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COMPLETION REPORT FOR THE GENERAL INTERFACE IN THE COUPLED CODE

Douglas A. Barber, Thomas J. Downar

School of Nuclear Engineering
Purdue University
W. Lafayette, IN 47907-1290

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I. Introduction

The General Interface is designed as a self-contained process which communicates with the thermal-hydraulic and neutronic processes using the Parallel Virtual Machine (PVM) package. As described in the Software Requirements Specification[(1)], the General Interface was designed such that it could be used to couple any thermal-hydraulics code with any neutronics code without the need for modifications to the General Interface source. To meet this requirement, separate code-specific data map routines are utilized for the thermal-hydraulics and neutronics code. These code-specific routines function as secondary interfaces by managing the transfer of data both to and from the General Interface

The General Interface contains three functional units and one error checking unit. The three functional units correspond to (1) initialization, (2) thermal-hydraulics to neutronics mapping, and (3) neutronics to thermal-hydraulics mapping. The data which is transferred through the General Interface relates to thermal-hydraulic and neutronic control information and thermal-hydraulic and neutronic property data. In addition, the mapping between the thermal-hydraulic and neutronic spatial domains is represented by permutation matrices, which are constructed by either of the code-specific routines and sent to the General Interface during the initialization.

Section II of this document discusses the execution results of the Qualification Assessment Test Plan (QATP) for the General Interface[(2)], which was designed to test the above requirements. Section III provides insight into the limitations of this General Interface design. And Section IV discusses a few improvements which could be made to the General Interface in the future.

II. Test Plan Results

The QATP for the General Interface was executed for each of the seven cases described in Appendix A of the QATP. Table 1 through Table 7 lists the test section for each of these cases and indicates whether the execution was successful. Table 1 also includes results from the parametrics described in the QATP. In addition, comments are included which provide some detail concerning the result which was obtained.

Table 1: Matrix of Test Results for Case 1 of the QATP

Test Section of QATP	Successful ?	Comments
Case 1: [QATP- Section II] Base test case.		
I.A.1	true	The initial thermal-hydraulic control buffers shown for Case 1 in Appendix E of the QATP were received correctly from the thermal-hydraulic process and sent correctly to the neutronic process.

Table 1: Matrix of Test Results for Case 1 of the QATP

I.A.2	true	The initial neutronic control buffers shown for Case 1 in Appendix E of the QATP were received correctly from the neutronic process and sent correctly to the thermal-hydraulic process.
I.A.4	true	The permutation matrices were received correctly from the neutronic process and were consistent with the data shown for Case 1 in Appendix B of the QATP.
I.B.1	true	The unpermuted thermal-hydraulic vector shown for Case 1 in Appendix C of the QATP was received correctly from the thermal-hydraulic process.
I.B.2	true	The matrix-vector multiply was performed and the resulting permuted vector was consistent with that shown for Case 1 in Appendix D of the QATP.
I.B.3	true	The permuted thermal-hydraulic vector was sent correctly to the neutronic process.
I.B.4	true	The time-dependent thermal-hydraulic control buffers shown for Case 1 in Appendix F of the QATP were received correctly from the thermal-hydraulic process and sent correctly to the neutronic process.
I.C.1	true	The unpermuted neutronic vector shown for Case 1 in Appendix C of the QATP was received correctly from the neutronic process.
I.C.2	true	The matrix-vector multiply was performed and the resulting permuted vector was consistent with that shown for Case 1 in Appendix D of the QATP.
I.C.3	true	The permuted neutronic vector was sent correctly to the thermal-hydraulic process.
I.C.4	true	The time-dependent neutronic control buffers shown for Case 1 in Appendix F of the QATP were received correctly from the neutronic process and sent correctly to the thermal-hydraulic process.
I.E.1	true	Normal termination was achieved resulting from detection of a signal sent from the thermal-hydraulic and neutronic processes.

