each state in the protocol. The SDL diagram shows the events and actions that lead to the transition from one state to another or the same state. The SDL diagram shows the state name enclosed in a circle at the top of the page. The next row are events followed by actions and then new state transitions at the bottom.

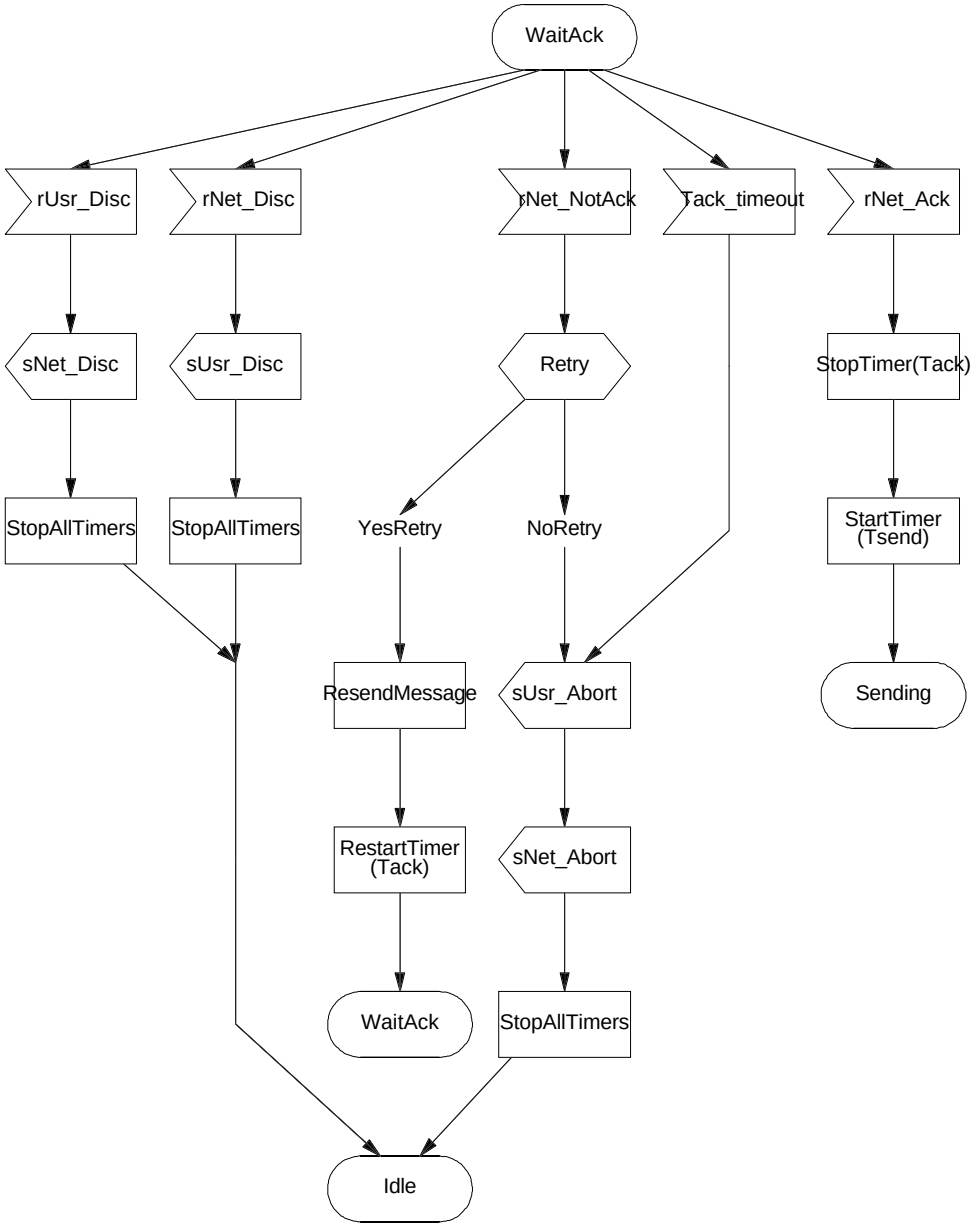


Figure 15. Example SDL Diagram

In the SDL diagram for the data transfer protocol state `WaitAck` shown above we can see that the event `rNet_NotAck` is handled in one of two ways. With a retry there is no state transition. Without retry there is a transition to the `Idle` state.

1.7. Organization of the manual

A summary of the chapters is described below.

Chapter 1 Introduces the features, architecture, and environment of the Bayfront CAPE Tools.

Chapter 2 Provides a quick start for users wishing to install and use the tools with minimum background reading. This includes installation, the creation of a Protocol Definition Language (PDL) file, CAPEGen Compiler invocation, CAPEDraw Viewer invocation, and the resulting output files.

Chapter 3 Describes the syntax and semantics of the Protocol Definition Language (PDL).

Chapter 4 Describes the C Code output files produced by the CAPEGen Compiler that are used to implement a protocol.

Chapter 5 Discusses the function, structure and use of the state machine executor.

Chapter 6 Provides a description of the action function prototype files produced by the CAPEGen Compiler.

Chapter 7 Discusses the structure of the protocol/state machine information file produced by the CAPEGen Compler for cross reference and documentation purposes.

Chapter 8 Discusses the use of the states/events names file produced by the CAPEGen Compiler for state/event simulation and debugging purposes.

Appendix A Documents the error messages generated by the CAPEGen Compiler and the CAPEDraw Viewer.

Appendix B Reproduces the Bayfront License Agreement from the diskette package.

The figure below illustrates the chapter contents in relation to the CAPE Tool output files.

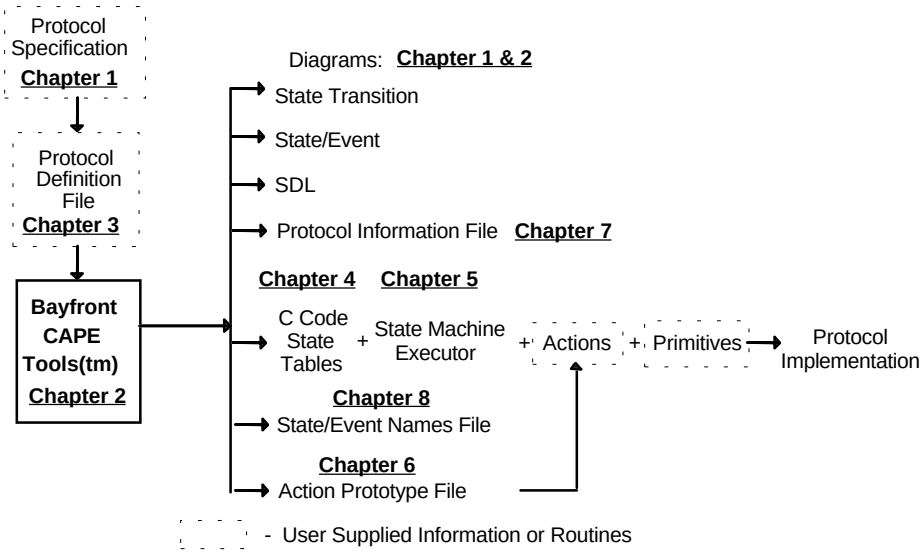


Figure 16. Bayfront CAPE Tools User Manual Contents

2. Quick Start

This chapter instructs you how to install and run the Bayfront CAPE Tools™.

2.1. Installation

Bayfront Technologies will ship either a 5 1/4" or 3 1/2" disk with the DOS, Windows or 386/486 Unix versions of the CAPE Tools and a 3 1/2" disk with the SUN Unix version of the CAPE Tools. If you have the wrong disk type please inform either your local distributor or Bayfront Technologies for immediate replacement.

2.1.1. Windows Installation

To install the Windows product, insert the disk into the appropriate drive and either from the File Manager select (double click) the file INSTALL.EXE **or** from the Program manager choose the `File|Run` menus and enter b:install (if the CAPE Tool disk is in the b drive). You will be prompted to select a directory to install the CAPE Tools or use the default directory `c:\bayfront`.

The `README` file should be read for any last minute information.

2.1.2. DOS Installation

To install the DOS product, insert the disk into the appropriate drive, create a directory `bayfront`, and copy the files to the newly created `bayfront` directory (e.g., `xcopy a: c:\bayfront\ /e/s` to copy the files from the `a:` drive to the `c:` drive). The final directory tree will look as follows:

BAYFRONT.DIR
- README
- CAPEGEN.EXE
- CAPEDRAW.EXE
- CAPE.H
- SM_EXEC.C
- ACTHDR.TXT
- ACTBODY.TXT
- ACTFILEH.TXT
- EXAMPLES.DIR

The `README` file should be read for any last minute information.

2.1.3. Unix Installation

To install the software on a Unix system, insert the disk in the appropriate drive, create a directory `bayfront`, and copy the files to the `bayfront` directory (e.g., `tar xvf device /bayfront/*`, where `device` is the local device name for your floppy drive). After installation the directory tree will look as follows:

bayfront
- readme
- cape.h
- sm_exec.c
- capegen
- acthdr.txt
- actbody.txt

```
actfileh.txt
examples
```

The readme file should be read for any last minute information. The Bayfront CAPEDraw Viewer is not available for Unix platforms. Unix CAPE Tool users wishing to generate state, state/event and SDL diagrams should use the CAPE Tools for DOS (included in the Unix CAPE Tool package) to layout and display the diagrams on a PC based platform. The DOS CAPE Tools can generate Postscript files of the diagrams which can be transported and viewed on Unix platforms with postscript viewers.

2.2. Creating the Protocol Definition Language Input File

The first step in using Bayfront CAPE Tools is to create a Protocol Definition Language (PDL) input file. PDL files describe a protocol/state machine in terms of states, events and actions. The protocols can be proprietary or created from standards based recommendations such as from the CCITT, ANSI, IEEE, and OSI organizations. An example PDL definition is shown below. The PDL language is described in detail in Chapter 3.

```
ex1 { InitialState = State1;

        state State1::
                Event1 -> Action1, Action2 >> State2;
                Event2 -> Action3;
        state State2::
                Event1 -> Action4;
                Event2 -> Action5, Action6 >> State1;
}
```

Figure 17. Example Protocol Definition Language File

The PDL file can be created using any text editor, the Windows CAPE Tools include an integrated editor. In the example above the PDL describes a protocol/state machine called `ex1` with two states, two events and six actions. The initial state is `State1`. The symbol `>>` indicates a transition to a new state. An example transition would be the occurrence of `Event1` while in `State1`, `Action1` and `Action2` would be executed and the new state would be `State2`. See the Bayfront CAPE Tools `examples` directory for more PDL file examples.

2.3. Using the Bayfront CAPE Tools for Windows

The Windows version of the CAPE Tools provides an easy to use interface. The top menus are shown below.

File Edit Compile View Options Window Help

Figure 18. Bayfront CAPE Tools Main Menus

All menu options will be deselected or 'grayed out' until they are active. For example if there is no PDL file selected then the `Edit` submenus will not apply and all options will be deselected. In addition to the menu structure above the CAPE Tools support a status line on the bottom line. The status line provides the user with menu specific information depending on the current location of the mouse.

2.3.1. File Submenus

The **`File` submenus** deal with PDL file opening and closing as well as both file and diagram saving and printing. The `File` submenu functions include:

File | New	Creates and opens a new PDL file for editing.
File | Open	Opens an existing PDL file for editing.
File | Save	Saves the current active PDL window in a file.

File | Save as	Saves the current active PDL window in a user selectable file.
File | Export	Exports a diagram file as an Adobe Postscript® (eps) file. The user will have the option and be prompted to rotate the diagram 90 degrees before file creation.
File | Print	Prints the current active window (PDL, text or diagram). If text is selected in an edit window then only the selected text may be printed. Text will be printed in the font selected in the `Options|Edit` menu. Diagrams will be printed using the font selected in the `Options|View` menu.
File | Printer setup	Configures the printer. Note: the printer settings have local significance only (i.e. within the CAPE Tools only).
File | Exit	Exits the CAPE Tools. If there are any unsaved modified PDL files open you will be prompted to save them upon exiting.

2.3.2. Edit Submenus

The **`Edit` submenus** deal with the editing of the PDL file. The edit capabilities work in a similar manner to the Windows predefined edit features. The `Edit` submenus functions include:

Edit | Cut	Removes the select text into the clipboard.
Edit | Copy	Copies the selected text into the clipboard (nondestructive cut). For a view (diagram) window this copies the diagram to the clipboard as a windows metafile for pasting into other applications (e.g. MS Word).
Edit | Paste	Copies the previously selected text from the clipboard to the current cursor position.
Edit | Delete	Clears the selected text.
Edit | Find	Finds the next occurrence of the user specified text. Find will pick up the search string from the selected text (can be manually overridden) if less than a line long.
Edit | Replace	Replaces the next occurrence of the user specified text with user specified text. Replace will pick up the search string from the selected text (can be manually overridden) if less than a line long.
Edit | Search Again F3	Repeats the previous Find or Replace operation from the current cursor.

While in an edit window the right mouse button brings up a popup menu for `Help|Topic Search` and the `Cut/Copy/Paste/Delete` editing functions.

2.3.3. Compile menu

The **`Compile` menu** reads the currently loaded and active PDL file and parses it. The output files specified in the `Options|Compile` dialog box will be generated upon successful parsing of the PDL file. Syntax errors detected during the parse will cause the compiler to halt and put the cursor at the point of error in the PDL window. The status line will indicate an error was found. Semantic errors such as state unreachable will cause the parser to halt at the end of the PDL file and open a dialog box with an error message.

When compiling the PDL file the current parse status which includes lines parsed and states currently parsed will be displayed in the status line at the bottom of the screen.

