



The Dynare Preprocessor

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CEPREMAP

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Overview



Outline

- 1 Invoking the preprocessor
- 2 Macro processing
- 3 Parsing
- 4 Data structure representing a mod file
- 5 Check pass
- 6 Transform pass
- 7 Computing pass
- 8 Writing outputs
- 9 Proposed Changes

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Calling Dynare

- Dynare is called from the host language platform with the syntax `dynare «filename».mod`
- This call can be followed by certain options:
 - ▶ Some of these options impact host language platform functionality
→ e.g. `nograph` prevents graphs from being displayed in MATLAB
 - ▶ Some cause differences in the output created by default
→ `notmpterm`s prevents temporary terms from being written to the static/dynamic files
 - ▶ While others impact the functionality of the macroprocessor or the preprocessor
→ e.g. `nostrict` shuts off certain checks that the preprocessor does by default
- MATLAB command line supports syntax completion since Dynare 6.x

Command line options in the mod-file

- Command line options can alternatively be defined in the first line of the .mod file
- Avoids to always have to invoke an option at the command line
→ particularly useful for the `nostrict` option during the development phase of a model
- Definition must be
 - ▶ a one-line Dynare comment, i.e. `begin //`
 - ▶ the options must be enclosed in `--+ options:` and `+++` and must be whitespace separated
 - ▶ As in the command line, if an option admits a value, the equal symbol must not be surrounded by spaces

Example

```
// --+ options: json=compute, stochastic, nostrict +++
```

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Macro processing

- The Dynare macro language provides a set of macro commands that can be used in `mod` files
- The macro processor employs text expansions/inclusions to transform a `mod` file with macro commands into a `mod` file without macro commands
→ result can be stored using `savemacro` option
- The result is fed to the parser
→ use `onlymacro` to stop after macro processing before parsing
- Attention: the macro processor only does text substitution; objects computed in later steps are not available yet and cannot be conditioned on for that reason

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Parsing overview

- Parsing is the action of transforming an input text (a mod file in our case) into a data structure suitable for computation
- The parser consists of three components:
 - ① the **lexical analyzer**, which recognizes the “words” of the mod file (analog to the *vocabulary* of a language)
 - ② the **syntax analyzer**, which recognizes the “sentences” of the mod file (analog to the *grammar* of a language)
 - ③ the **parsing driver**, which coordinates the whole process and constructs the data structure using the results of the lexical and syntax analyses

Undesired Parsing

- Dynare will try to parse all tokens it recognizes
- Code not recognized by the parser is directly passed to the preprocessor output
→ allows using MATLAB/Octave commands directly in the mod-file
- Causes problems when one wants to invoke commands containing recognized tokens

Bypassing the parsing

- The `verbatim` block instructs Dynare not to parse text contained in it
- In the following example, `stoch_simul` would otherwise be recognized as a Dynare command during parsing

Verbatim example

```
verbatim;  
rhos = [ 0.8, 0.9, 1];  
for iter = 1:length(rhos)  
    set_param_value('rho',rhos(iter));  
    [info, oo_, options_, M_] = stoch_simul(M_, options_, oo_, var_list_)  
    if info(1)~=0  
        error('Simulation failed for parameter draw')  
    end  
end  
end;
```

1. Lexical analysis

- The lexical analyzer recognizes the “words” (or **lexemes**) of the language
- Defined in `DynareFlex.ll`, it is transformed into C++ source code by the program `flex`
- This file details the list of known lexemes (described by regular expressions) and the associated **token** for each of them
- For punctuation (semicolon, parentheses, ...), operators (+, -, ...) or fixed keywords (e.g. `model`, `varexo`, ...), the token is simply an integer uniquely identifying the lexeme
- For variable names or numbers, the token also contains the associated string for further processing
- When invoked, the lexical analyzer reads the next characters of the input, tries to recognize a lexeme, and either produces an error or returns the associated token

Lexical analysis

An example

- Suppose the mod file contains the following:
`model;`
`x = log(3.5);`
`end;`
- Before lexical analysis, it is only a sequence of characters
- The lexical analysis produces the following stream of tokens:

```
MODEL  
SEMICOLON  
NAME "x"  
EQUAL  
LOG  
LEFT_PARENTHESIS  
FLOAT_NUMBER "3.5"  
RIGHT_PARENTHESIS  
SEMICOLON  
END  
SEMICOLON
```

2. Syntax analysis

In Dynare

- The `mod` file grammar is described in `DynareBison.yy`, which is transformed into C++ source code by the program `bison`
- The grammar tells a story which looks like:
 - ▶ A `mod` file is a list of statements
 - ▶ A statement can be a `var` statement, a `varexo` statement, a `model` block, an `initval` block, ...
 - ▶ A `var` statement begins with the token `VAR`, then a list of `NAMES`, then a semicolon
 - ▶ A `model` block begins with the token `MODEL`, then a semicolon, then a list of equations separated by semicolons, then an `END` token
 - ▶ An equation can be either an expression, or an expression followed by an `EQUAL` token and another expression
 - ▶ An expression can be a `NAME`, or a `FLOAT_NUMBER`, or an expression followed by a `PLUS` and another expression, ...