Table 1: Matrix of Test Results for Case 1 of the QATP

Case 1a: [QATP- Section II] Parametric on receipt of permutation matrices.		
I.A.3	true	The permutation matrices were received correctly from the thermal-hydraulic process and were consistent with the data shown for Case 1 in Appendix B of the QATP.
Case 1b: [QATP- Section II: Initialization, 1b] Parametric for Initialization error.		
I.D.1 (Initialization)	true	Both the neutronic and thermal-hydraulic processes attempted to send the permutation matrices. This resulted in both an error message being printed and the safe termination of all three processes.
Case 1c: [QATP- Section II: Initialization, 1a] Parametric for Initialization error.		
I.D.1 (Initialization)	true	Neither the neutronic or thermal-hydraulic process attempted to send the permutation matrices. This resulted in both an error message being printed and the safe termination of all three processes.
Case 1d: [QATP- Section II: Initialization, 2a,2b,3a,3b] Parametric for Initialization error.		
I.D.2,3 (Initialization)	true	Permutation matrix elements were greater than 1.0. This resulted in both an error message being printed and the safe termination of all three processes.
Case 1e: [QATP- Section II: Initialization, 2c,2d,3c,3d] Parametric for Initialization error.		
I.D.2,3 (Initialization)	true	Permutation matrix elements were less than 0.0. This resulted in both an error message being printed and the safe termination of all three processes.
Case 1f: [QATP- Section II: T/H-to-Neut. Mapping, 1a] Parametric for T/H-to-Neut. error.		
I.D.1 (T/H-to-Neut.)	true	Decreasing the dimension of the unpermuted T/H vector during the first mapping step resulted in both the printing of an error message and the safe termination of all three processes.
Case 1g: [QATP- Section II: T/H-to-Neut. Mapping, 1b] Parametric for T/H-to-Neut. error.		
I.D.1 (T/H-to-Neut.)	true	Decreasing the dimension of the unpermuted T/H vector during the second mapping step resulted in both the printing of an error message and the safe termination of all three processes.

Table 1: Matrix of Test Results for Case 1 of the QATP

Case 1h: [QATP- Section II: T/H-to-Neut. Mapping, 2] Parametric for T/H-to-Neut. error.		
I.D.2 (T/H-to-Neut.)	true	Forcing elements of the vector data to be less than the 0.0 resulted in both the printing of an error message and the safe termination of all three processes.
Case 1i: [QATP- Section II: Neut.-to-T/H Mapping, 1a] Parametric for Neut.-to-T/H error.		
I.D.1 (Neut.-to-T/H)	true	Decreasing the dimension of the unpermuted neutronic vector during the first mapping step resulted in both the printing of an error message and the safe termination of all three processes.
Case 1j: [QATP- Section II: Neut.-to-T/H Mapping, 1b] Parametric for Neut.-to-T/H error.		
I.D.1 (Neut.-to-T/H)	true	Decreasing the dimension of the unpermuted neutronic vector during the second mapping step resulted in both the printing of an error message and the safe termination of all three processes.
Case 1k: [QATP- Section II: Neut.-to-T/H Mapping, 2] Parametric for Neut.-to-T/H error.		
I.D.2 (Neut.-to-T/H)	true	Forcing elements of the vector data to be less than the 0.0 resulted in both the printing of an error message and the safe termination of all three processes.
Case 1l: [QATP- Section II] Parametric for process error.		
I.E.2	true	Setting the first, second, and third logicals in the initial neutronic control buffer to “TRUE” resulted in both the printing of an error message and the safe termination of all three processes.
Case 1m: [QATP- Section II] Parametric for process error.		
I.E.2	true	Setting the first, second, and third logicals in the initial T/H control buffer to “TRUE” resulted in both the printing of an error message and the safe termination of all three processes.
Case 1n: [QATP- Section II] Parametric for process error.		
I.E.2	true	Setting the first, second, and third logicals in the time-dependent neutronic control buffer to “TRUE” resulted in both the printing of an error message and the safe termination of all three processes.