2.3.4. View Submenus

The **`View` submenus** display the **previously generated diagrams** for the PDL in the active window. The selections for the diagram types will be deselected (i.e., grayed) if there are not any previously generated diagrams by the compiler (see `Options` | `Compile` dialog box options). The `View` menu also allows the user to zoom in or out to optimize the viewing of selected diagrams. The `View` submenus include:

C Header file (.h)	View the C Code header file in a text edit window
C Code file (.c)	View the C Code table file in a text edit window
Action prototype file (.act)	View the action prototype file in a text edit window
Information file (.txt)	View the protocol information file in a text edit window
Names file (.str)	View the state/event names file in a text edit window
State transition diagram	View the state transition diagram in a diagram window. This window can be selected and printed by using the `File|Print` selection.
State event diagram	View the state/event transition diagram in a diagram window. This window can be selected and printed by using the `File|Print` selection.
SDL diagram	Opens a dialog box with a list of the SDL diagrams. The user can select which diagram to view in a diagram window. This window can be selected and printed by using the `File|Print` selection.
Zoom x25%	Zooms out of the currently active diagram window by 25%.
Zoom x50%	Zooms out of the currently active diagram window by 50%.
Zoom x75%	Zooms out of the currently active diagram window by 75%.
No Zoom	Views the currently active diagram window with no zoom.
Zoom x125%	Zooms into the currently active diagram window by 125%.
Zoom x150%	Zooms into the currently active diagram window by 150%.
Zoom x175%	Zooms into the currently active diagram window by 175%.

All diagrams are automatically laid out before viewing for the first time. The status line will show the layout progress. On slower CPU's (e.g., 386's) layout might take a few minutes for a complex diagram.

If the diagram file was generated after the PDL file was modified the CAPE Tools will open a dialog box cautioning that the diagram might be out of date. The user can then either ignore the warning and display the diagram or generate an updated diagram file. SDL diagrams can be displayed all at once (i.e., all states) or the user can specify which diagram to display.

All diagrams can be minimized for later viewing. The minimized icons display the diagram name and have different shapes for each type of diagram: state transition, state/event transition or SDL.

Diagram display can be zoomed in and out in increments. This allows maximum flexibility when viewing diagrams. All diagrams when selected will display the zoom factor in the status line at the bottom of the screen.

Diagrams can be copied to the Windows clipboard (see `Edit|Copy` above) and can be exported to an Encapsulated Postscript file (see `File|Export` above).

Warning: depending on both the size and complexity of the diagram and the speed of your CPU, diagram display might take a few minutes to complete.

2.3.5. Options Submenus

The **`Options` submenus** allow the user to select options for the `Edit, Compile` and `View` menus and allows the user to save, restore and backup the options configuration file (BCT.CTO). The options submenus include:

Edit	Sets tab spacing and font selection for edit window and edit printing.
Compile	Selects the output files generated from the parse of the input PDL.
View	Selects the diagram font characteristics.
Open	Opens a CAPE Tools configuration file.
Save BCT.CTO	Saves the current configuration settings in the default BCT.CTO configuration file.
Save as	Saves the current configuration settings in a user selectable file.

The **Compile options** specify the generation of the following files:

- C Code Files
- Action Prototype File
- Protocol Information File
- State/Event Names File
- State Transition Diagram file
- State/Event Transition Diagram file
- SDL Diagram File.

The **View options** dialog box allows the user to customize the diagram display. The View options include:

arc grouping	Similar reference lines in a diagram are grouped together to form one line. This simplifies the appearance of complex diagrams.
letters per line	Adjusts the number of letters in a line in a box. This allows the use of longer state, event or action names.
lines per label	Adjusts the number of lines of text in a box. This allows the use of longer state, event or action names (names are truncated if the total letters in a box are less than the name).
change font	Allows the user to specify the font type, font style, font size and provides a sample of the selections. This option affects the overall display size of the diagram.

Note: all View options will apply to diagrams viewed **after** the option modification. All currently active diagrams will retain the option settings when they were initially displayed.

2.3.6. Windows Submenus

The **`Windows` submenus** support the Windows Multiple Document Interface (MDI) features. The submenus allow the user to tile or cascade the current windows, arrange the icons or close all Windows. The minimize command minimizes all windows which is useful for examining the many SDL diagrams from a large protocol.

2.3.7. Help Submenus

The **`Help` submenus** support the Windows Help features. The Bayfront CAPE Tools™ User Manual is contained in a condensed format in the Help window. To activate help use the `Help|Index` option. For a tutorial on using help select the `Help|How to Use Help` menu option.

The Help window also implements context sensitive help while in a PDL editing window. To use this feature place the insertion cursor on a reserved word (e.g. state, event, action, etc.) in the PDL and call help by pressing the shift and F1 keys, select the `Help|Topic Search`, or press the right mouse button in an edit Window and select `Topic Search`. Context sensitive help gives the user a quick way to reference the PDL syntax.

2.4. Using the Bayfront CAPEGen Compiler (DOS/Unix)

Bayfront supports a command line version of the CAPEGen Compiler when operating under the DOS or Unix operating systems. The CAPEGen Compiler is invoked by typing `capegen` with the desired options. The Protocol Definition Language (PDL) input file is checked for correct syntax. If the PDL file parse is successful, output files are created describing the protocol or state machine. These output files are linked with the supplied state machine executor (`sm_exec`) file. An overview of the files supplied by the users and the files supplied/generated by Bayfront is given in Chapter 1. Other CAPEGen Compiler options generate input to the CAPEDraw Viewer (DOS only). The CAPEGen Compiler command line and the associated options are described below.

```
capegen <options> infile.pdl <options>
```

where `infile.pdl` is a user supplied input PDL file, suffix must be `.pdl` and `<options>` refers to optional command line switches, zero or more can be present. The name of output files is taken from the name of the state machine in the `.pdl` file. The acceptable option switches are shown below:

`-c` Generates both a header file (`.h`) and a state table code file (`.c`) that describes the protocol state machine in the C language. The content of these files is discussed in Chapter 4.

`-sdl` Generates a Specification and Description Language (SDL) file (`.sdl`) that is input to the CAPEDraw Viewer for layout and display. An SDL diagram shows the state to events to actions to new state transitions for a single state. The `.sdl` file contains all such diagrams for a protocol state machine. Example SDL diagrams are in the Bayfront CAPE Tools `examples` directory .

`-s` Generates a state transition file (`.s`) that is input to the CAPEDraw Viewer for layout and display. A state transition diagram displays a protocol state machine's states and the transitions between them. Example state transition diagrams are in the Bayfront CAPE Tools™ `examples` directory .

`-se` Generates a state/event transition file (`.se`) that is input to the CAPEDraw Viewer for layout and display. A state/event transition diagram displays the state to event to new state transitions for a protocol state machine. Example state/event diagrams are given in the Bayfront CAPE Tools™ `examples` directory .

`-a` Generates an action prototype file (`.act`) containing the templates of action routines that must be hand coded by the user. Chapter 6 discusses the contents and use of this file.

`-i` Generates a text file (`.txt`) containing information about the protocol state machine that is used for documentation. Chapter 7 discusses this file.

`-n` Generates a file (`.str`) containing C language state and event names used for simulation and debugging purposes. Chapter 8 gives the format of this file and Chapter 5 discusses its uses.

For example purposes the remainder of this manual will use the Q.931 protocol. Q.931 is a protocol from the CCITT that describes how data and voice calls are setup in an Integrated

Services Digital Network (ISDN). Q.931 is a complex protocol with many states, events, and actions. This makes it an excellent example to show the power of Bayfront CAPE Tools. The figure below illustrates the generation of all possible output files from this input `q931.pdl` file.

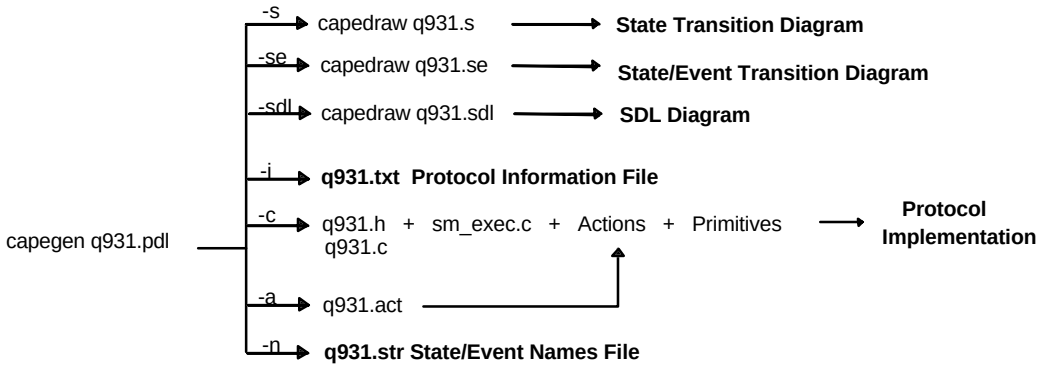


Figure 19. CAPEGen Compiler applied to the Q.931 Protocol

2.5. Using the Bayfront CAPEDraw Viewer (DOS)

Bayfront supports a command line version of the CAPEDraw Viewer when operating under the DOS operating system. The Bayfront CAPEDraw Viewer uses output files from the Bayfront CAPEGen Compiler to draw state transition, state/event and Specification and Description Language (SDL) diagrams. These graphics may be displayed on the screen, displayed on a printer, or sent to an Adobe PostScript® file for inclusion in protocol documentation by word processing programs.

Currently the CAPEDraw Viewer is available only under DOS and Microsoft Windows operating systems. Unix CAPE Tools packages include a DOS version. Unix users wishing to draw and view diagrams should transfer the PDL files to a PC and convert them to PostScript files. These can then be viewed using any PostScript Viewer under the Unix operating system.

A state transition, state/event transition or SDL diagram is drawn by a two or three step process.

1. Invoke the CAPEGen Compiler with the appropriate options (`-s`, `-se` and/or `-sdl`).
2. Layout the diagram(s) in the file by invoking the CAPEDraw Viewer with the `-l` option and the input file name. The resulting file (either `.s` -> `.sd`, `.se` -> `.sed`, or `.sdl` -> `.sdd`) contains page layout information for the diagrams. If the protocol is very complex this layout phase can take some time.
3. Draw the diagram(s) in the layout files by invoking the CAPEDraw Viewer with the `-d` option and the input file name. The diagrams are then drawn by invoking `draw` with the appropriate input file name and options. The diagrams may be displayed on the screen, sent directly to a printer, or sent to a PostScript graphics file. If an SDL layout file contains more than one diagram, then all of the diagrams are drawn unless the `-n` switch selecting a subset of diagrams is specified.

Note that steps two and three may be combined in one command line (e.g., `capedraw -l -d q931.sdl`). For files that take a long time to layout and will be displayed in more than one way (e.g., printer and screen) it is faster to lay out the diagrams in one step and draw them in another.

The figure below illustrates this process.

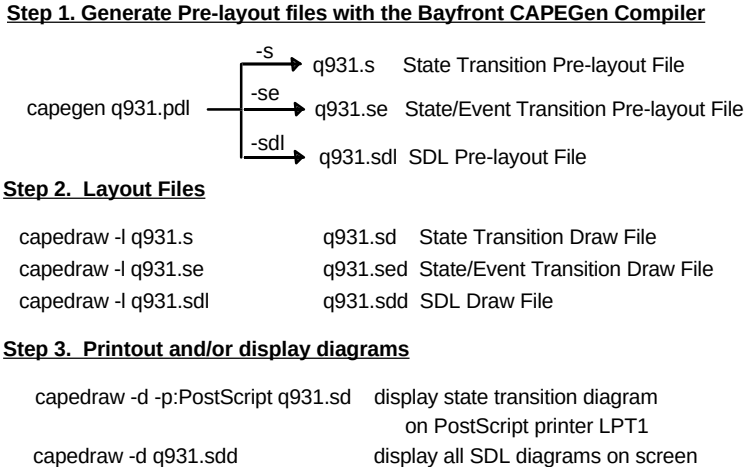


Figure 20. CAPEDraw Viewer Usage

When the CAPEDraw Viewer displays diagrams on the screen it waits for the user to strike a key between diagrams. Press the ESC key to escape out of the CAPEDraw Viewer. During the output of PostScript files the CAPEDraw Viewer draws the current diagram on the screen but does not wait for the user to strike a key between diagrams.

The CAPEDraw Viewer command line is given below.

```
capedraw <options> infile.ext <options>
```

The `infile.ext` is a diagram file from the CAPEGen Compiler or a layout file from the CAPEDraw Viewer. The CAPEDraw Viewer options are discussed below.

`-l` Layout all diagrams contained in the input file that was produced by the CAPEGen Compiler. Creates layout files as follows: state transition diagrams `.s` -> `.sd`, state/event diagrams `.se` -> `.sed`, and SDL diagrams `.sdl` -> `.sdd`.

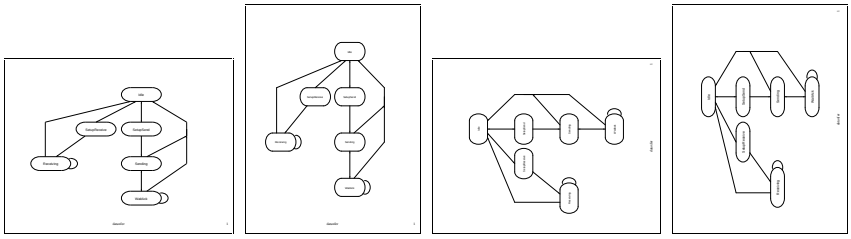
`-d` Draw the diagrams contained in the input file that was produced by the `-l` option of the CAPEDraw Viewer. If both `-l` and `-d` are specified, then layout is performed before drawing and the input file is expected to be a CAPEGen Compiler diagram file. Otherwise the input file is expected to be a CAPEDraw Viewer layout file.