Syntax analysis

Using the list of tokens produced by lexical analysis, the syntax analyzer determines which “sentences” are valid in the language, according to a **grammar** composed of **rules**.

A grammar for lists of additive and multiplicative expressions

```
%start expression_list;

expression_list := expression SEMICOLON
                 | expression_list expression SEMICOLON;

expression := expression PLUS expression
            | expression TIMES expression
            | LEFT_PAREN expression RIGHT_PAREN
            | INT_NUMBER;
```

- $(1+3)*2$; $4+5$; will pass the syntax analysis without error
- $1++2$; will fail the syntax analysis, even though it has passed the lexical analysis

Semantic actions

- So far we have only described how to accept valid mod files and reject others
- But validating is not enough: one needs to do something with the parsed mod file
- Every grammar rule can have a **semantic action** associated with it: C/C++ code enclosed by curly braces
- Every rule can return a semantic value (referenced by \$\$ in the action)
- In the action, it is possible to refer to semantic values returned by components of the rule (using \$1, \$2, ...)

Semantic actions

An example

A simple calculator which prints its results

```
%start expression_list
```

```
%type <int> expression
```

```
expression_list := expression SEMICOLON
                  { cout << $1 << endl; }
                  | expression_list expression SEMICOLON
                  { cout << $2 << endl; };
```

```
expression := expression PLUS expression
              { $$ = $1 + $3; }
              | expression TIMES expression
              { $$ = $1 * $3; }
              | LEFT_PAREN expression RIGHT_PAREN
              { $$ = $2; }
              | INT_NUMBER
              { $$ = $1; };
```

3. Parsing driver

The class `ParsingDriver` has the following roles:

- It opens the `mod` file and launches the lexical and syntactic analyzers on it
- It implements most of the semantic actions of the grammar
- By doing so, it creates an object of type `ModFile`, which is the data structure representing the `mod` file
- Or, if there is a parsing error (unknown keyword, undeclared symbol, syntax error), it displays the line and column numbers where the error occurred and exits

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The ModFile class

- This class is the internal data structure used to store all the information contained in a mod file
- One instance of the class represents one mod file
- The class contains the following elements (as class members):
 - ▶ a symbol table, numerical constants table, external functions table
 - ▶ trees of expressions: dynamic model, static model, original model, ramsey dynamic model, steady state model, trend dynamic model, ...
 - ▶ the list of the statements (parameter initializations, shocks block, check, steady, simul, ...)
 - ▶ model-specification and user-preference variables: block, bytecode, use_dll, no_static, ...
 - ▶ an evaluation context (containing initval and parameter values)
- An instance of ModFile is the output of the parsing process (return value of `ParsingDriver::parse()`)

The symbol table (1/3)

- A **symbol** is simply the name of a variable (endogenous, exogenous, local, auxiliary, etc), parameter, external function, ... basically everything that is not recognized as a Dynare keyword
- **SymbolTable** is a simple class used to maintain the list of the symbols used in the `mod` file
- For each symbol, it stores:
 - ▶ its name, `tex_name`, and `long_name` (strings, some of which can be empty)
 - ▶ its type (an enumerator defined in `CodeInterpreter.hh`)
 - ▶ a unique integer identifier (also has a unique identifier by type)

The symbol table (2/3)

Existing types of symbols:

- Endogenous variables
- Exogenous variables
- Exogenous deterministic variables
- Parameters
- Local variables inside model: declared with a pound sign (`#`) construction
- Local variables outside model: no declaration needed (e.g. lhs symbols in equations from `steady_state_model` block, expression outside of model block, ...)
- External functions
- Trend variables
- Log Trend variables
- Unused Endogenous variables (created when `nostrict` option is passed)

The symbol table (3/3)

- Symbol table filled in:
 - ▶ using the `var`, `varexo`, `varexo_det`, `parameter`, `external_function`, `trend_var`, and `log_trend_var` declarations
 - ▶ using pound sign (`#`) constructions (“model-local variables”) in the model block
 - ▶ on the fly during parsing: local variables outside models or unknown functions when an undeclared symbol is encountered
 - ▶ during the creation of auxiliary variables in the transform pass
- Roles of the symbol table:
 - ▶ permits parsimonious and more efficient representation of expressions (no need to duplicate or compare strings, only handle a pair of integers)
 - ▶ ensures that a given symbol is used with only one type

Expression trees (1/3)

- The data structure used to store expressions is essentially a **tree**
- Graphically, the tree representation of $(1 + z) * \log(y)$ is:



- No need to store parentheses
- Each circle represents a **node**
- A non external function node has at most one parent and at most three children (an external function node has as many children as arguments)