Table 1: Matrix of Test Results for Case 1 of the QATP

Case 1o: [QATP- Section II] Parametric for process error.		
I.E.2	true	Setting the first, second, and third logicals in the time-dependent T/H control buffer to “TRUE” resulted in both the printing of an error message and the safe termination of all three processes.

Table 2: Matrix of Test Results for Case 2 of the QATP

Test Section of QATP	Successful ?	Comments
I.A.1	true	The initial thermal-hydraulic control buffers shown for Case 2 in Appendix E of the QATP were received correctly from the thermal-hydraulic process and sent correctly to the neutronic process.
I.A.2	true	The initial neutronic control buffers shown for Case 2 in Appendix E of the QATP were received correctly from the neutronic process and sent correctly to the thermal-hydraulic process.
I.A.4	true	The permutation matrices were received correctly from the neutronic process and were consistent with the data shown for Case 2 in Appendix B of the QATP.
I.B.1	true	The unpermuted thermal-hydraulic vector shown for Case 2 in Appendix C of the QATP was received correctly from the thermal-hydraulic process.
I.B.2	true	The matrix-vector multiply was performed and the resulting permuted vector was consistent with that shown for Case 2 in Appendix D of the QATP.
I.B.3	true	The permuted thermal-hydraulic vector was sent correctly to the neutronic process.
I.B.4	true	The time-dependent thermal-hydraulic control buffers shown for Case 2 in Appendix F of the QATP were received correctly from the thermal-hydraulic process and sent correctly to the neutronic process.
I.C.1	true	The unpermuted neutronic vector shown for Case 2 in Appendix C of the QATP was received correctly from the neutronic process.

Table 2: Matrix of Test Results for Case 2 of the QATP

I.C.2	true	The matrix-vector multiply was performed and the resulting permuted vector was consistent with that shown for Case 2 in Appendix D of the QATP.
I.C.3	true	The permuted neutronic vector was sent correctly to the thermal-hydraulic process.
I.C.4	true	The time-dependent neutronic control buffers shown for Case 2 in Appendix F of the QATP were received correctly from the neutronic process and sent correctly to the thermal-hydraulic process.
I.E.1	true	Normal termination was achieved resulting from detection of a signal sent from the thermal-hydraulic and neutronic processes.

Table 3: Matrix of Test Results for Case 3 of the QATP

Test Section of QATP	Successful ?	Comments
I.A.1	true	The initial thermal-hydraulic control buffers shown for Case 3 in Appendix E of the QATP were received correctly from the thermal-hydraulic process and sent correctly to the neutronic process.
I.A.2	true	The initial neutronic control buffers shown for Case 3 in Appendix E of the QATP were received correctly from the neutronic process and sent correctly to the thermal-hydraulic process.
I.A.4	true	The permutation matrices were received correctly from the neutronic process and were consistent with the data shown for Case 3 in Appendix B of the QATP.
I.B.1	true	The unpermuted thermal-hydraulic vector shown for Case 3 in Appendix C of the QATP was received correctly from the thermal-hydraulic process.
I.B.2	true	The matrix-vector multiply was performed and the resulting permuted vector was consistent with that shown for Case 3 in Appendix D of the QATP.
I.B.3	true	The permuted thermal-hydraulic vector was sent correctly to the neutronic process.

Table 3: Matrix of Test Results for Case 3 of the QATP

I.B.4	true	The time-dependent thermal-hydraulic control buffers shown for Case 3 in Appendix F of the QATP were received correctly from the thermal-hydraulic process and sent correctly to the neutronic process.
I.C.1	true	The unpermuted neutronic vector shown for Case 3 in Appendix C of the QATP was received correctly from the neutronic process.
I.C.2	true	The matrix-vector multiply was performed and the resulting permuted vector was consistent with that shown for Case 3 in Appendix D of the QATP.
I.C.3	true	The permuted neutronic vector was sent correctly to the thermal-hydraulic process.
I.C.4	true	The time-dependent neutronic control buffers shown for Case 3 in Appendix F of the QATP were received correctly from the neutronic process and sent correctly to the thermal-hydraulic process.
I.E.1	true	Normal termination was achieved resulting from detection of a signal sent from the thermal-hydraulic and neutronic processes.

