



# **PiComp:**

**the PicOS Compiler**

version 0.3



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## Introduction

PiComp performs two types of jobs:

1. Preprocessing source files in "enhanced" PicOS language (see below), such that they can be handled by the (standard) C compiler (say, *gcc* in *mspgcc*).
2. Transforming PicOS praxes (possibly multiprogram praxes) into VUEE models.

Regarding the first type of job, we would like to have a more convenient way of expressing certain PicOS constructs than what can be achieved by relying solely on C preprocessor macros. Old versions of some of those constructs, especially process (strand/thread) declarations, look weird. In addition to resolving those problems, a more powerful pre-compiler will allow us to think about new syntactically viable constructs that could be added to the PicOS language to facilitate programming in its true spirit. While, at this time, the contribution of PiComp to enhancing the programming language of PicOS may appear moderate, we may view it as the first step. It may be comforting to know that, should we come up with something more creative, the path to adding new (possibly non-trivial) constructs to the language is essentially open.

For the second role of PiComp, the manual effort needed to maintain VUEE compatibility of PicOS praxes has been quite serious and irritating, despite our attempts to simplify the rules and recommendations. There has been a rather destructive tradeoff between the ease of maintenance (of VUEE-compliant code) and the degree of structural finesse of the program that one was willing to indulge in (having to keep in mind the complexity of maintenance). While the most recent set of rules and recommendations for achieving VUEE compliance "manually" may not be excessively complicated, those rules nonetheless force you to organize your program into a rigid collection of files while paying close attention to several counter-intuitive and messy details (like the multiple *contexts* of a variable declaration). The easiest way to avoid mistakes is to minimize the number of all those tricky places that must be carefully checked/updated when modifying the praxis, which in turn stimulates restrictive simplicity, like making all variables global and keeping them all in one place.

In this context, the role of PiComp is to transform the source program in PicOS mechanically into a set of files that can be then comfortably (and automatically) processed by the VUEE/SMURPH compiler. The original source program doesn't have to be especially prepared for that task, except for the avoidance of some obscure and basically irrelevant constructs, which reasonable programmers would statistically never use anyway. While I can give you examples where PiComp will fail, there is no need to advertise them formally as something that a programmer should learn and memorize before embarking on a programming task. For one thing, it is hoped that all failures of PiComp to process a correct program will be detected and diagnosed (as opposed to producing incorrect but formally runnable code). Then, the compiler can be extended, if the discovered limitation proves serious enough.

## Quick start

Make sure that all three components: PICOS, SIDE, and VUEE have been installed, e.g., according to the rules described in *Installation.pdf*.

Move to *SIMPLE\_TWO* for a simple example of a multiprogram praxis.

Execute:

```
mkmk WARSAW
```



and things should compile for PicOS (producing the usual Image files).

Now execute:

```
picomp
```

which should produce the *side* executable (*side.exe* under Cygwin). You will also see a directory named *VUEE\_TMP*. PiComp places in it the intermediate sources that it submits to the SMURPH/SIDE compiler (*vuee*).

## New syntax for some PicOS constructs

Don't panic! The old syntax still works. In particular, if you execute *mkmk* on an old program, followed by *make*, it is going to do the same kind of job it did before. Similarly, when you execute *vuee* on your old, handcrafted, VUEE-compliant praxis, it will work exactly as before.

The newest version of *mkmk* (followed by *make*) will additionally handle programs using the new constructs (described below), but only for the source files with suffix *.cc* (not *.c*). Even for those files, it will do nothing if the new constructs are not there (so they are optional).

However, if you want to use PiComp to do the VUEE conversion for you, the program **MUST** use the new constructs (and the names of its source files must end with *.cc*).

Another thing: don't try to run *picomp* on a manually converted VUEE-compliant praxis. It won't work. The primary reason is the extra files (which don't really belong to PicOS, but to SMURPH/SIDE). While *mkmk* would walk around them, *picomp* will try to interpret them as bona-fide members of the praxis. There's no sense to insist on PiComp compatibility with the manual conversion mess.

