Extensions to the Basic Model Interface to Support Serialization of a Model's State Variables for Load Balancing and Checkpointing

Scott D. Peckham[1,4], Jessica L. Garrett[1,3], Jonathan M. Frame[1,5], Keith S. Jennings[1,3], Luciana L. Kindl da Cunha[1,6], Shengting Cui[1,2], Robert L. Bartel[1], Nels J. Frazier[1,2], Donald W. Johnson[1], Fred L. Ogden[1], Trey C. Flowers[1]

[1]NOAA National Water Center, [2]ERT Inc., [3]Lynker Technologies, [4]University of Colorado, [5]University of Alabama, [6]West Consultants, Inc.

2021 AGU Fall Meeting

NOAA's NextGen National Water Model & BMI

In coordination with federal water prediction partners, NOAA's Office of Water Prediction (OWP) leads development of a model coupling framework called the Next Generation Water Resources Modeling Framework (Nextgen). As the next version of the National Water Model, this framework uses a non-invasive, community-standard API for computational models called the Basic Model Interface (BMI). Nextgen uses an Adapter-Mediator pattern to access model functions using calls to BMI functions.

BMI function calls provide fine-grained control (initialize, update, finalize), variable getters and setters, and functions to retrieve information about a model's input and output variables (e.g. grid, type, and units). This information allows the framework to automatically call mediators, when needed, to facilitate passing values of variables between models (e.g. for regridding, time interpolation and unit conversion). BMI supports models written in **C, C++, Fortran and Python**. The Nextgen project has implemented BMI for several hydrologic models and has run proof-of-concept tests.

BMI provides something like a universal remote control for interacting with a set of ***heterogeneous*** models, written by different authors in different languages, etc.

The Basic Model Interface (BMI) v2.0

BMI was developed by NSF-funded CSDMS = Community Surface Dynamics Modeling System

See: *https://bmi.readthedocs.io/en/latest/*

Model Control Functions

initialize
update
update_until
finalize

Model Info Functions

get_component_name
get_input_item_count
get_input_var_names
get_output_item_count
get_output_var_names

BMI

Variable Info Functions

get_var_type
get_var_units
get_var_itemsize
get_var_nbytes
get_var_grid
get_var_location

Time Info Functions

get_start_time
get_current_time
get_end_time
get_time_step
get_time_units

Grid Info Functions

get_grid_type
get_grid_shape
get_grid_spacing
(and more…..)

Variable Getter and Setter Functions

get_value
get_value_ptr
get_value_at_indices
set_value
set_value_at_indices

Extending BMI with Variable Roles

In BMI version 2.0, the focus was on coupling models, i.e. passing the values of variables between models and automatically calling mediators for regridding, unit conversion, and temporal interpolation. BMI variable information functions (i.e. get_var_*) therefore only needed to provide metadata for a model's input and output variables.

We've extended BMI to provide metadata for *any* model variable, including its role. This supports new capabilities such as model serialization and calibration.

New Variable Role Names

- all
- array_length
- constant
- diagnostic
- directory
- filename
- file_offset
- info_string
- input_from_bmi
- input_from_file
- not_set
- option
- output_to_bmi
- output_to_file
- parameter_adjustable
- parameter_fixed
- state
- time_info

Extending BMI with New Functions

BMI Function	Description
get_bmi_version	Get the version of the Basic Model Interface.
get_var_count	Get the number of variables that have the given role.
get_var_names	Get the names of all variables that have the given role.

Variable Information Functions

BMI Function	Description
get_var_type	Get the data type of a variable.
get_var_units	Get the units of a variable.
get_var_itemsize	Get size of one element of a variable (in bytes).
get_var_nbytes	Get the total size of a variable (in bytes).
get_var_grid	Get the integer grid identifier for a variable.
get_var_location	Get the grid element type of a variable (e.g. “node”, “face”)
get_var_role	Get the role of a variable.
get_var_length	Get total number of elements of a variable.
get_var_index	Get the index of a variable (in struct array).

A new role-based get_var_count() generalizes the BMI v. 2.0 functions: get_input_item_count() and get_output_item_count().