`-n:pattern` Only valid if `-d` is specified. The pattern is matched against the state names of diagrams held in the layout file. Only diagrams that match the pattern are output. The pattern consists of literal case insensitive letters, `?` which matches any one character, and `*` which matches all remaining characters. Thus the pattern `U0?_*` would match `U00_Null` and `U01_CallInitiated` q931 states.

`-p:printer` Only valid if `-d` is specified. This switch requests graphics output to the printer selected. The supported graphic printer and paper size choices are shown in the figure below. Some selections produce Adobe PostScript® files and some send the graphics output to the printer assumed to be device `LPT1:` with landscape orientation. The Adobe PostScript® (`.PS`) and Encapsulated PostScript output files (`.EPS`) can be used by word processors to insert CAPE graphics into documents. The output graphics file is specified by giving a file name with no extension (e.g., `-p:eps:afile` will create the output file `afile.eps`).

`-lpt2`	Only valid if both `-d` and `-p` are specified. This directs the output to printer port `LPT2:`. The default printer port is `LPT1:`.
`-nogroup`	Only valid if `-l` is specified. By default similar reference lines in a diagram are grouped together to form one line. This simplifies the appearance of complex diagrams. This suppresses the grouping action.
`-nopagenum`	Only valid if `-d` is specified. By default the diagram page number is placed at the bottom right of the diagram. This suppresses the page number.
`-notitle`	Only valid if `-d` is specified. By default the diagram title is placed at the bottom center of the diagram. This suppresses the title.
`-portrait`	Only valid if both `-d` and `-p` are specified. This indicates that the diagram is to be oriented with the vertical axis parallel to the longest paper edge. The default is landscape where the vertical axis is parallel to the shortest paper edge.
`-rotate`	Only valid if `-d` and `-p` specifies a form of Adobe PostScript® output. The next section demonstrates the use of `-portrait` and `-rotate` for PostScript output.

Adobe PostScript® output is used to prepare documentation graphics and high resolution printer output. Most word processing programs support the insertion of Encapsulated PostScript (EPS) graphics with size scaling. Some word processors are unable to rotate the graphic upon insertion. This requires four orientations to be supported. The figure below shows the four orientations supported.



default -portrait -rotate -portrait -rotate

Figure 21. Adobe Postscript Output Page Formats

If you are sending your CAPE graphics directly to a PostScript printer that defaults to printing in the default "portrait" mode you will need to specify the `-portrait` and `-rotate` options.

-p:PostScript	PostScript Printer	1800x1800 dpi, 8.5"x11.0" paper
-p:PS:<filename>	PostScript File	1800x1800 dpi, 8.5"x11.0" paper
-p:EPS:<filename>	PostScript EPS File	1800x1800 dpi, 8.5"x11.0" paper
-p:Epson_FX80_Low	Epson FX80	60x 72 dpi, 8.5"x11.0" paper
-p:Epson_FX80_Medium	Epson FX80	120x 144 dpi, 8.5"x11.0" paper
-p:Epson_FX80_High	Epson FX80	240x 216 dpi, 8.5"x11.0" paper
-p:Epson_FX100_Low	Epson FX100	60x 72 dpi, 13.6"x11.0" paper
-p:Epson_FX100_Medium	Epson FX100	120x 144 dpi, 13.6"x11.0" paper
-p:Epson_FX100_High	Epson FX100	240x 216 dpi, 13.6"x11.0" paper
-p:Epson_LQ850_Low	Epson LQ850	180x 180 dpi, 8.5"x11.0" paper
-p:Epson_LQ850_High	Epson LQ850	360x 360 dpi, 8.5"x11.0" paper
-p:Epson_LQ950_Low	Epson LQ950	180x 180 dpi, 11.0"x11.0" paper
-p:Epson_LQ950_High	Epson LQ950	360x 360 dpi, 11.0"x11.0" paper
-p:Epson_LQ1050_Low	Epson LQ1050	180x 180 dpi, 13.6"x11.0" paper
-p:Epson_LQ1050_High	Epson LQ1050	360x 360 dpi, 13.6"x11.0" paper
-p:HPLJ_Letter_Low	HP Laser Jet II	100x 100 dpi, 8.5"x11.0" paper
-p:HPLJ_Letter_Medium	HP Laser Jet II	150x 150 dpi, 8.5"x11.0" paper
-p:HPLJ_Letter_High	HP Laser Jet II	300x 300 dpi, 8.5"x11.0" paper
-p:HPLJ_Legal_Low	HP Laser Jet II	100x 100 dpi, 8.5"x13.0" paper
-p:HPLJ_Legal_Medium	HP Laser Jet II	150x 150 dpi, 8.5"x13.0" paper
-p:HPLJ_Legal_High	HP Laser Jet II	300x 300 dpi, 8.5"x13.0" paper
-p:HPPJ_Low	HP Paint Jet	90x 90 dpi, 8.5"x11.0" paper
-p:HPPJ_High	HP Paint Jet	180x 180 dpi, 8.5"x11.0" paper

Figure 22. Graphic Printers and Formats Supported by the CAPEDraw Viewer

3. Protocol Definition Language (PDL)

3.1. Overview

The purpose of the Protocol Definition Language (PDL) is to define the essential structure of a protocol without becoming mired in the details of a particular programming language. Since the PDL definition is used to generate code, diagrams, analysis reports, and simulations we have attempted to remove elements specific to one of these areas from the language. When there are options related to these different processes, they are specified when the process is invoked.

3.2. PDL Elements

Most protocol layers are composed of one or more state machines. The state machines of the protocol layer may enable, disable, and interact with each other. They share the data and queue definitions for the layer. With this understanding the primary unit of definition in PDL is the state machine. The figure below presents a simple PDL definition.

```
[ example protocol state machine
    multiline comments in brackets ]

sm1  { InitialState = State1;

        state State1::
                Event1  -> Action1, Action2 >> State2;
                Event2  -> Action3;                     [ goes to State1])
                Event3 |
                Event4  -> Action2 >> State2;           [ Event3 or Event4 ]
                default -> Action7;                     [ any other events ]
        state State2::
                Event1-> Action4;
                Event2-> Action5, Action6 >> State1;
}
```

Figure 23. Example PDL Definition

In the above figure the reserved words and punctuation are shown in bold. The name of the protocol layer state machine `sm1` is given first followed by the definition of the initial state of the protocol.

3.2.1. Spacing, Comments and Syntax Diagrams

The fields of a PDL definition do not have to be aligned. It is a good idea to align the fields to make the definition easier to read. Whitespace which includes spaces, tabs, carriage returns, line feeds, and form feeds may be freely inserted anywhere a single space is accepted. Whitespace is accepted between all keywords, punctuation, identifiers, and numbers.

Comments are enclosed in square brackets (`[]`). They may contain multiple lines and be included anywhere spaces are accepted.

In the syntax diagrams given below the reserved words and punctuation are shown bolded in ovals. The invocation of another syntax diagram is shown by a rectangle labeled with the diagram name. Some single character syntax diagrams are not shown. `numeral` stands for any one numeral character `0` through `9`. `alphabetic` stands for any one upper or lower alphabetic character `A` through `Z` and `a` through `z`. `underscore` stands for the underscore character _. No whitespace is allowed between these single character syntax diagrams.

3.2.2. Identifiers

Identifiers used in PDL definitions are a maximum of 36 characters long.

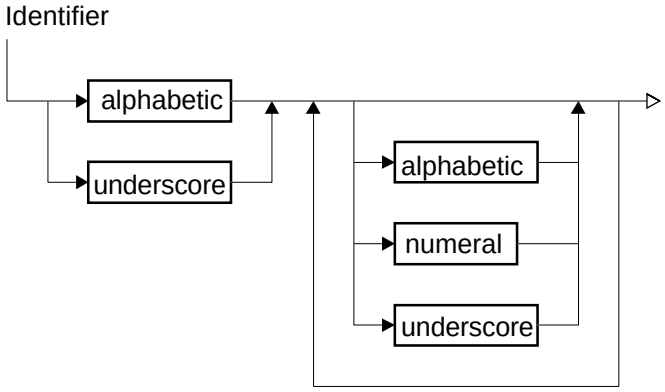


Figure 24. Identifier

The identifiers must not conflict with the reserved words of PDL. This check is *case insensitive* to allow for the generation of code in case insensitive languages. The reserved words include:

action	allocate	assign	break
deallocate	deassign	dec	event
inc	InitialState	macro	recv
resetflag	RestartTimer	send	setflag
setvalue	signal	StartTimer	StopAllTimers
Stop	Timer	State	timeout
TimerRunning			

Figure 25. PDL Reserved Words

3.2.3. Numbers

Numbers in PDL are unsigned integers with the usual syntax.

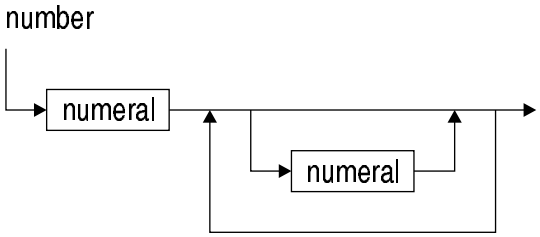


Figure 26. Numbers

These are used to pass constants to user supplied routines in actions.

3.3. PDL Structure

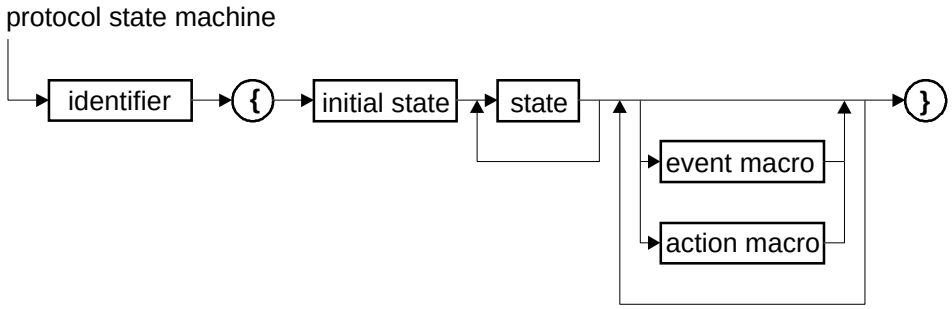


Figure 27. PDL Structure Syntax

The basic structure of a PDL definition identifies and defines the protocol state machine and context. The initial identifier provides the state machine name.

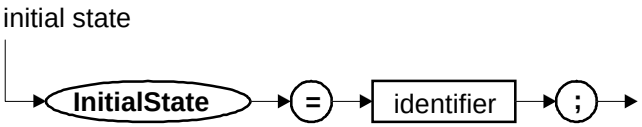


Figure 28. PDL Initial State Syntax

The initial state rule identifier provides the beginning state when the protocol state machine is enabled. The rest of the definition is a series of state definitions. The optional macro definitions at the end of the state definitions are a convenient shorthand for specifying repetitive parts of the protocol definition. Notice that the entire set of state and macro definitions must be enclosed in set braces `{}`.

3.4. States

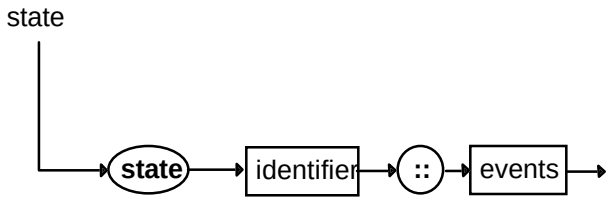


Figure 29. PDL State Syntax

A state definition starts with the reserved word `state` and an identifier that names the state. The set of events that follow specify the events that are handled by the state machine in this state. Each event specifies what triggers the particular event, what actions are to be taken, and what state transition (if any) to make after taking those actions. Within a state all of the event triggers must be mutually exclusive. This means that one outside stimulus can never trigger two state events. If an event is not handled in a state, then no actions are taken and no state transition takes place.

3.5. Events

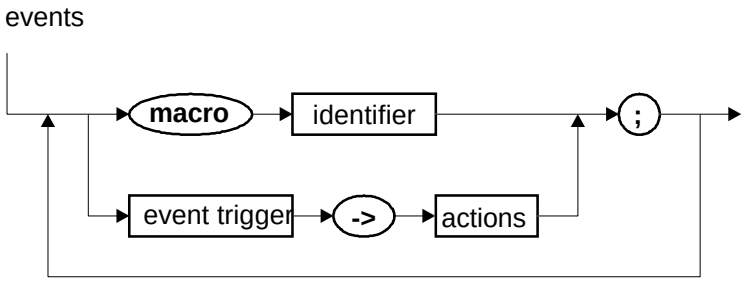


Figure 30. PDL Event Syntax

Each event specifies the set of triggers for a transition in the state machine. The actions to take upon this transition are also specified. Transition to a new state in the state machine may be specified as the final action in the `actions`. An event macro is just a convenient way to specify the same information under the given macro name. Event macros are specified after all state definitions.

The external events that moves the state machine along are specified as event triggers.