Here is a sample thread:

```
fsm receiver {
    address rpkt;
    entry RC_TRY:
        rpkt = tcv_rnp (RC_TRY, sfd);
    entry RC_SHOW:
        show (RC_SHOW, rpkt);
        tcv_endp (rpkt);
        proceed RC_TRY;
}
```

First of all, the declaration now involves a standard set of braces "{ ... }" which are properly matched (no ugly keywords at the end). All threads in PicOS are now declared with the same keyword *fsm*. Strands are differentiated from threads by an argument following the FSM's name, like in:

```
fsm sender (char *msg) {
    entry SN_SEND:
        address spkt;
        spkt = tcv_wnp (SN_SEND, sfd, plen (msg));
        spkt [0] = 0;
        strcpy ((char*) (spkt + 1), msg);
        tcv_endp (spkt);
}
```



```

    finish;
}

```

The argument must be a type name possibly followed by a variable name, which will override the default name `data`. Please read the *PicOS* document for details. It contains an elaborate discussion of the new constructs and their semantics.

The most important difference that you should be immediately aware of is that local variables declared at the top of an FSM, e.g., `rpkt` in `receiver`, are now automatically rendered `static`. If you want to use truly local (transition-volatile) variables, you should declare them at states, like `spkt` in `sender`.

The *PicOS* document doesn't mention two new keywords, which are relevant only to VUEE: `trueconst` and `idiosyncratic`.

Normally, when you have a `const` variable, and you switch to a VUEE model, you want to have it "constant" on a per node basis (such that different nodes have different views of that constant). This basically means that you want it appear as a node attribute. Consequently, PiComp will transform global `const` variables into node attributes (similar to other, non-`const` variables). In some situations, a `const` is really constant once for all, and corresponds to something that should be hardwired into the code flash of all nodes looking exactly the same everywhere (e.g., a fixed message string). In such a case, you can declare the constant as `trueconst`, as in this example:

```

static trueconst char ee_str [] = OPRE_APP_MENU_A
    "EE from %lu to %lu size %u\r\n";

```

While *PicOS* will just strip the "true" part of the keyword, VUEE will make sure to treat the declared item (or items) as actual constants (and place them in code rather than at the nodes). Note that `trueconst`, while being formally ignored by *PicOS*, may play an advisory role (as a useful comment) by referring to those items that are in fact supposed to be identical and immutable across all nodes ever running the program. For example, the program may use constants that are settable on a per-node basis, like a HOST ID being "burned" into the flash but with different values for different nodes. Such (mutable) constants should be declared as `const`, while true constants should be marked as `trueconst`.

Another VUEE-specific keyword is `idiosyncratic`, which can appear in front of a function definition or announcement, as in:

```

idiosyncratic int tr_offset (headerType*);

```

or

```

idiosyncratic int tr_offset (headerType *h) {
    return 0;
}

```

It is ignored by *PicOS*, but for VUEE it means that the function should be turned into a node method, rather than being defined as global or static. The difference becomes relevant in two situations (which pretty much amount to the same problem):

1. You have a multiprogram praxis with different programs using the same names for some of their non-static functions. When such programs are linked together into a VUEE model, those names will cause linkage conflicts.



2. VUEE models of a few TARP functions (parameterizing the scheme for the praxis) are implemented as **virtual** methods of the node. Thus, their program-specific instances must be also provided as node methods in order to properly substitute for the dummy originals (i.e., they cannot be straightforward functions).