Similarly, a new get_var_names() generalizes the BMI v. 2.0 functions: get_input_var_names() and get_output_var_names().

Variable Information Functions now return info for ***any*** model variable, not just input and output variables.

Three new functions (left, in red) have been added to get the ***role***, array ***length*** and (var_info) ***index***.

Framework Utility for Serialization & Deserialization

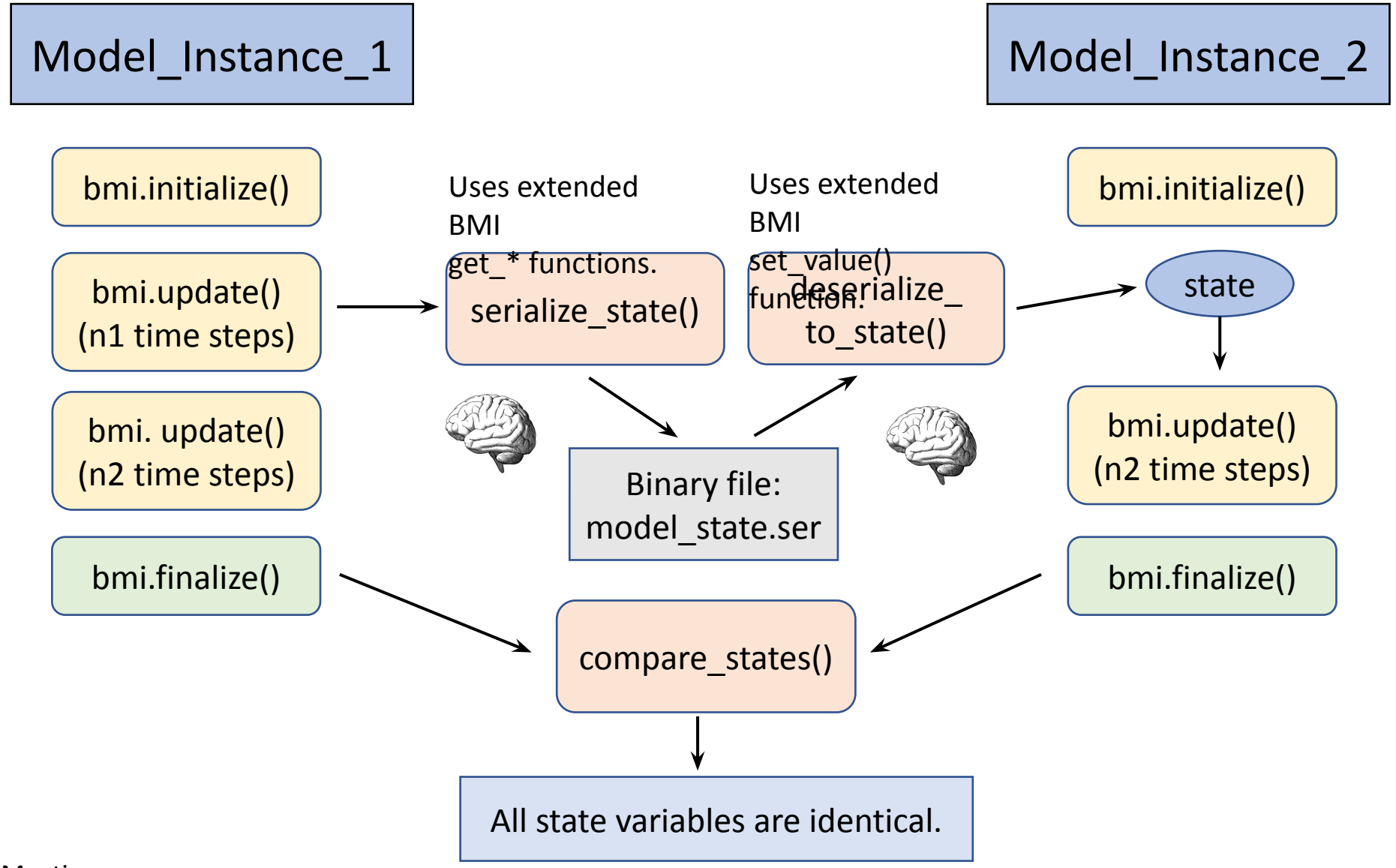
BMI follows a **separation of concerns** philosophy that provides model developers with maximum added value for a minimum amount of extra work. The modeling framework (e.g. CSDMS or NextGen) uses information provided by BMI functions in order to ***automatically*** perform tasks such as ***coupling*** (i.e. mediation required to exchange values), ***calibration*** & ***serialization***. The framework calls general-purpose **framework utilities** to perform these tasks without user intervention.