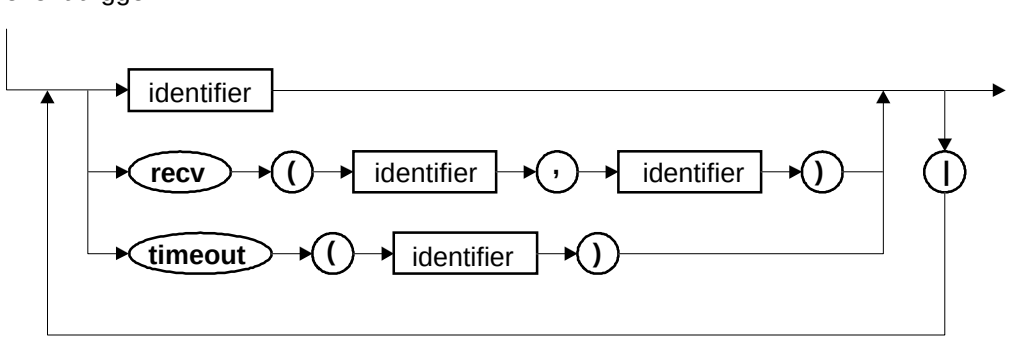


Figure 31. PDL Event Trigger Syntax

The basic event forms may be combined into a trigger using a logical or (`|`) to mean that any one of the given events triggers the actions to be taken.

identifier — This name is the name of an external user indicated event. This is the name of an external event that the user-written event processor will use to signal to the Bayfront-supplied state machine executor that the external event has occurred. This allows the user to completely define the external events and control the protocol state machine transitions.

`recv(`**message,queue**`)` — This event is indicated when a message of the given type is received on the given queue, stream, or mailbox. The indicating constant for this event is named as "`r`queue_message" on code generation. As an example the PDL event `recv(AbortMsg,Net)` would be indicated as the named constant `rNet_AbortMsg` to the state machine executor.

`timeout(`**timer**`)`	This event is indicated when the given timer expires. The event is renamed to "timer_`timeout`" on code generation. Thus the event `timeout(AckTimer)` would be indicated as the named constant `ActTimer_timeout`.
`recv(default,`**queue**`)`	This event is indicated when any message type except the ones specifically defined for this state via the `recv(message,queue)` event have been received on the given queue, stream, or mailbox. An event processor does not explicitly indicate this event with a named constants as it does for the above three event types. Instead the event processor implicitly indicates this event by indicating any explicit `recv` message event for the given queue that is not used in any trigger in this state.
`timeout(default)`	This event is indicated when any timer timeout is ending except those timeouts specifically defined in this state. An event processor does not explicitly indicate this event. Instead the event processor implicitly indicates this event by indicating any explicit `timeout` event that is not used in any trigger in this state.
`default`	This event is indicated when any external user indicated event is pending that is not explicitly part of any trigger in this state. This cannot serve as a default event for `timeout` and `recv` events. The above two event types serve that purpose. There does not have to be a default trigger. An event processor does not explicitly indicate this event. Instead the event processor implicitly indicates this event by indicating any explicit external user indicated event that is not used in any trigger in this state.

If in a given state an event is indicated that is not part of any trigger, then no actions are performed. An example would be a message `MsgType` arriving on a queue `MsgQueue`. If this case is not handled explicitly (e.g., `recv(MsgType,MsgQueue)`) or implicitly (e.g., `recv(default,MsgQueue)`), then no actions are performed and no state transition occurs.

3.6. Event Macros

Event macros are an efficient shorthand for specifying repetitive events that appear in many states. An example would be the "disconnect request received go to the idle state" kind of operation. The shorthand is invoked by the keyword `macro` and the name. The event macros are defined after all of the states have been specified.

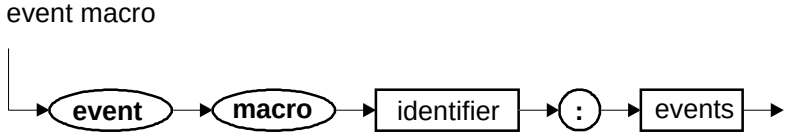


Figure 32. PDL Event Macro Syntax

The single macro identifier can expand to one or more event trigger to action sequences. Event macros cannot be nested. The meaning of the macro is as if the macro was expanded directly for its name. If an action causes a transition to the same state, then the state is the state where the macro usage occurred.

3.7. Actions

Actions modify the protocol execution environment as the state machine makes transitions from state to state.

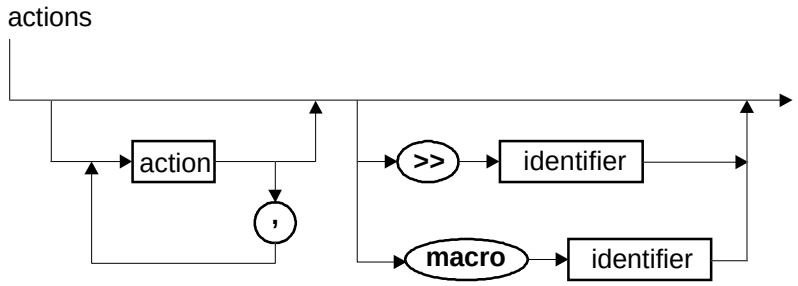


Figure 33. PDL Actions Syntax

Each event can trigger zero or more actions. More than one action is separated by commas. Optionally the last action in an action sequence can cause a transition to another state. The >> syntax with a state identifier requests the transition to that state. If no transition action is performed, then the state machine remains in the same state. As with event macros an entire set of actions for an event trigger including a state transition may be specified as an action macro. The action macro invocation may follow some actions particular to a state/event pair.

Most individual actions call user supplied routines. Some kinds of actions, like message sending, are identified by syntax to isolate concepts needed to analyze the protocol.

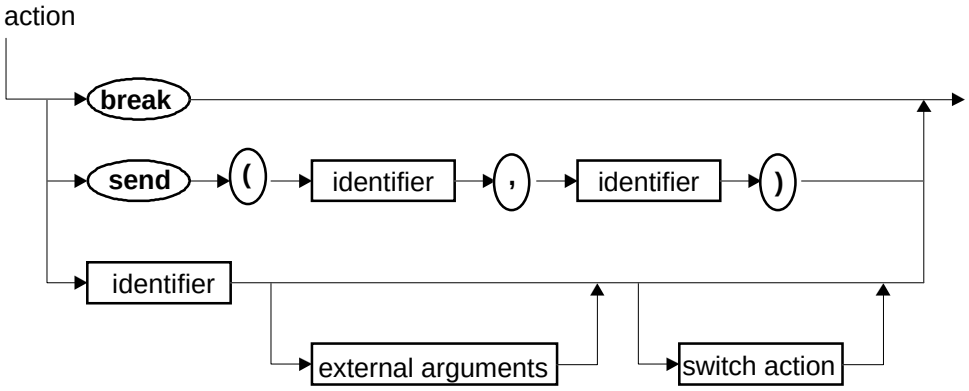


Figure 34. PDL Action Syntax

The `break` action is only legal in the context of a switch action.

3.7.1. Actions on Timers and Messages

The keywords `RestartTimer`, `send`, `StartTimer`, `StopAllTimers`, `StopTimer`, and `TimerRunning` identify certain actions and ultimately call user supplied routines.

`send(message,queue)` — This action generates a call to the user supplied routine called "`Squeue_message`". As an example the PDL action `send(Release,Net)` would call the user-supplied routine `sNet_Release` with context. This routine is responsible for assembling the message using context information and putting it on the given queue.

`StartTimer(timer)`	This action generates a call to the user supplied routine called `StartTimer` with a generated timer code as an argument. The routine starts the given timer.
`StopTimer(timer)`	This action generates a call to the user supplied routine called `StopTimer` with a generated timer code as an argument. The routine stops the given timer.
`RestartTimer(timer)`	This action generates a call to the user supplied routine called `RestartTimer` with a generated timer code as an argument. The routine restarts the given timer.
`StopAllTimers`	Generates a call to the user-supplied routine `StopAllTimers` that stops all timers defined for the state machine.
`TimerRunning(timer)`	Calls the user supplied routine `TimerRunning` with a generated timer code. The routine returns one of the defined values `YesRunning` or `NoRunning` whether or not the timer is running. This action is used in switch actions to be discussed later.

3.7.2. Action Calls to User Routines

The `identifier` acceptable as an action refers to a user-supplied action routine with the same name. These routines may be passed arguments as shown below.

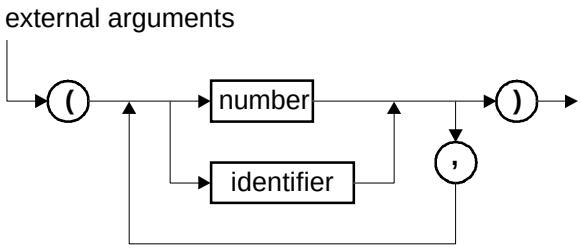


Figure 35. PDL External Routine Argument Syntax

The external argument `number` refers to an unsigned 16 bit integer. The external argument `identifier` refers to user supplied variables in the protocol execution environment that may be manipulated by user supplied action routines.

3.7.3. Switch Actions

Many times the protocol state machine is controlled by environmental conditions not available in the state machine context. To test these conditions we use a switch action. In the `action` syntax diagram a switch action is preceded by an `identifier` giving the name of an user supplied external routine and optionally `external arguments`. In a switch action a value returned by the user routine is tested. The call to the user routine is followed by the switch/case syntax below.

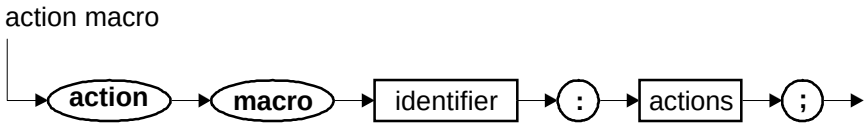


Figure 36. PDL Switch Action Syntax

There are a series of `identifier` and `action` pairs. The identifier stands for a discrete value constant that is returned by the user routine. The actual value is defined by the code generator. The actions associated with the given return value are called by the state machine executor.

A switch action appears in a PDL definition as follows:

```
check_msg {
        msg_ok -> ... ;
        msg_too_small -> ... ;
        msg_too_large -> ... ;
        msg_format_error -> ... ; }
```

In this example `check_msg` is a user-supplied action routine that returns the switch return names `msg_`. The restrictions on switch return names include:

1. Return names must be unique to the specific switch statement. For example if the switch statement `check_msg` returns the value `msg_ok`, then no other switch statement except `check_msg` can use the name `msg_ok`.

2. Switch functions must return the same number of switch return values each place the function is called. For example if the switch statement check_msg returns four switch return values, `msg_ok`, `msg_too_large`, `msg_too_small`, and `msg_format_error`, then all instances of `check_msg` must return these four switch return values.

Notice that this syntax is recursive on the `actions` rule. The `break` keyword syntax may only be used inside the context of a switch action. It causes execution to continue with the action after the enclosing switch action.

3.8. Action Macros

Action macros are an efficient shorthand for specifying a complete list of actions and state transitions. An action macro invocation may be used anywhere `actions` are expected. This includes after `event triggers` in `events` and inside of an `switch action`. As with event macros, action macros are treated as if they were expanded where they are invoked. They are very efficient in execution with minimum calling overhead.

Action macros are defined with event macros after all states have been defined. Their definitions have the following syntax.

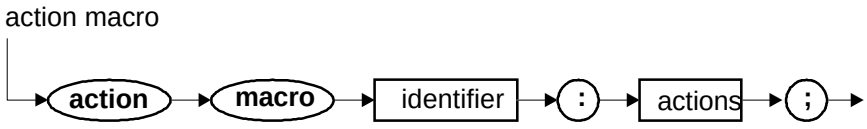


Figure 37. PDL Action Macro Syntax

Action macro definitions may not be nested.

3.9. Error Recovery and Reporting

If a syntax error occurs during the parsing of a PDL program, a syntax error will be reported and the parser will attempt to recover and report more errors (DOS/Unix) or the parsing will halt and the cursor will be positioned at the error in the PDL edit window (Windows). Semantic errors are analyzed after the syntax has been parsed. Any kind of error will inhibit the creation of output files. The errors reported by the CAPEGen Compiler are given in Appendix A.

3.10. PDL Example

The PDL definition illustrated below uses many linguistic constructs available in a PDL definition.

```
[The following example illustrates many of the syntax features of the pdl. ]

ex_ch3 { InitialState = S1;

state S1::
   E1 -> sw1 { [switch action]
            rtn1 -> A1, break;          [after A1 execute A6 below]
            rtn2 -> A2, A3 >> S2;
            rtn3 -> A4, macro MA5;      [execute A4, goto action macro MA5]
            rtn4 -> ;                   [no actions triggered, return]
           }, A6 >> S2;                 [action after sw1 switch action]

   E2 -> sw2(p1,10) {                   [switch action with passed parameters]
              rtn5 -> break;            [exit sw2 and execute A7 below]
              rtn6 -> A7 >> S1;
             }, A7 >> S2;
   E3 -> ;                              [no actions are triggered]

state S2::
   macro ME12;                          [go to macro ME12 below]
   E3 -> A11, A12(p1, p2), A13, A14 >> S1;

[note: only action macros can be called within an event macro]
event macro ME12:
   E1 |                                 [trigger on event E1 or E2]
   E2 -> A8, macro MA5;                 [execute A8, goto action macro MA5]

[note: no other macros can be called within an action macro]
action macro MA5:
   A9, A10;                             [execute actions A9 & A10, no state change]
}
```

Figure 38. PDL Syntax Example

Notice that the example above uses an action macro inside of an event macro.

3.11. PDL Restrictions

A summary of the language restrictions is given below.

1. Event macro definitions may not be nested.
2. Action macro definitions may not be nested.
3. The `break` action is only legal inside the context of a switch action.
4. All switch actions based on the same user supplied function must handle the same result cases.
5. There can only be one `default` event for a state. Although a state definition may contain one each of `default`, `recv(default,` queue`)`, and `timeout(default)`.
6. There can be only one `recv(default,` queue`)` event in a state for each queue used in the state machine.
7. There can be only one `timeout(default)` event for a state.
8. An event not included in any trigger in a state performs no operation when indicated by the event processor in that state.