I have chosen the name **idiosyncratic**, because this prefix allows different functions with the same name, appearing in different programs of the same praxis (destined for different node types), to coexist within the VUEE model without upsetting the linker. In this sense, the keyword makes each of the possible multiple copies of the function *idiosyncratic* to one program of the (multiprogram) praxis. For situation 2, the reason why the function is **idiosyncratic** (becoming a node method) is to allow it to properly override its default **virtual** variant. In PicOS such functions are simply *expected* (by the linker) and must be provided by the praxis (as regular global functions). In a VUEE model, they must be associated with nodes (or rather node types) because multiprogram praxes may (and usually do) define different versions of such functions for the different programs. The VUEE way of modeling them is thus constrained by their inherent idiosyncratic nature in PicOS which, basically, also boils down to the name overlapping problem.

When you call *picomp* with *-i* (see below), it will automatically implement all non-static functions as **idiosyncratic**, i.e., turning them into node methods. Do this whenever you have a multiprogram praxis with conflicting function names. With that option, the **idiosyncratic** keyword will be superfluous. This feature is optional because the resulting program is going to be a bit less efficient than otherwise (and in most cases you need not be aware of the issue at all).

As it turns out, the *-i* option is rather popular for multiprogram praxes, because it is natural in such praxes to use similar functions (with identical names) in the multiple programs. When applying that option, you will occasionally need an exception from the blanket treatment of all (global) functions as **idiosyncratic**. Note that **static** functions are automatically exempt from that treatment: their names, being confined to a single file, cannot possibly collide in the linkage stage. If you need a (global) function to be non-**idiosyncratic** for some reason, put **nonidiosyncratic** in front of its declaration. This only makes sense with *-i*; otherwise the ugly specifier is completely ignored. One situation when you may want a function to be non-**idiosyncratic** is when it is passed as an argument to another function. This is because the signature of an **idiosyncratic** function is changed (mangled) by PiComp, so it will not fit the original (non-mangled) type specification as a function argument.

## Compilation

At the first level of approximation, you may assume that there is nothing special about a PicOS program being prepared for VUEE. As long as all the PicOS components referenced by the program have their VUEE models, it should be pretty much automatic. Needless to say, if you insist on referencing some arcane features (symbols or constructs) associated with a specific board, sensor, etc., you may have to apply conditions, like:

```
#ifdef __SMURPH__
...
#else
...
#endif
```



which work as before. However, you do not need them for structuring the program into separate blocks for PiComp and VUEE, nor you need to provide any VUEE-specific kludges, glues, headers, etc., as you did with the manual conversion.

Version 0.1 of PiComp (which nobody saw) couldn't handle compound variable initializers, e.g., ones like this:

```
struct MTag t = { 1, 2, 3 };
```

which had to be circumvented with ugly conditional compilation. The present version does handle such initializers. The problem with them is that when a variable becomes a node attribute (which happens to all non-automatic variables in a VUEE model), its initialization cannot be carried out statically, so one has to transform such declarative initializers into dynamically executed code. While there is no problem with a simple initializer, e.g.,

```
int sid = -1;
```

which can be trivially converted to an assignment statement, a compound initializer cannot be treated this way. PiComp handles such an initializer by declaring a dummy **static const** version of the variable (which can be initialized statically) and copying its memory area (**memcpy**) to the actual variable at initialization.

Note that, similar to plain C, you don't have to (dynamically) initialize those components of structures and arrays that are supposed to be zero. VUEE will first zero out the entire set of node attributes (the node's "global" RAM) and then do the detailed initialization.

One occasionally painful problem (only surfacing when compiling for VUEE) is that the names of local variables (of FSMs and functions) collide with the names of global variables, so they should be different. This is to say, you can use the same names for the local variables of different functions or FSMs, but when you name a global variable as one of the local variables, that will cause a conflict. The conflict will be detected at compilation time, usually with a cryptic message referring to the line of the local declaration. The problem is that global variables are replaced with macros looking like remote references (`node_pointer -> node_attribute`), and the appearance of the global name in a local declaration context will result in an attempt to declare something weird.