Table 4: Matrix of Test Results for Case 4 of the QATP

Test Section of QATP	Successful ?	Comments
I.A.1	true	The initial thermal-hydraulic control buffers shown for Case 4 in Appendix E of the QATP were received correctly from the thermal-hydraulic process and sent correctly to the neutronic process.
I.A.2	true	The initial neutronic control buffers shown for Case 4 in Appendix E of the QATP were received correctly from the neutronic process and sent correctly to the thermal-hydraulic process.
I.A.4	true	The permutation matrices were received correctly from the neutronic process and were consistent with the data shown for Case 4 in Appendix B of the QATP.

Table 4: Matrix of Test Results for Case 4 of the QATP

I.B.1	true	The unpermuted thermal-hydraulic vector shown for Case 4 in Appendix C of the QATP was received correctly from the thermal-hydraulic process.
I.B.2	true	The matrix-vector multiply was performed and the resulting permuted vector was consistent with that shown for Case 4 in Appendix D of the QATP.
I.B.3	true	The permuted thermal-hydraulic vector was sent correctly to the neutronic process.
I.B.4	true	The time-dependent thermal-hydraulic control buffers shown for Case 4 in Appendix F of the QATP were received correctly from the thermal-hydraulic process and sent correctly to the neutronic process.
I.C.1	true	The unpermuted neutronic vector shown for Case 4 in Appendix C of the QATP was received correctly from the neutronic process.
I.C.2	true	The matrix-vector multiply was performed and the resulting permuted vector was consistent with that shown for Case 4 in Appendix D of the QATP.
I.C.3	true	The permuted neutronic vector was sent correctly to the thermal-hydraulic process.
I.C.4	true	The time-dependent neutronic control buffers shown for Case 4 in Appendix F of the QATP were received correctly from the neutronic process and sent correctly to the thermal-hydraulic process.
I.E.1	true	Normal termination was achieved resulting from detection of a signal sent from the thermal-hydraulic and neutronic processes.

Table 5: Matrix of Test Results for Case 5 of the QATP

Test Section of QATP	Successful ?	Comments
I.A.1	true	The initial thermal-hydraulic control buffers shown for Case 5 in Appendix E of the QATP were received correctly from the thermal-hydraulic process and sent correctly to the neutronic process.
I.A.2	true	The initial neutronic control buffers shown for Case 5 in Appendix E of the QATP were received correctly from the neutronic process and sent correctly to the thermal-hydraulic process.
I.A.4	true	The permutation matrices were received correctly from the neutronic process and were consistent with the data shown for Case 5 in Appendix B of the QATP.
I.B.1	true	The unpermuted thermal-hydraulic vector shown for Case 5 in Appendix C of the QATP was received correctly from the thermal-hydraulic process.
I.B.2	true	The matrix-vector multiply was performed and the resulting permuted vector was consistent with that shown for Case 5 in Appendix D of the QATP.
I.B.3	true	The permuted thermal-hydraulic vector was sent correctly to the neutronic process.
I.B.4	true	The time-dependent thermal-hydraulic control buffers shown for Case 5 in Appendix F of the QATP were received correctly from the thermal-hydraulic process and sent correctly to the neutronic process.
I.C.1	true	The unpermuted neutronic vector shown for Case 5 in Appendix C of the QATP was received correctly from the neutronic process.
I.C.2	true	The matrix-vector multiply was performed and the resulting permuted vector was consistent with that shown for Case 5 in Appendix D of the QATP.
I.C.3	true	The permuted neutronic vector was sent correctly to the thermal-hydraulic process.