4. C Code Files

4.1. Overview

The CAPEGen Compiler generates two files when the `capegen -c` option (DOS/Unix) or the `Options|Compile|C Code Generation File` menu options (Windows) are selected. These files include the state machine header file (`.h`) and the protocol state machine table file (`.c`). These files are generated from the input PDL file and are compilable by an ANSI C compiler. The figure below illustrates the *process* of constructing a protocol implementation.

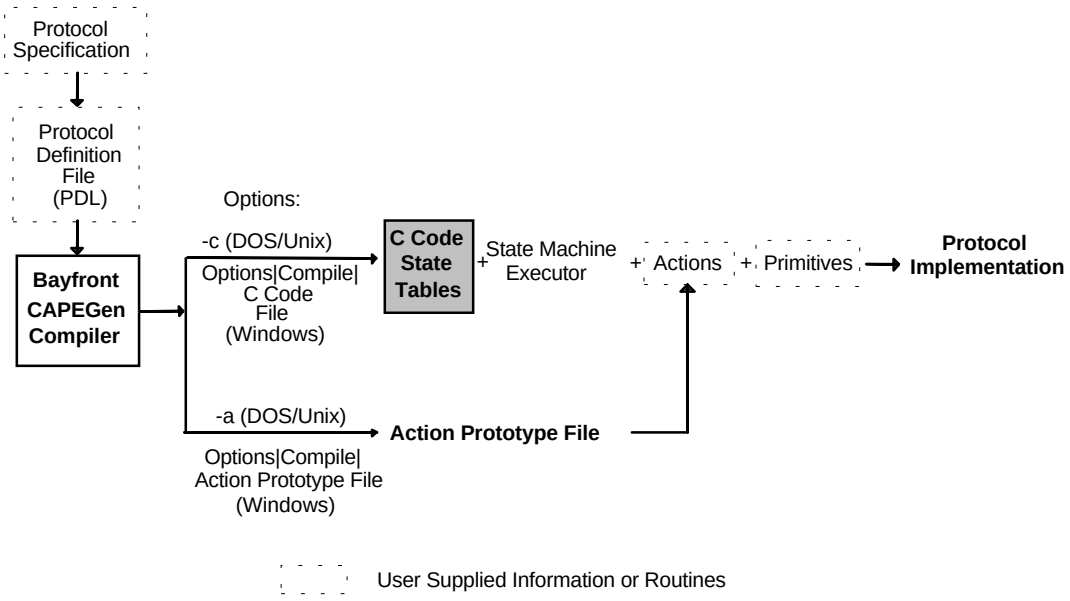


Figure . C Code Table File Generation

The state tables are used to drive the Bayfront-supplied state machine executor (`sm_exec.c`). When the state machine table file is linked with the Bayfront-supplied state machine executor (`sm_exec.c`), the user-supplied actions, the user-supplied event handler and the user-supplied operating system primitives, a protocol implementation results.

The figure below describes the *architecture* of the resulting protocol implementation.

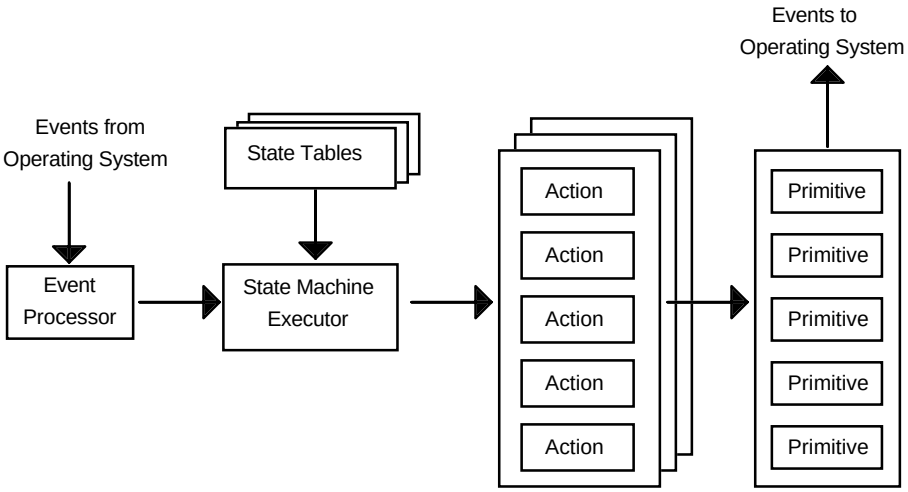


Figure 40. Protocol Layer Architectural Model

This architecture is discussed in detail in Chapter 1. Briefly a user-written event processor stimulates the state machine executor with external events (e.g., received messages, timeouts, interrupts, etc.). The state machine executor is supplied by Bayfront Technologies in source form and is discussed in Chapter 5. The state machine executor implements a protocol state machine by interpreting state tables output by the CAPEGen Compiler. There is at least one set of state tables for each protocol state machine in each communications layer, realtime process or client/server module. Also for each state machine there is a set of user-written actions. These actions affect the operating environment through user-written primitives.

For explanation purposes we will be using the protocol definition file `q931.pdl` which is included in the `examples` directory of the Bayfront CAPE Tool product disk. The name of this PDL state machine is `q931`. Invoking `capegen` with the `-a` option (DOS/Unix) or the `Options|Compile|Action Prototype File` menu options (Windows) on `q931.pdl` results in the generation of the action prototype file (`q931.act`) which is discussed in Chapter 6. Invoking `capegen` with the `-c` option (DOS/Unix) or the `Compiler/Options/Code Generation File` on `q931.pdl` results in two files: the protocol/state machine header file (`q931.h`) and the protocol/state machine table file (`q931.c`). The contents of these files will be discussed in the remaining sections of this chapter. All of these files are shown in their entirety in the CAPE Tools `examples` directory.

This chapter presents an interpretive approach to protocol implementation that minimizes space instead of execution time. It is Bayfront Technologies experience that the most important part of systems design and implementation is to get the protocol to work and then optimize. Optimization should only be directed toward the 10% of the code that is executed 90% of the time. In the architecture presented in Chapter 1 this "inner loop" will be located in the user-supplied event processor, actions, or primitives. Optimize the primitives first the actions second and the event processor third. Optimizing the entire design leads to individual designer "craftsman" efforts that are inflexible and hard to maintain by anyone except the original author.

4.2. Protocol/State Machine Header File Contents

The header file produced for a protocol state machine (`.h`) contains the following definitions:

1. protocol state definitions
2. protocol event definitions
3. timers (if defined in the PDL file)
4. switch action return values
5. external action function declarations

Each of these header file definitions are discussed in the sections below.

4.2.1. State Definitions

Constants for all the states contained in the PDL file are defined alphabetically in the state machine header file.

```
/* ---- States ---- */
#define U00_Null 0
#define U01_CallInitiated 1
#define U02_OverlapSending 2
#define U03_OutgoingCallProc 3
#define U04_CallDelivered 4
#define U06_CallPresent 5
#define U07_CallReceived 6
#define U08_ConReq 7
#define U09_IncomingCallProc 8
#define U10_Active 9
#define U11_DiscReq 10
#define U12_DiscInd 11
#define U15_SuspendReq 12
#define U17_ResumeReq 13
#define U19_ReleaseReq 14
#define U25_OverlapReceiving 15

#define q931_MaxStates 16
#define q931_InitialState U00_Null
```

Figure 41. State Definitions from q931.h

Users should include this file when coding their user-supplied event processor, actions, and primitives. User-supplied codes should only refer to the states by name since a change to the PDL definition could change the underlying values.

The maximum number of states is defined as `q931_MaxStates`. The state machine structure uses the maximum states definition to check for out of bounds states during the execution of the protocol/state machine (see file `sm_exec.c`).

The initial state name is defined as `q931_InitialState`. The initial state name is used to initialize the state machine. The current state is kept in the context block which is discussed in Chapter 5.

4.2.2. Event Definitions

All events contained in the PDL file are listed alphabetically in the state machine header file. The user-supplied event processor, actions, and primitives should include the header file and refer to the events by name.

It is the function of the user-supplied event processor (see architecture in Chapter 1) to translate an incoming operating system event into one of the event definitions in the header file before calling the state machine executor (`sm_exec`). As discussed in Chapter 3 some events are renamed from their PDL definitions (e.g., `recv(Alerting,net)` becomes `rnet_Alerting`). The events for q931 are shown below.

```
/* ---- Events ---- */
#define T302_timeout 0
#define T303_timeout 1
#define T304_timeout 2
#define T305_timeout 3
#define T308_timeout 4
#define T309_timeout 5
```

```
#define T310_timeout 6
#define T313_timeout 7
#define T318_timeout 8
#define T319_timeout 9
#define rnet_Alerting 10
#define rnet_CallProc 11
#define rnet_ConAck 12
#define rnet_Connect 13
#define rnet_DL_Est_Conf 14
#define rnet_DL_Est_Ind 15
#define rnet_DL_Rel_Ind 16
#define rnet_Disc 17
#define rnet_Info 18
#define rnet_Notify 19
#define rnet_Progress 20
#define rnet_Release 21
#define rnet_ReleaseComp 22
#define rnet_ResumeAck 23
#define rnet_ResumeRej 24
#define rnet_SetUp 25
#define rnet_SetUpAck 26
#define rnet_Status 27
#define rnet_StatusEnquiry 28
#define rnet_SuspendAck 29
#define rnet_SuspendRej 30
#define rnet_UnrecognizedMsg 31
#define ruser_AlertingReq 32
#define ruser_DiscReq 33
#define ruser_InfoReq 34
#define ruser_MoreInfoReq 35
#define ruser_NotifyReq 36
#define ruser_ProcReq 37
#define ruser_ProgressReq 38
#define ruser_RejReq 39
#define ruser_ReleaseReq 40
#define ruser_RestartReq 41
#define ruser_Resume 42
#define ruser_SetUp 43
#define ruser_SetUpRsp 44
#define ruser_SuspendReqcallid 45

#define q931_MaxEvents 46
```

Figure 42. Event Definitions from q931.h

The figure above illustrates that the q931 events all come from only three sources: timeouts, messages from the `net` queue, and messages from the `user` queue. There are no user defined custom events.

4.2.3. Timer Defines

Timer definitions are created from the appearance of the special actions `StartTimer`, `StopTimer` and `StopAllTimers`. As with state and event definitions, user routines that deal with timers should include the header file and only refer to timers by their defined names. The user-supplied action routines such `StartTimer` and `StopTimer` take the timer as a passed parameter.

```
/* ---- Timer Defines ---- */
#define T302 0
#define T303 1
```

```
#define T304 2
#define T305 3
#define T308 4
#define T309 5
#define T310 6
#define T313 7
#define T318 8
#define T319 9
```

Figure 43. Timer Definitions from q931.h

4.2.4. Switch Action Return Values

Switch action return defines are the values returned from the PDL switch actions. The state machine executor (`sm_exec.c`) performs a runtime bounds check on the return value every time the switch action is called. Out of bounds return values will cause the `sm_exec` to immediately return to the caller with a value indicating an out of bounds condition (see state machine executor discussion in Chapter 5). In the `q931.h` example the switch action `ActOption` returns only two values, `YesAck` with a value of 0 and `NoAck` with a value of 1. Users should code the `ActOption` action function by including the header file and using the `YesAck` and `NoAck` definitions to return one of these two values.

```
/* ---- Switch Labels ---- */

/* 'AckOption' return values */
#define YesAck 0
#define NoAck 1

/* 'AnyTimersRunning' return values */
#define NoTimersRunning 0
#define YesTimersRunning 1

/* 'CSZeroNonZero' return values */
#define CSZero 0
#define CSNonZero 1

/* 'CauseOption' return values */
#define C1 0
#define C2 1

/* 'CheckSetUpMsg' return values */
#define SetUpOk 0
#define SetUpManElementMissing 1
#define SetUpManElementError 2

/* 'CheckStatusCsField' return values */
#define CsZero 0
#define CsNotZero 1

/* 'CompatibleStateCheck' return values */
#define YesCompatible 0
#define NoCompatible 1

/* 'DLOption' return values */
#define DLStatusOpt 0
#define DLStatusEnqOpt 1
#define DLDefaultOpt 2

/* 'DLRelOption' return values */
#define NullOption 0
#define NoNullOption 1

/* 'FirstTimeOut' return values */
```

```
#define YesFirst 0
#define NoFirst 1

/* 'ProgressType' return values */
#define InterNetworking 0
#define Tone 1

/* 'RejectOption' return values */
#define YesReject 0
#define NoReject 1

/* 'RelOption' return values */
#define RelOpt 0
#define RelCompOpt 1

/* 'StatusEnqOption' return values */
#define YesEnqOption 0
#define NoEnqOption 1

/* 'TimerRunning' return values */
#define YesRunning 0
#define NoRunning 1

/* number of unique switch labels = 32 */
```

Figure 44. Switch Function Return Values from q931.h

4.2.5. External Action Function Declarations

The external action declarations refer to the user-supplied protocol or state machine actions. All actions except switch actions should return a value of one to indicate successful completion. Actions that return a value other than one cause the state machine executor to quit triggering the actions and return to the event processor. See Chapter 5 for more details. All actions are passed an Event Control Block pointer whose type is user defined, e.g., void. For more information on the possible structure of this type see Chapter 5.

```
/* ---- Action Subroutine Declarations ---- */
   extern int AckOption();
   extern int AnyTimersRunning();
   extern int BChanMaintenance();
   extern int CSZeroNonZero();
   extern int CallRefSelection();
   extern int CauseOption();
   extern int CheckSetUpMsg();
   extern int CheckStatusCsField();
   extern int CompatibleStateCheck();
   extern int DLOption();
   ...
   extern int suser_StatusInd();
   extern int suser_SuspendConf();
   extern int suser_TimeoutInd();
```

Figure 45. Portion of External Action Prototypes from q931.h

4.3. Protocol/State Machine Table File Contents

The state machine table file (`.c`) contains structures and tables used by the state machine executor (`sm_exec.c`, see Chapter 5). We will continue using `q931.pdl` as an example. The information in the following sections comes from `q931.c` which can be found in the Bayfront CAPE Tool™ product disk under the `examples` directory.