Also, when compiling for VUEE you should not re-declare as **extern** in the praxis global variables declared (as **extern**) in library files. For example, you may be tempted to re-declare in the praxis `local_host` and `master_host` declared in `tarp.h` as **extern**. That will cause another type of conflict, because the library files are not visible to PiComp, and in-praxis **extern** declarations are preprocessed in some tricky way. Fortunately, you never have to do it. When you include the `tarp.h` header file and just reference `local_host` and `master_host` as (regular) variables, things should be fine. Relevant global variables belonging to library files are treated by VUEE in a special way, but they are made visible to the praxis (via macros) as needed.

One more restriction that comes to my mind is that you cannot declare types (**struct**, **union**, **typedef**) with the same name in different files of the same program (you still can in different programs of the same praxis). The reason is that wherever you declare your variables in the source program, they are eventually put together as attributes of the same class in the VUEE model. Consequently, all the types used in the declarations of those variables are visible at the same time, and they must not interfere.



PiComp may occasionally complain about something it cannot handle. Here is one example of a PiComp-generated error diagnostic:

```
app_peg.cc:27: picomp prohibits empty size in array typedefs
```

caused by a statement like this:

```
typedef arr_type [][][3];
```

This illustrates a restriction on what kind of static/automatic data can be transformed into node attributes with definite memory layouts. Also, this kind of declaration:

```
int my_arr [][][3];
```

will yield:

```
app_peg.cc:27: empty size only allowed with an initializer
```

As you can infer from the diagnostic, this:

```
int my_arr [][][3] = { { 1, 2, 3 }, { 4, 5, 6 } };
```

will work fine (PiComp will derive the size along the first dimension of `my_arr` from the initializer).

If you stumble upon something weird, please let me know and I will see what I can do. Note that despite the rather significant transformations undergone by the source program before it is submitted to the VUEE (SMURPH/SIDE) compiler, and subsequently to g++, PiComp tries very hard to tag the generated code with proper line sequencing marks, such that the errors reported by g++ should reasonably closely refer to the original source (which does not mean that they are never confusing).

In terms of its layout as a collection of files, a praxis to be compiled by PiComp should essentially conform to the expectations of *mkmk* (see the *mkmk* document). The praxis may consist of multiple programs rooted at files named *app\_xxx.cc*, where *xxx* is a program-specific tag (we shall call them *app* files). All files in the current directory (where the compiler has been called) whose names fit this pattern are assumed to represent separate programs of the praxis. If there is only one program, the *app* file can be named *app.cc*. Any remaining files contributing to those programs, including sources and/or headers, may appear within the same directory (at the same level as the *app* files) or in any of its subdirectories. Well, not quite *any*. Some subdirectories are excluded based on their names which, among other things, allows you to keep other stuff in the praxis directory without having to worry that it might be accidentally “compiled”. Two (exact) names excluded from search are *CVS* and *VUEE\_TMP*. The latter is the directory where PiComp puts the intermediate files for SMURPH compilation. Additionally any directory whose name (ignoring the case) starts with *KTMP* or contains any of the strings *JUNK*, *ATTIC*, *OSSI* is ignored as well, regardless of its level.

Headers are sought automatically as needed and can be placed into any (qualifying) subdirectories, not necessarily ones related to those containing the referencing files. A source file must be referenced either from the *app* file or from one of the other files already deemed to belong to the set (be it a header or a source) via the special comment sequence `//+++` (as described in the *mkmk* document). For example:

```
//+++ app_diag_peg.cc "lib_app_peg.cc" <msg_io_peg.cc>
```



adds three source files to the program's set (the delimiters are optional). All the subdirectories of the current directory (with the exceptions noted above) are scanned automatically for files requested this way (as well as for any `#included` headers). There is no need to specify exact paths. For example, the file *lib\_app\_peg.cc* referenced above can be provided in any subdirectory (at any level) of the praxis's main directory.