Table 5: Matrix of Test Results for Case 5 of the QATP

I.C.4	true	The time-dependent neutronic control buffers shown for Case 5 in Appendix F of the QATP were received correctly from the neutronic process and sent correctly to the thermal-hydraulic process.
I.E.1	true	Normal termination was achieved resulting from detection of a signal sent from the thermal-hydraulic and neutronic processes.

Table 6: Matrix of Test Results for Case 6 of the QATP

Test Section of QATP	Successful ?	Comments
I.A.1	true	The initial thermal-hydraulic control buffers shown for Case 6 in Appendix E of the QATP were received correctly from the thermal-hydraulic process and sent correctly to the neutronic process.
I.A.2	true	The initial neutronic control buffers shown for Case 6 in Appendix E of the QATP were received correctly from the neutronic process and sent correctly to the thermal-hydraulic process.
I.A.4	true	The permutation matrices were received correctly from the neutronic process and were consistent with the data shown for Case 6 in Appendix B of the QATP.
I.B.1	true	The unpermuted thermal-hydraulic vector shown for Case 6 in Appendix C of the QATP was received correctly from the thermal-hydraulic process.
I.B.2	true	The matrix-vector multiply was performed and the resulting permuted vector was consistent with that shown for Case 6 in Appendix D of the QATP.
I.B.3	true	The permuted thermal-hydraulic vector was sent correctly to the neutronic process.
I.B.4	true	The time-dependent thermal-hydraulic control buffers shown for Case 6 in Appendix F of the QATP were received correctly from the thermal-hydraulic process and sent correctly to the neutronic process.

Table 6: Matrix of Test Results for Case 6 of the QATP

I.C.1	true	The unpermuted neutronic vector shown for Case 6 in Appendix C of the QATP was received correctly from the neutronic process.
I.C.2	true	The matrix-vector multiply was performed and the resulting permuted vector was consistent with that shown for Case 6 in Appendix D of the QATP.
I.C.3	true	The permuted neutronic vector was sent correctly to the thermal-hydraulic process.
I.C.4	true	The time-dependent neutronic control buffers shown for Case 6 in Appendix F of the QATP were received correctly from the neutronic process and sent correctly to the thermal-hydraulic process.
I.E.1	true	Normal termination was achieved resulting from detection of a signal sent from the thermal-hydraulic and neutronic processes.

Table 7: Matrix of Test Results for Case 7 of the QATP

Test Section of QATP	Successful ?	Comments
I.A.1	true	The initial thermal-hydraulic control buffers shown for Case 7 in Appendix E of the QATP were received correctly from the thermal-hydraulic process and sent correctly to the neutronic process.
I.A.2	true	The initial neutronic control buffers shown for Case 7 in Appendix E of the QATP were received correctly from the neutronic process and sent correctly to the thermal-hydraulic process.
I.A.4	true	The permutation matrices were received correctly from the neutronic process and were consistent with the data shown for Case 7 in Appendix B of the QATP.
I.B.1	true	The unpermuted thermal-hydraulic vector shown for Case 7 in Appendix C of the QATP was received correctly from the thermal-hydraulic process.

Table 7: Matrix of Test Results for Case 7 of the QATP

I.B.2	true	The matrix-vector multiply was performed and the resulting permuted vector was consistent with that shown for Case 7 in Appendix D of the QATP.
I.B.3	true	The permuted thermal-hydraulic vector was sent correctly to the neutronic process.
I.B.4	true	The time-dependent thermal-hydraulic control buffers shown for Case 7 in Appendix F of the QATP were received correctly from the thermal-hydraulic process and sent correctly to the neutronic process.
I.C.1	true	The unpermuted neutronic vector shown for Case 7 in Appendix C of the QATP was received correctly from the neutronic process.
I.C.2	true	The matrix-vector multiply was performed and the resulting permuted vector was consistent with that shown for Case 7 in Appendix D of the QATP.
I.C.3	true	The permuted neutronic vector was sent correctly to the thermal-hydraulic process.
I.C.4	true	The time-dependent neutronic control buffers shown for Case 7 in Appendix F of the QATP were received correctly from the neutronic process and sent correctly to the thermal-hydraulic process.
I.E.1	true	Normal termination was achieved resulting from detection of a signal sent from the thermal-hydraulic and neutronic processes.