The user does not have to know about the inner workings of this file or the interaction between this file and the state machine executor to implement protocols or state machines. The information in this section is included for users who wish to know how the protocol state machine is implemented.

4.3.1. Include files

The state machine table file, `q931.c` includes both the Bayfront CAPE Tools header file, `cape.h`, and the state machine header file `q931.h` (see previous section). The `cape.h` file (see Figure below) contains structure prototypes used to define the state machine such as `SWTBL` (switch table), `AAEntry` (action table entry), and `SM` (state machine structure). The PDL header file contains necessary defines such as the number of states and events in the protocol definition.

4.3.2. Action Parameter Definitions

The action parameter definition section of the `q931.c` file contains all non-numeric action parameters except the user defined Event Control Block pointer `pECB` parameter.

```
/* ---- action parameter definitions ---- */
int error;    /* ?type? from action: 'suser_SetUpCompInd' */
int ok;       /* ?type? from action: 'suser_SetUpCompInd' */
```

Figure 46. Action Parameter Definitions

The parameter types are defaulted as integers and will contain the `/*?type?*/` comment as a reminder these types were defaulted to integers and can be changed. Also contained in the comment will be the last action that uses this parameter. The user may change these parameters as necessary. **Use caution. Modifications of `q931.c` will be lost if the CAPEGen Compiler code generation option `-c` is used to regenerate this file**.

4.3.3. Switch Return Value Table and the Switch Table

The switch table is an array of tuples each containing an index into the switch return value table and the number of switch return values defined for this switch statement. Both tables as generated from the q931.pdl are shown below.

```
/* Indices into the q931_SwLblVect array, # of return values */
static SWTBL q931_SwTbl[] = {
   {0, 2},
   {2, 2},
   {4, 2},
   {6, 2},
   {8, 2},
   {10, 2},
   {12, 2},
   {14, 2},
   {16, 2},
   {18, 3},
   {21, 3},
   {24, 2},
   {26, 2},
   {28, 3},
   {31, 2},
   {33, 2},
   {35, 2},
   {37, 2},
   {39, 2},
   {41, 2},
   {43, 2},
```

```
    {45, 2},
    {47, 2},
    {49, 2},
};
```

Figure 47. Switch Table from q931.c

```
/* Switch Return Value Table (indices into the Action Vector Table) */
static int q931_SwLblVect[] = {
   106,   107,         /* 'AckOption' */
    96,    97,         /* 'AckOption' */
    73,    74,         /* 'AckOption' */
    55,    56,         /* 'AckOption' */
   247,   248,         /* 'AnyTimersRunning' */
   250,   252,         /* 'CSZeroNonZero' */
   190,   191,         /* 'CSZeroNonZero' */
   272,   273,         /* 'CauseOption' */
   234,   235,         /* 'CauseOption' */
     9,    12,    13,  /* 'CheckSetUpMsg' */
     5,     6,     7,  /* 'CheckSetUpMsg' */
    15,    16,         /* 'CheckStatusCsField' */
   253,   254,         /* 'CompatibleStateCheck' */
   240,   241,   242, /* 'DLOption' */
   244,   246,         /* 'DLRelOption' */
   184,   186,         /* 'FirstTimeOut' */
    46,    48,         /* 'FirstTimeOut' */
    67,    69,         /* 'ProgressType' */
   114,   115,          /* 'RejectOption' */
    24,    26,         /* 'RelOption' */
    17,    19,         /* 'RelOption' */
   270,   271,         /* 'StatusEnqOption' */
   232,   233,         /* 'StatusEnqOption' */
    59,    60,         /* 'TimerRunning' */
};
```

Figure 48. Switch Return Value Table from q931.c

For example the first entry `{0, 2}` in the switch table indicates that in the zero position of the switch return value table the `AckOption` switch returns two values. Referring to the switch return value table if `AckOption` returns `YesAck` (value 0) the tuple in the action array starting at 106 will be executed and if `AckOption` returns `NoAck` (value 1) the tuple in the action array starting at 107 will be executed.

4.3.4. Action Routines that Pass Parameters

All actions that pass parameters other than the Event Control Block pointer `pECB` are indirectly called due to ANSI C language limitations. Indirectly calling the actions allow the passed parameters to be included in the action call. The user-supplied timer operations are an example of an action routine that takes a parameter because they must be passed the timer and `pECB`. All parameters other than the `pECB` are defaulted as integers.

```
/* ---- Action routines which pass arguments ---- */

int FirstTimeOutT308(pECB)
void *pECB;
{ return(FirstTimeOut(T308,pECB)); }

int RestartTimerT304(pECB)
void *pECB;
{ return(RestartTimer(T304,pECB)); }

int StartTimerT309(pECB)
```

```
void *pECB;
{ return(StartTimer(T309,pECB)); }

int snet_Release0(pECB)
void *pECB;
{ return(snet_Release(0,pECB)); }

int snet_ReleaseComp100(pECB)
void *pECB;
{ return(snet_ReleaseComp(100,pECB)); }

int suser_SetUpCompIndok(pECB)
void *pECB;
{ return(suser_SetUpCompInd(ok,pECB)); }
```

Figure 49. Portion of Action Routines that Pass Parameters from q931.c

4.3.5. State/Event To Action Array Jump Table

This composite structure is a two dimensional array which is indexed by the State and Event. The entries of the state/event table contains numbers which are indices into the action array table. Given the state and the event these tables provide the index for the next action list to perform in the action array table.

```
static int *q931_StateEvent[] = {
        q931_U00_Null,
        q931_U01_CallInitiated,
        q931_U02_OverlapSending,
        q931_U03_OutgoingCallProc,
        q931_U04_CallDelivered,
        q931_U06_CallPresent,
        q931_U07_CallReceived,
        q931_U08_ConReq,
        q931_U09_IncomingCallProc,
        q931_U10_Active,
        q931_U11_DiscReq,
        q931_U12_DiscInd,
        q931_U15_SuspendReq,
        q931_U17_ResumeReq,
        q931_U19_ReleaseReq,
        q931_U25_OverlapReceiving
};
```

Figure 50. State/Event Table from q931.c

```
/* ---- q931 Action Vector Jump Table [MaxStates][MaxEvents] ---- */
static int q931_U00_Null[] = {
    23, 23, 23, 23, 23, 31, 23, 23, 23, 23, 23, 23, 23, 30,
    23, 29, 23, 23, 23, 23, 20, 22, 23, 23, 4, 23, 14, 27, 23,
    23, 23, 23, 23, 23, 23, 23, 23, 23, 23, 28, 1, 8, 23,
    23
};
static int q931_U01_CallInitiated[] = {
    212, 45, 212, 212, 212, 226, 212, 212, 212, 212, 50, 42, 212, 52, 225,
    227, 224, 212, 212, 212, 212, 212, 39, 212, 212, 214, 36, 217, 216, 212,
    212, 213, 212, 33, 32, 212, 212, 212, 212, 212, 212, 215, 212, 212, 212,
    212
};
static int q931_U02_OverlapSending[] = {
    212, 212, 78, 212, 212, 88, 212, 212, 212, 212, 64, 61, 212, 70, 87,
    83, 84, 212, 81, 212, 66, 221, 220, 212, 212, 214, 212, 217, 216, 212,
    212, 213, 212, 82, 57, 212, 212, 212, 212, 212, 75, 215, 212, 212, 212,
```

```
    212
};
static int q931_U03_OutgoingCallProc[] = {
    212, 212, 212, 212, 212, 226, 98, 212, 212, 212, 91, 212, 212, 93, 225,
    227, 224, 222, 219, 212, 89, 221, 220, 212, 212, 214, 212, 217, 216, 212,
    212, 213, 212, 223, 218, 212, 212, 212, 212, 212, 101, 215, 212, 212, 212,
    212
};
static int q931_U04_CallDelivered[] = {
    212, 212, 212, 212, 212, 226, 212, 212, 212, 212, 212, 212, 212, 104, 225,
    227, 224, 222, 219, 212, 212, 221, 220, 212, 212, 214, 212, 217, 216, 212,
    212, 213, 212, 223, 218, 212, 212, 212, 212, 212, 212, 215, 212, 212, 212,
    212
};
```

Figure 51. Portion of the Action Array Jump Table from q931.c

4.3.6. Action Vector Table

This structure is an vector of tuples containing the actions to be triggered upon specific state/event occurrences. It is indexed by the state/event table of the previous section.

```
/* ---- Action Vector Table ---- */
static AAEntry    q931_ActArray[] = {
    /* Null Entry */ {0, 0, 0},    /* fcn, type, jmp or newstate */
    /* Action   1 */  {CallRefSelection, 1, 521},
    /* Action   2 */  {snet_Resume, 1, 521},
    /* Action   3 */  {StartTimerT318, 5, 13},
    /* Switch   4 */  {CheckSetUpMsg, 3, 10},
    /* Action   5 */  {suser_SetUpInd, 1, 5},
    /* Action   6 */  {snet_ReleaseComp96, 5, 520},
    /* Action   7 */  {snet_ReleaseComp100, 5, 520},
    /* Switch   8 */  {CheckSetUpMsg, 3, 9},
    /* Action   9 */  {CallRefSelection, 1, 521},
    /* Action  10 */ {snet_SetUp, 1, 521},
    /* Action  11 */ {StartTimerT303, 5, 1},
    /* Action  12 */ {snet_ReleaseComp96, 5, 520},
    /* Action  13 */ {snet_ReleaseComp100, 5, 520},
    /* Switch  14 */ {CheckStatusCsField, 3, 11},
    /* Action  15 */ {0, 2, 520},
    /* Switch  16 */ {RelOption, 3, 20},
    /* Action  17 */ {snet_Release101, 5, 521},
    /* Action  18 */ {StartTimerT308, 5, 14},
```

Figure 52. Portion of the Action Vector Table in q931.c

Each tuple contains three fields. One field contains the action to call or a zero for a null action (i.e., state change without action) or goto action/event macro call. Another field contains the type of tuple. The final field contains the new state transition or an indication of the jump index.

4.3.7. State Machine Definition Structure

This structure ties together all the structures in the state machine table file (`q931.c`).

```
/* ---- q931 state machine definitions ---- */
SM q931 = {
    q931_MaxStates,          /* max states */
    q931_MaxEvents,          /* max events */
    q931_ActArraySize,       /* # of entries in the action array */
    q931_SwLblVect,          /* Switch return value ActArray indicies */
    q931_SwTbl,              /* SwLblVect index & # of rtn values */
```

```
    q931_StateEvent,        /* state/event to action vector tbl */
    q931_ActArray           /* action vector table */
};
```

Figure 53. State Machine Definition Structure in q931.c

This structure contains the maximum number of states, maximum number of events, the action array size, a pointer to the switch return value and the switch tables, a pointer to the state/event to action array vector table and a pointer to the action array. A pointer to this structure is passed to the state machine executor (`sm_exec`). See Chapter 5 for an example call from the user-supplied event processor to the state machine executor.

4.3.8. Interrelations Between Generated Structures

In this chapter we have discussed as an example the static structures in `q931.c` generated by the Bayfront CAPEGen Compiler `-c` option parsing `q931.pdl`. The pointer and index relationships between these structures is shown below.

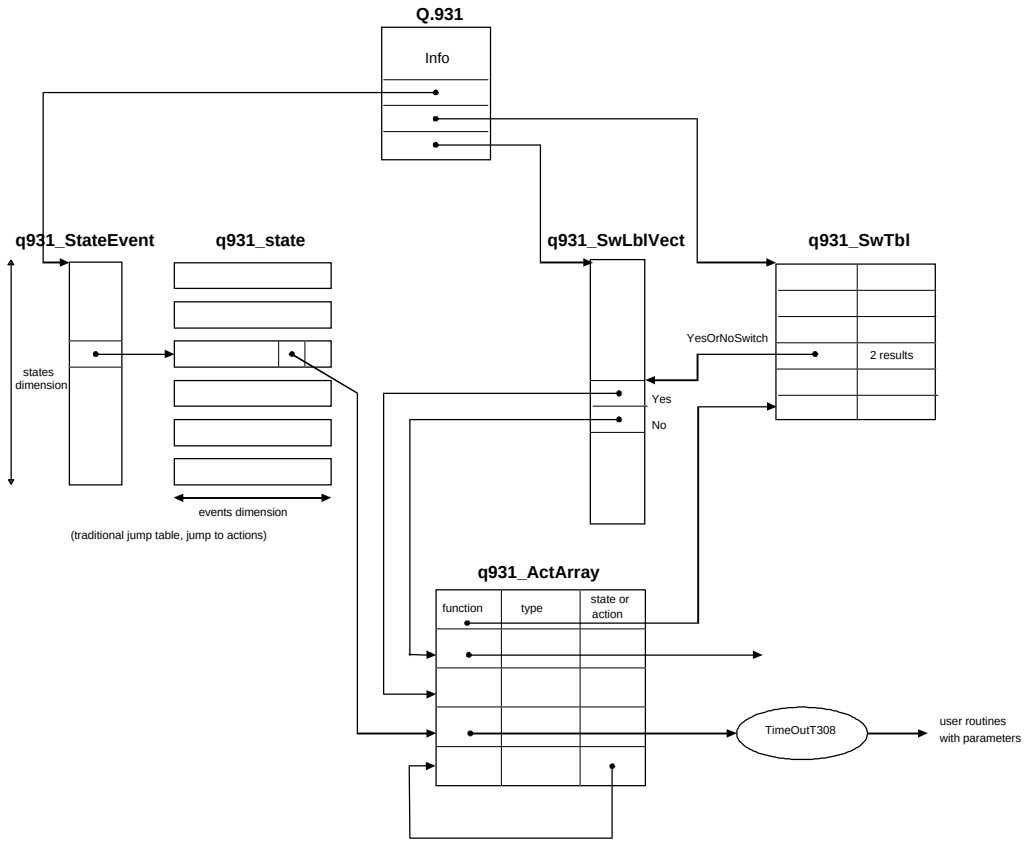


Figure 54. Relationships between Generated q931 Structures

The table below identifies the C Code structures with the q931 structure names.