When you invoke the compiler as:

```
picomp
```

it will do the following things:

1. Check for the completeness of the environment (in particular VUEE and SIDE).
2. Scan the current directory for app files and build the list of tags representing the programs belonging to the praxis. If there is an app file named *app.cc* (empty tag, a single-program praxis), then no other app files are legal (the compiler will complain if it sees any).
3. For each program, the compiler will parse all source files belonging to the program and create their compiled versions in directory *VUEE\_TMP*. Any headers referenced by those files will be expanded in (so they will not show up in *VUEE\_TMP*). The compiler will add two extra files for each program: the VUEE header (included by all compiled files) and the VUEE initializer (containing code for starting and resetting the node model),
4. Having processed all programs, the compiler will add one more file to *VUEE\_TMP* containing the root process of the SIDE simulator and providing a glue for the (semi-independent) models of different nodes (for the multiple programs).
5. Finally, if there were no errors thus far, the compiler will invoke the VUEE compiler (*vuee*) on the produced set of files. If the compilation succeeds, the executable (*side* or *side.exe*) will be moved to the praxis main directory.

You can say:

```
picomp -n
```

to omit the last step of the above sequence. Note that you can then move (*cd*) to *VUEE\_TMP* and execute *vuee* by hand.

If you say:

```
picomp -- ...
```

then any arguments following *--* will be passed to *vuee* (rather than being interpreted by *picomp*).

When invoked this way:

```
picomp -p
```

the compiler acts as a filter (stdin to stdout) to translate a PicOS source file using the new syntax (*fsm* and so on) into "traditional" PicOS (gcc + macros) code. You are not supposed to ever have to do that by hand. Such calls are inserted by *mkmk* into *Makefiles* at the pertinent stages. If a source file doesn't reference the new keywords, it





will be passed unchanged by the filter, which makes the procedure downward compatible without any extra hints. Also note that new and old constructs can be mixed this way (but not if you are compiling into VUEE!).

Here are the remaining parameters:

- v Selects the VUEE compiler (as opposed to the PicOS compiler). This is the default (i.e., the counterpart of -p)
- i Forces all functions to be compiled as idiosyncratic, except for those that are explicitly declared as `static` or `nonidiosyncratic`.
- e Invokes the SMURPH compiler on the existing contents of `VUEE_TMP`, e.g., created previously with `picomp -n`.
- G Produces debug output (on standard output). It can be a lot.
- A Stops on the first compilation error (diagnosed by PiComp).
- D Defines a symbol (as explained below).
- V Just print the version number and exit.

When you specify `-n` together with `-e`, the compiler will do nothing, but only list the status of the present contents of `VUEE_TMP` (for example “OK, no errors, no warnings” means that the last compilation fully succeeded, so `-e` should now work).

The last type of argument is illegal with `-p`, i.e., it only applies to VUEE compilation. You can use it to define symbols for the compiled model. The letter `D` should be immediately followed (no space) by one of these constructs:

```
symbol
symbol=something
tag+symbol
tag+symbol=something
```

The last two variants will set the specified symbol only for the specified program (of a multiprogram praxis). For example:

```
picomp -Dpeg+BOARD_TYPE=WARSAW
```

will set `BOARD_TYPE` to `WARSAW` for the `peg` program. Needless to say, multiple arguments of this kind are allowed, e.g.,

```
picomp -i -Dpeg+BOARD_TYPE=WARSAW -Dtag+BOARD_TYPE=ARTURO_PMT
```

Arguments of this type are used by PIP to pass to the program the board information. This way the program(s) of a VUEE model compiled under PIP automatically receive board information (symbols `BOARD_TYPE` and also `SYSVER_B` – see Section 3.2 of the *mkmk* document) in the same way as for a program compiled for a real board.

## A bit about the internals

I am only discussing here the PicOS-to-VUEE translation. This is all very preliminary. I may write more later. Things may still change without a warning.