III. Lessons Learned

In an effort to maintain flexibility in coupling any thermal-hydraulic code with any neutronic code, it was necessary to require that the code-specific data map routines handle much of the calculational control. This may be intuitive, but the most prominent drawback of this approach is the fact that the code-specific routines can no longer be specific to just the respective code, and replacing either the thermal-hydraulics or neutronics code would require modifications to both the thermal-hydraulic and neutronic data map routines. In retrospect, this is most likely the best of all possible approaches since in most cases, the modifications to existing data map routines would be minimal when interchanging thermal-hydraulic codes or neutronic codes. However, with sufficient resources, it is possible that the interface could have been designed to manage some of the computational burden without sacrificing generality, thus removing the need for the code-specific data map routines to be specific to both the thermal-hydraulic and neutronic codes.

IV. Future Improvements

The following improvements could be made to the General Interface in the future:

IV.A. Simultaneous Execution

In the current implementation, PVM barriers are utilized during the initialization of the T/H-Specific Data Map Routine, General Interface, and Neutronic-Specific Data Map Routine, which synchronize the three processes such that the communication paths between the processes can be established. The design of these coding sections restricts the number of simultaneous coupled executions to one. More precisely, it is possible for many simultaneous jobs to be initiated, but there is no guarantee of safe execution. In addition, the use of the PVM barrier in this coding section limits the fault detection of the three processes because there is no associated time limit for how long a process should wait on a barrier. As an example, the General Interface will wait on a barrier until the thermal-hydraulic and neutronic processes join the group. If either of these processes are not started or one of them fails to reach the barrier call, then the General Interface will be suspended indefinitely with no mechanism for terminating the execution. Thus, implementing a more sophisticated barrier could allow for the safe execution of several simultaneous coupled jobs, and could provide better fault detection for failed or unstarted processes.

IV.B. Processing Order for the Initial Control Buffers

In the current design, the processing of the initial control buffers is hard-wired such that the neutronics buffer is always processed prior to the thermal-hydraulic buffer. In the future, it may be necessary to generalize this treatment and allow the user to determine which buffer should be processed first.

IV.C. Time-Dependent Calculational Control

The current design of the General Interface lends itself to the explicit temporal coupling in which the thermal-hydraulics code lags the neutronics code by one time step. Specifically, during a time step, the thermal-hydraulics to neutronics mapping unit is called first, followed by the neutronics to thermal-hydraulics mapping unit. This design does not preclude the coupling of the two codes in time such that the neutronics code lags the thermal-hydraulics code. However, it does make it slightly more cumbersome. In the future, it would be beneficial to modify the General Interface to provide flexibility concerning the flow through the mapping units.

V. Summary

The primary purpose of the General Interface is to facilitate the coupling of any thermal-hydraulics code with any neutronics code. To meet this objective, the General Interface was designed with several functional requirements as described in the Software Requirements Specification. The successful execution of the Qualification Assessment Test Plan, which was designed to test these functions, was discussed in Section II.

The limitations of this General Interface are few, but those that exist warrant future attention, as discussed in Section IV. It should be noted that these limitations do not affect the applicability of the General Interface, but simply reduce its ease of use for certain coupling strategies. The modifications necessary to remove these limitations would be minimal, and would increase the flexibility of the General Interface in treating many different thermal-hydraulic/neutronic couplings.

VI. References

1. D. Barber and T. Downar, "Software Requirements Specification for the General Interface in the Coupled Code," Technical Report, PU/NE-98-8, Purdue University, (1998).

2. D. Barber, T. Downar, W. Wang, and G. Mortensen, "Qualification Assessment Test Plan for the General Interface in the Coupled Code," Technical Report, PU/NE-98-9, Purdue University, (1998).