C Code Structure	`q931 Structure Name`
Switch Table	`q931_SwTbl`
Switch Return Value Table	`q931_SwLblVect`
Action Routines w/Params	`func FirstTimeOutT308`
State/Event Table	`q931_StateEvent`
Action Array Jump Table	`q931_state`
Action Vector Table	`q931_ActArray`
State Machine Definition	`q931`

5. State Machine/Protocol Executor

The Bayfront-supplied state machine executor (`sm_exec.c`) is called from the user-supplied event processor with specific state and event information: a pointer to protocol state table information defined by Bayfront and a pointer to the user defined Event Control Block (or context) structure (pECB).

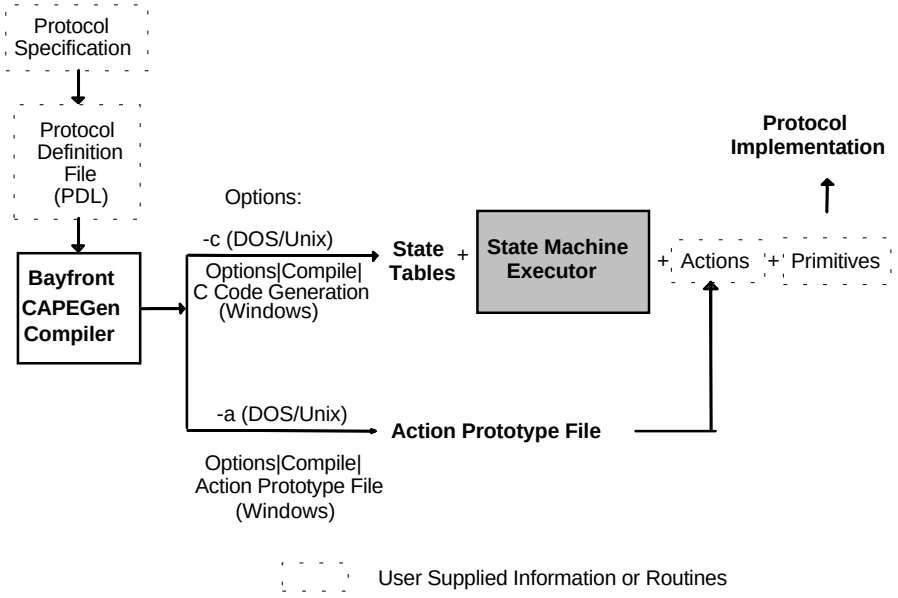


Figure 55. State Machine Executor Use

The state machine executor interprets the state table structures described in Chapter 4 and triggers the actions for the state/event pair. Only one instance of the state machine executor is required for all the protocol state machines in all layers of a protocol stack.

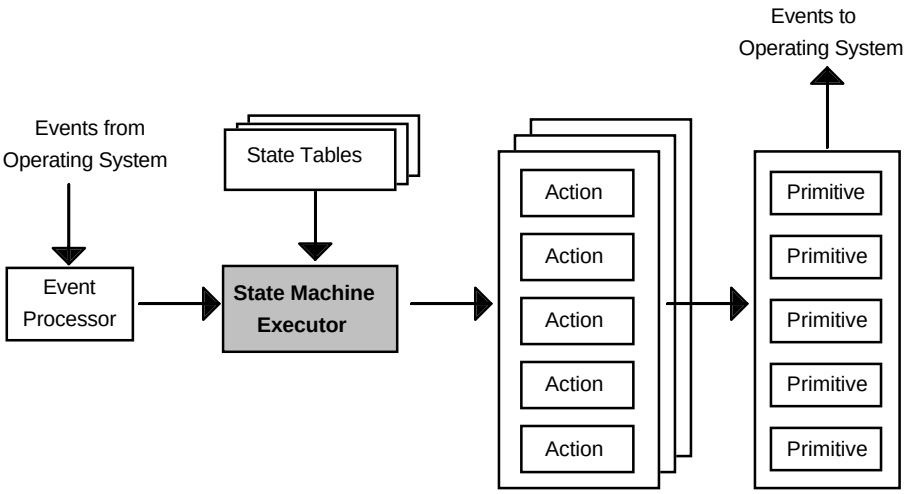


Figure 56. CAPE Tools Communications Model

5.1. Calling the State Machine Executor

The call from the event processor to the state machine executor has the following C language syntax:

```
sm_exec(SM *pSM,              /* state machine structure pointer      */
        int *CurState,        /* ptr to current state                 */
        int CurEvent,         /* current triggering event             */
        void *pECB);          /* event control block ptr    (context)*/
```

Several parameters are passed including the protocol or state machine structure pointer (`*pSM`), the current triggering event (`CurEvent`), a pointer to the current state (`*CurState`, this is updated by `sm_exec`) and a pointer to the user defined event processor control block (`*pECB`).

The state machine structure pointer (`*pSM`) is contained in the PDL table file generated by the CAPEGen Compiler (see Chapter 4). The current event is the triggering event preprocessed (e.g., translated into a defined event in the PDL header `.h` file (see example event values for q931 in Chapter 4) by the event processor. The triggering event is usually a received message from an interlayer communications channel, a timeout message from the operating system or a realtime interrupt. The event processor manages the context of each event using an event control block. The Event Control Block is a user defined private structure that is used to pass information to the resulting triggered actions and primitives. The design of this structure is very important and is dependent on the information needed by the specific state protocol or state machine. An example event processor control block for implementing q931 is illustrated below.

```
typedef struct ECB {
        Q931MSG *pMsg; /* ptr to the received message */
        Q931CCB *pCCB; /* ptr to the control block for this specific circuit */
        int msgfree;            /* pMsg can be used for reply flag */
} ECB_t;
```

Most actions of protocols require the triggering event message, the context (e.g., virtual circuit for q931) and other implementation dependent information to be passed between the event processor, the action routines, and primitives.

5.2. State Machine Executor Return Values

The state machine executor (`sm_exec`) performs runtime validation checks when executing a protocol or state machine PDL table file. If any of the validation checks fail, `sm_exec` will return a status code to the calling event processor The user-supplied event processor can decide what to do in each case. The validation checks include:

1. action index out of range (a corruption of the action array table)
2. switch return value out of range (error in the coding of the switch action)
3. state out of range (bounds error in the current state value passed to the state machine executor)
4. event out of range (bounds error in the current event value passed to the state machine executor)
5. unknown action type in array (a corruption of the action array table).

The actual return values are listed in the `cape.h` file and are listed below.

```
/* sm_exec() return values */
#define smOk            0       /* return ok */
#define smActIndError   1       /* action table index error */
#define smSwRtnError    2       /* switch return value error */
#define smStateError    3       /* state out of bounds */
#define smEventError    4       /* event out of bounds */
#define smATypeError    5       /* unknown action type encountered */
```

5.3. State Machine Test/Debug Procedures

One of the most time consuming areas of software systems implementation is static code path checking. To debug a protocol implementation the user should create a debugging event

processor that injects user controlled events into the state machine. The resultant actions can be examined and debugged. This will allow the effective static checking of nearly all protocol state machine code paths including resource bounds checking. The program below can be used to manually exercise the q931 state machine.

The q931 state machine test program illustrated below takes the current state and current event from the environment line and calls the state machine executor. The state machine executor will trigger the actions that print out their names. This program can be found on the Bayfront CAPE Tool product disk and can be easily modified to test any other state machine. When message encoding is added to this program a very effective method of static code path checking results.

```
/* test file to test the q931 state machine */

#include "cape.h"   /* SM structure defined here */
#include "q931.h"   /* q931_MaxStates/q931_MaxEvents defined here */
#include "q931.str"/* State/Event names file */

extern sm_exec();   /* state machine executor (sm_exec.c) */
extern SM q931;                 /* from q931.c */

void
main(argc, argv)
int argc;
char **argv;
{
        int rtnval;
        int State, Event, InitState;
        unsigned char *pECB = 0;

        /* -- read passed state/event from input line -- */
        if (argc != 3) {
                printf("Usage: q931test <state #> <event #>\n");
                exit(1);
        }

        if ((InitState = State = atoi(argv[1])) > (q931_MaxStates-1)) {
                printf("State out of range (max = %d)\n",q931_MaxStates-1);
                exit(1);
        }
        if ((Event = atoi(argv[2])) > (q931_MaxEvents-1)) {
                printf("Event out of range (max = %d)\n",q931_MaxEvents-1);
                exit(1);
        }

        /* -- display start state/event names -- */
        printf("start: State= %s     Event= %s\n",
                q931_StateNames[State], q931_EventNames[Event]);

        /* -- call state machine executor -- */
        rtnval = sm_exec(&q931, &State, Event, pECB);

        /* -- printout new state and sm_exec return value if not ok -- */
        if (State != InitState)
                printf("     New State = %s\n",q931_StateNames[State]);
        if (rtnval != smOK)
                printf("WARNING: sm_exec return value=%d\n",rtnval);
        else
                printf(" execute ok\n");
}
```

Figure 57. Example q931 State Machine Test Program

The program is created by creating a code file and an action prototype file from the CAPEGen Compiler from the `q931.pdl` file (e.g., `capegen q931.pdl -c -a`). Be sure the action

body text file (`actbody.txt`) contains the following line to print out the action name and return ok.

```
printf("!\n"); return(1);
```

The state machine table file (`q931.c`), the action prototype file (`q931.act`), the state machine executor (`sm_exec.c`) and the program above (`q931test.c`) are all linked together to create the q931 state machine test program executable.

5.4. Implementation of a Protocol Layer

The following is a general implementation example in pseudo code illustrating how the event processor and state machine executor tie together using AT&T streams operating environment.

```
/* streams put routine, events that should be serviced immediately */
layer_put(q, mp)
queue_t *q;
mblk_t *mp;
{
        /* initial event processor */
        queue non-priority messages for the layer_service routine and exit
        else
                service messages that do not require state machines
        else
                layer_event_processor(q, mp);
}

/* service routine, scheduled event processing */
layer_service(q)
queue_t *q;
{
        mblk_t *mp;

        while (mp = getq(q))
                layer_event_processor(q, mp);
}

/* event processor routine, prepare data structures & call sm_exec */
void
layer_event_processor(q, mp)
queue_t *q;
mblk_t *mp;
{
        translate message type into an event readable by the state machine
        find specific context (e.g., circuit for the q931 example)
        assign event control block pointers
                e.g., for q931:
                        pECB->pMsg = mp, pECB->pCCB = get_circuit(mp)
        call state machine executor
                e.g., rtn_val =
                        sm_exec(&q931, &pECB->pCCB->state, event, pECB)
        handle rtn_val values
                e.g., if state/event out of bounds clear circuit, etc.
        implementation cleanup details
                e.g., if (pECB->msgfree) freemsg(mp);
}
```

Figure 58. Event Processor Pseudo Code

This example illustrates the relationship between the event processor, the operating system and the state machine executor. The operating system's communications channels are the `put` and `getq` routines. These are specific to AT&T's streams operating system but similar real time

operating systems have similar communications channel, queue or mailbox management routines. The event processor simply handles the message if no state machine processing is necessary. Otherwise it builds the necessary structures and calls the state machine executor (`sm_exec`).

5.5. Communications Systems Implementation

Previous sections discussed testing individual state machines and creating protocol layers utilizing Bayfront CAPE Tools. To implement an entire protocol stack the same procedures for layer implementation are followed, usually by different members of the implementation team. The files for an example system with four layers and their relationship are illustrated below.

layer1ep.c layer2ep.c layer3ep.c layer4ep.c	Layer event processors (1 per layer)
layer1a.c layer1b.c layer2.c layer3.c layer4a.c layer4b.c layer4c.c layer4d.c	Layer PDL table files from "capegen -c layerx.pdl", where x = 1,2,3 or 4 (DOS/Unix) or from the menus "Compile|Options|Code Generate" (Windows) there can be multiple state machines per layer. For example: Layer 4 has four different state machines generated from four PDL definitions
sm_exec.c	State machine executor (1 per system)
layera1a.c layera1b.c layera2.c layera3.c layera4a.c layera4b.c layera4c.c layera4d.c	State machine action files (1 per state machine)
sysprim.c	System primitives (one or more files, exported to entire system)
os.c	Operating system

Figure 59. C Files to Implement an Example Four Layer Communications System

6. Action Prototype File

The automatic generation of the action prototype file offloads much tedious and error prone work from the implementor. The action prototype file contains action routine prototypes for all actions defined in the PDL file. The action prototype file presents a template of information that is completed by the user during the construction of the user supplied routines. The prototype definitions are sorted alphabetically.