We have written a general framework utility for efficient, ***binary*** serialization and deserialization of model state variables that provides the functions shown here.

It gets required information from BMI functions and uses the **msgpack-c** library.

Utility Function	Description
get_file_size	Get size of file with binary, serialized model state.
get_state_var_count	Get the total number of model “state” variables.
get_state_var_names	Get the names of all model ”state” variables.
get_state_var_types	Get the types of all model ”state” variables.
get_state_var_lengths	Get the array lengths of all model ”state” variables.
get_state_var_ptrs	Get pointers to all model ”state” variables.
serialize	Serialize all model ”state” variables to a binary file.
deserialize_to_state	Deserialize saved model state and write to new instance.
compare_states	Compare all ”state” variables for 2 instances of a model.

Serialization and Transference of Model State



Simplified BMI Implementation for C Models

```c
typedef struct Variable{
    unsigned int index;
    char name[BMI_MAX_VAR_NAME];
    char type[BMI_MAX_TYPE_NAME];
    unsigned int length;  // (nbytes / itemsize)
    char role[BMI_MAX_ROLE_NAME];
    char units[BMI_MAX_UNITS_NAME];
    char location[BMI_MAX_LOCATION_NAME];  // e.g. "node", "face"
    int grid; // e.g. 0
} Variable;
```

Define a type “Variable” as a struct with fields for all of the variable attributes in the C header file.

Then define “var_info” as an array of type “Variable” as shown below.

Advantages

Easier to implement the BMI functions.

Helps to prevent “misalignment errors”.

Most BMI get_var_* functions can then be written to get variable info from here and can be reused with little or no change for all C models

```c
Variable var_info[] = {
{ 0,  "input_dir",  "char",   80, "directory",           "none", "none", -1 }
{ 1,  "input_file", "char",   80, "filename",            "none", "none", -1 },
{ 2,  "pi",         "double",  1, "constant",            "none", "node", -1 },
{ 3,  "x",          "double", 10, "input_from_bmi",         "m", "node",  0 },
{ 4,  "y",          "double", 10, "output_to_bmi",          "m", "node",  0 },
{ 5,  "m",          "double",  1, "parameter_adjustable", "none", "none", -1 },
{ 6,  "b",          "double",  1, "parameter_adjustable",    "m", "none", -1 },
{ 7,  "verbose",    "int",     1, "option",              "none", "node", -1 },
{ 8,  "n_steps",    "int",     1, "time_info",           "none", "none", -1 },
{ 9,  "time_step",  "int",     1, "time_info",              "h", "none", -1 },
{ 10, "model_name", "char",   80, "info_string",         "none", "none", -1 },
{ 11, "error_code", "int",     1, "diagnostic",          "none", "none", -1 } }
```

Summary

To support the requirements of NOAA's NextGen Modeling Framework, we have extended the Basic Model Inferface (BMI) v. 2.0 by:

(1) Introducing a variable's ***role*** as a new attribute (with 17 role names),

(2) Implementing ***reusable*** Variable Information Functions for ***all*** variables.

(3) Adding a few new BMI functions.

(4) Providing a simplified "var_info" mechanism for BMI implementation.

These enhancements extend the capabilities of BMI beyond ***model coupling*** to support ***calibration***, ***serialization*** and other future, role-based capabilities.

Serialization & deserialization is provided to models with a ***new framework utility*** that supports HPC ***load balancing*** and ***checkpointing***.

You can email me at: scott.peckham@noaa.gov for more information.

Thank You!

Scott D. Peckham, NOAA Affiliate
University of Colorado, Boulder

scott.peckham@noaa.gov

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