The compilation is heuristic, but it should work for all (or most of) sane cases. I am almost sure that the compiler will never produce incorrect code without a warning. Other



than that, it may fail on good and healthy source. Whenever that happens, I will do my best to fix the problem, if it can be fixed at all.

This is how it works in a nutshell:

Having determined the list of programs to compile (note that one program may consist of multiple files), PiComp proceeds to handle them one at a time. No information survives from one program to another (note that "program" is not synonymous here with "file"), except for the global list of tags (the xxx parts from *app\_xxx.cc*), which are needed at the end to generate the root file of the SMURPH simulator (also called the glue).

When processing a program, the compiler starts from its app file. The file is read and scanned for preprocessor directives (conditions and includes). All files **#included** by it are read as needed and processed recursively. An included file that belongs to VUEE (comes from *VUEE/PICOS*), as opposed to the praxis, is not fully expanded (it will be included later again for the "true" compilation), but its definitions are preserved (and conditions are obeyed), such that the resultant output file from that stage is devoid of macro references and conditional code. Note that macros must be pre-expanded (before parsing) as they may produce (translate into) PicOS keywords or type declarations.

The stage produces a set of preprocessed (expanded) files comprising the program. Note that all those files are source files (all praxis-specific headers have been already incorporated into them). They may still reference things (but, notably, not macros) that are not defined within them, but all such things share one property: they already belong to the virtual world (i.e., to the model), so PiComp doesn't have to worry about transforming them into anything different from what they are.

Each of those files is subsequently parsed and processed. The processing order is exactly the same as that of their addition to the set (as requested with the special comments *//+++*), with the app file going first. This is what happens:

All type declarations (**typedef**, **struct**, **union**), including those implicit in variable declarations, are identified and removed. They are stored in a list (eliminating duplicates and detecting any conflicts) to be included as a single set of type declarations for the entire program (to be provided in a special header file). The reason is that the (necessarily single and centralized) declaration of the node class, including all its attributes, must in principle see all those data types.

Function announcements are left intact except for those announcing **idiosyncratic** functions, which are turned into macros transforming references to them into references to the corresponding node methods. Similarly, actual definitions of **idiosyncratic** functions are transformed into mangled definitions of node methods. The signatures of those methods are stored for inclusion (declaration) within the node class.

Global variable declarations are analyzed and split into lists of variables, including their types and initializers. Those lists are stored for inclusion (declaration) as node attributes. The original declarations are removed and replaced with macros referencing those (mangled) attributes via the global node pointer. Static declarations are treated the same way, except that their mangling is file-specific. This way, the same static name appearing in two different files will translate into two different attributes. This closely resembles what you were doing manually, except that now, with all this being done by a program, we can afford to be more exacting and careful.

FSM's are transformed into code methods of SMURPH processes. Information regarding their names, types (thread/strand), and lists of states is stored until all files have been handled. Also, *local* declarations within FSM's (which formally become static) are



transformed into macros referencing the appropriately mangled node attributes. Those macros are `#defined` in front of the code method and `#undef(ined)` at its end. This way, the “local” variables (turned static) are only visible within the FSM. Note that there is no need to do anything about the automatic declarations (appearing at states). FSM states are collected, to be inserted into the definition of the corresponding SMURPH process class.

PicOS-specific keywords, like `runfsm`, `proceed`, are identified and processed as required.

When all files of the program have been processed, PiComp generates a header file to be included by all of them. That file combines all the declarations of types extracted from all the program files and follows them by the declaration of the node type along with all the attributes and methods. Then it declares the process types for all the FSM's.

Finally, one more source file is created which contains the reset code to initialize the node attributes and to start the root FSM. Any dummy variables needed by compound initializers are declared as `static const` within that file.

Having handled all the programs, PiComp creates the glue file containing the root process of the simulator. Then, if there were no errors (and the compiler wasn't called with -n), PiComp invokes `vuee` to compile the contents of `VUEE_TMP`.