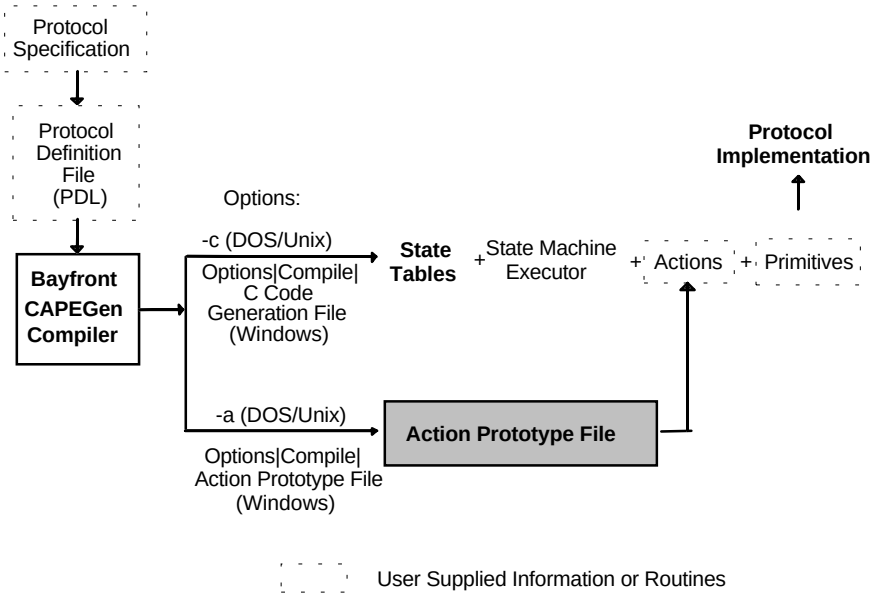


Figure 60. Action Prototype File Generation

Most of the information that the user needs to write event processors and action routines that interface to the CAPEGen Compiler generated code is included in the index under "user supplied routines" and "user supplied definitions".

User definable text can be added at the start of the action function prototype file, at the start of the action definitions and in the action bodies. The text is copied from the `actfileh.txt`, `acthdr.txt` and `actbody.txt` files respectively.

To generate the action prototype file select either the `-a` option (DOS/Unix) or the `Compile|Options|Action File` menu options (Windows). This file is typically generated after the PDL file has stabilized with no further changes expected. The generation of the action prototype file will NOT write over an existing file with the same name. If a file already exists with the same name it should be erased prior to generating another one.

All three action prototype insertion files (`actfileh.txt`, `acthdr.txt` and `actbody.txt`) use two special substitution characters. These characters when found will be substituted by the names below:

Substitution Character	**Replacement Name**
!	action name
?	state machine name

6.1. Action Header File

The ASCII file `actfileh.txt` is inserted in the beginning of the action prototype file. This file usually contains source code control information (`%W% %G% %U%` is used by some source code control systems), the protocol/state machine name, the company name and user definable copyright information. An example of the `actfileh.txt` file is shown below.

```
/*
 *
 *          %W% %G% %U%
 *              ? Actions
 *    Copyright © 1993 Your Name Here
 *          All Rights Reserved
 */

/*                  Revision Log:
 *                          R01             "date" file created.
 */
```

Figure 61. actfileh.txt contents

The figure above illustrates an example action function prototype. It contains the special character `?` which is replaced with the state machine name. The example also contains source code control header information along with a user definable copyright notice.

6.2. Action Function Prototype Header File

The ASCII file `acthdr.txt` contains text that is inserted before each action function. This text can assist in the standardization of software coding practices. An example file is illustrated below.

```
/***********************************************

        Action: !
        Purpose:
        Input:
        Output:
        Libraries Used:
        Copyright 1993 © Your Name Here

***********************************************/
```

Figure 62. acthdr.txt contents

6.3. Action Function Body File

The ASCII file `actbody.txt` contains text that is inserted in each action function. The example action prototype files contained the CAPE Tools `examples` directory were constructed using an action function body file similar to the one shown below.

```
TRACE("Enter action !");
/* code here */
TRACE("Exit action !");
return(1);
```

The example illustrated above calls a trace procedure that traces the action and execution. The special character **!** is replaced by the action function name. The example also returns a success value. Note that all action functions should return a one except for switch actions that return a range of values.

7. Protocol Information File

The protocol/state machine information file is generated using either the `-i` option (DOS/Unix) or the `Options|Compile|Info File` option (Windows). This file is a text file (extension `.txt`) that contains information about the protocol/state machine such as the states, events, actions, messages received and sent by the state machine and the timers used. This file can be used in both the support documentation and in the actual source code. Part of the protocol/state machine information file from the protocol q931 is shown below.

```
/* ---- q931 state machine information file ----

State Machine Name: q931

States defined: 16
Events defined: 46
Actions defined: 62

Msgs Received by 'q931'

   Alerting
   AlertingReq
. . .
   SuspendReqcallid
   UnrecognizedMsg

Msgs Sent by 'q931'

   Alerting
   Connect
. . .
   TimeoutInd

Timers Managed by 'q931':

   T302
   T303
   T304
. . .
   T318
   T319

States:

   U00_Null
   U01_CallInitiated
   U02_OverlapSending
. . .
   U17_ResumeReq
   U19_ReleaseReq
   U25_OverlapReceiving

Events:

   T302_timeout
   T303_timeout
. . .
   rnet_Alerting
   rnet_CallProc
   rnet_ConAck
. . .
   ruser_AlertingReq
   ruser_DiscReq
```

```
    ruser_InfoReq
    ruser_SetUp
. . .
    ruser_SuspendReqcallid

Actions:

    AckOption
    AnyTimersRunning
    BChanMaintenance
. . .
    suser_SuspendConf
    suser_TimeoutInd
*/
```

Figure 63. Q.931 State/Event Names File

8. State/Event Names File

The State/Event names file is composed of two C character arrays containing the state and event names. This file (extension `.str`) is generated using the `-n` option of the CAPEGen Compiler (DOS/Unix) or the `Options|Compile|Names File` menu selections (Windows), see figure below.

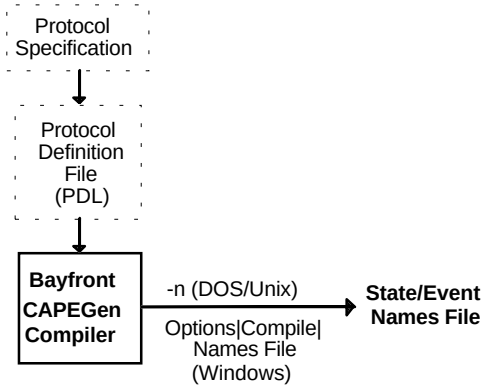


Figure 64. State/Event Names File Generation

The purpose of this file is to display the state and event names in ASCII text for debugging purposes. The state/event names file from the q931 protocol is shown below.

```
/* -- State Name Array -- */

static char *q931_StateNames[] = {

"U00_Null",
"U01_CallInitiated",
"U02_OverlapSending",
"U03_OutgoingCallProc",
"U04_CallDelivered",
"U06_CallPresent",
"U07_CallReceived",
"U08_ConReq",
"U09_IncomingCallProc",
"U10_Active",
"U11_DiscReq",
"U12_DiscInd",
"U15_SuspendReq",
"U17_ResumeReq",
"U19_ReleaseReq",
"U25_OverlapReceiving",
};

/* -- Event Name Array -- */

static char *q931_EventNames[] = {

"T302_timeout",
"T303_timeout",
"T304_timeout",
"T305_timeout",
"T308_timeout",
"T309_timeout",
"T310_timeout",
"T313_timeout",
```

```
"T318_timeout",
"T319_timeout",
"rnet_Alerting",
"rnet_CallProc",
"rnet_ConAck",
"rnet_Connect",
"rnet_DL_Est_Conf",
"rnet_DL_Est_Ind",
"rnet_DL_Rel_Ind",
"rnet_Disc",
"rnet_Info",
"rnet_Notify",
"rnet_Progress",
"rnet_Release",
"rnet_ReleaseComp",
"rnet_ResumeAck",
"rnet_ResumeRej",
"rnet_SetUp",
"rnet_SetUpAck",
"rnet_Status",
"rnet_StatusEnquiry",
"rnet_SuspendAck",
"rnet_SuspendRej",
"rnet_UnrecognizedMsg",
"ruser_AlertingReq",
"ruser_DiscReq",
"ruser_InfoReq",
"ruser_MoreInfoReq",
"ruser_NotifyReq",
"ruser_ProcReq",
"ruser_ProgressReq",
"ruser_RejReq",
"ruser_ReleaseReq",
"ruser_RestartReq",
"ruser_Resume",
"ruser_SetUp",
"ruser_SetUpRsp",
"ruser_SuspendReqcallid",
};
```

Figure 65. State/Event Names File for q.931 (q931.str)

An example source code line that utilizes the state/event names file is shown below.

```
printf("start: State= %s    Event=%s\n",
        q931_StateNames[State], q931_EventNames[Event]);
```

Appendix A Error Messages

Bayfront CAPEGen Compiler Error Messages

The error messages are arranged in alphabetical order.

Action macro: <name> referenced but not defined
The specified action macro referenced in by not defined in the action macro section.

ACTION PROTOTYPE FILE EXISTS, cannot create a new one
The CAPEGen Compiler will overwrite an existing action prototype file. You must either erase the existing file or rename the existing action prototype file.

Cannot open Action Prototype output file
The CAPEGen Compiler could not open the action prototype file, a system error.

Cannot open header output file
The CAPEGen Compiler could not create the header output file, a system error.

Cannot open Information output file
The CAPEGen Compiler could not create the Information output file, a system error.

Cannot open SDL output file
The CAPEGen Compiler could not create the SDL output file, a system error.

Cannot open State/Event Names output file
The CAPEGen Compiler could not create the state/event names file, a system error.

Cannot open State/Event Transition output file
The CAPEGen Compiler could not create the header output file, a system error.

Cannot open State Transition output file
The CAPEGen Compiler could not create the state transition output file, a system error.

Duplicate Event Name Found: <name>
A duplicate event was detected within the same state. Events within a single state must be unique.

Duplicate State Name Found: <name>
A duplicate state was detected in the pdl. State names must be unique.

Duplicate Switch Label detected: <name>
The specified switch label was used in more that one switch action. All switch labels must be unique to a specific switch action.

Event macro: <name> referenced but not defined
The event macro specified was referenced by not defined in the event macro section.

Initial State specified not defined: <name>
The initial state specified with the "InitialState" reserved word was not found among the defined states (check spelling).

Internal error: Empty stack popped

Please notify Bayfront Technologies if this error occurs. This error indicates that the CAPEGen Compiler failed reading the PDL file.

Not enough memory, stopped after allocating: x bytes

The PDL file was too large to parse. If you are using the DOS version try to remove memory resident utilities and try again. If you still get the memory error try either the WINDOWS or Unix CAPEGen Compiler versions.

Number of action/switch passed variables must match: <name>

The number of parameters to an action or a switch action must match for each occurrence of that action/switch action.

State is unreachable (not called): <name>

The defined state is not reachable from any other state. Check the PDL to make sure that a state transition (`>>state`) to this state exists in a least one other state.

Switch Label count mismatch, Switch: <name>

The number of switch labels were not exactly correct for each occurrence of the specified switch action.

Switch label field not defined: <name>

There is an extra switch label defined that is not included in all of the switch actions. The number and names of the switch labels must match.

Switch name = action name (not allowed): <name>

Switch names cannot be the same as actions names.

There are no EVENTS defined

You must specify at least one event.

There are no ACTIONS defined

You must specify at least one action.

Undefined State: <name>

The specified state was referenced but not defined.

Bayfront CAPEDraw Viewer Error Messages

CAPEGen Compiler diagram file corrupted

The input file appears to be a CAPEGen Compiler diagram file but the internal structure is not consistent.

Command line option "<option>" unknown (DOS/Unix)

The given command line option is not accepted by the CAPEDraw Viewer. Enter "capedraw" with no command line arguments for a list of the acceptable options.

Diagram too large (DOS)

The diagram contains more than 4000 boxes. The demonstration version is limited to 100 boxes. Factor the protocol into more state machines or less complex states.

Draw input file "<filename>" does not exist

The `-d` option was specified and the file could not be found.

Graphics - <graphics hardware problem message>

A problem with initializing the graphics hardware has been encountered. "Not enough memory" problems can be resolved by removing TSRs and drivers from the lower 640k of memory.

Input file "<filename>" is not a CAPEDraw Viewer layout file

The `-d` option was specified and the input file was not produced by a previous `-l` pass (DOS/Unix) or the `Compile/Options/<specific diagram file>` type menu option was not previously selected.

Input file "<filename>" is not a CAPEGen Compiler diagram file

The `-l` option was specified and the input file does not conform to the structure of a CAPEGen Compiler diagram file.

Layout input file "<filename>" does not exist

The `-l` option was specified and the input file does not exist.

No input file specified

Operations were specified but no input file was specified.

No operation (specify -l or -d or both)

Either layout or drawing or both must be specified for the CAPEDraw Viewer to take action.

Out of memory

The protocol is too large to be laid out or drawn using the available lower 640K of memory. Try the following solutions. Free memory by removing TSRs and drivers. Factor the protocol into smaller state machines. Use the WINDOWS version of the CAPEDraw Viewer.

PS and EPS require filename w/no extension (e.g., -p:PS:afile)

The extensions of these graphic output files default to `.PS` and `.EPS` respectively. The above example specification would produce the file `afile.PS`.

Unable to open <filename> for output

The specified output file cannot be constructed either because previous write protected version exists or the disk is full.

Unable to register font: <fontname>

There is not enough memory to allow the use of the given graphics font. Some memory in the lower 640K is required.

Unknown printer "<printer>"

The given printer is no a supported printer. Enter "capedraw" with no command arguments for a list of the supported printers.

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