Expression trees (2/3)

- A tree node is represented by an instance of the abstract class `ExprNode`
- This class has 5 sub-classes, corresponding to the 5 types of non-external-function nodes:
 - ① `NumConstNode` for constant nodes: contains the identifier of the numerical constants it represents
 - ② `VariableNode` for variable/parameters nodes: contains the identifier of the variable or parameter it represents
 - ③ `UnaryOpNode` for unary operators (e.g. unary minus, log, sin): contains an enumerator representing the operator, and a pointer to its child
 - ④ `BinaryOpNode` for binary operators (e.g. $+$, $*$, pow): contains an enumerator representing the operator, and pointers to its two children
 - ⑤ `TrinaryOpNode` for trinary operators (e.g. *normcdf*, *normpdf*): contains an enumerator representing the operator and pointers to its three children

Expression trees (3/3)

- The abstract class `ExprNode` has an abstract sub-class called `AbstractExternalFunctionNode`
- This abstract sub-class has 3 sub-classes, corresponding to the 3 types of external function nodes:
 - 1 `ExternalFunctionNode` for external functions. Contains the identifier of the external function and a vector of its arguments
 - 2 `FirstDerivExternalFunctionNode` for the first derivative of an external function. In addition to the information contained in `ExternalFunctionNode`, contains the index w.r.t. which this node is the derivative.
 - 3 `SecondDerivExternalFunctionNode` for the second derivative of an external function. In addition to the information contained in `FirstDerivExternalFunctionNode`, contains the index w.r.t. which this node is the second derivative.

Classes DataTree and ModelTree

- Class DataTree is a container for storing a set of expression trees
- Class ModelTree is a sub-class container of DataTree, specialized for storing a set of model equations.
- In the code, we use ModelTree-derived classes: DynamicModel (the model with lags) and StaticModel (the model without lags)
- Class ModFile contains:
 - ▶ one instance of DataTree for storing all expressions outside model block
 - ▶ several instances of DynamicModel, one each for storing the equations of the model block for the original model, modified model, original Ramsey model, the Ramsey FOCs, etc.
 - ▶ one instance of StaticModel for storing the equations of model block without lags
- Expression storage is optimized through three mechanisms:
 - ▶ symbolic simplification rules
 - ▶ sub-expression sharing
 - ▶ pre-computing of numerical constants

Constructing expression trees

- Class `DataTree` contains a set of methods for constructing expression trees
- Construction is done bottom-up, node by node:
 - ▶ one method for adding a constant node (`AddPossiblyNegativeConstant(double)`)
 - ▶ one method for a log node (`AddLog(arg)`)
 - ▶ one method for a plus node (`AddPlus(arg1, arg2)`)
- These methods take pointers to `ExprNode`, allocate the memory for the node, construct it, and return its pointer
- These methods are called:
 - ▶ from `ParsingDriver` in the semantic actions associated to the parsing of expressions
 - ▶ during symbolic derivation to create derivatives expressions
 - ▶ when creating the static model from the dynamic model
 - ▶ ...

Reduction of constants and symbolic simplifications

- The construction methods compute constants whenever possible
 - ▶ Suppose you ask to construct the node $1 + 1$
 - ▶ The `AddPlus()` method will return a pointer to a constant node containing 2
- The construction methods also apply a set of simplification rules, such as:
 - ▶ $0 + 0 = 0$
 - ▶ $x + 0 = x$
 - ▶ $0 - x = -x$
 - ▶ $-(-x) = x$
 - ▶ $x * 0 = 0$
 - ▶ $x/1 = x$
 - ▶ $x^0 = 1$
- When a simplification rule applies, no new node is created
- Attention: this may cause the program to detect issues not directly visible to users like a division by 0

Sub-expression sharing (1/2)

- Consider the two following expressions: $(1 + z) * \log(y)$ and $2^{(1+z)}$
- Expressions share a common sub-expression: $1 + z$
- The internal representation of these expressions is:



Sub-expression sharing (2/2)

- Construction methods implement a simple algorithm which achieves maximal expression sharing
- Algorithm uses the fact that each node has a unique memory address (pointer to the corresponding instance of ExprNode)
- It maintains 9 tables which keep track of the already-constructed nodes: one table by type of node (constants, variables, unary ops, binary ops, trinary ops, external functions, first deriv of external functions, second deriv of external functions, local variables)
- Suppose you want to create the node $e_1 + e_2$ (where e_1 and e_2 are sub-expressions):
 - ▶ the algorithm searches the binary ops table for the tuple equal to (address of e_1 , address of e_2 , op code of $+$) (it is the **search key**)
 - ▶ if the tuple is found in the table, the node already exists and its memory address is returned
 - ▶ otherwise, the node is created and is added to the table with its search key
- Maximum sharing is achieved because expression trees are constructed bottom-up

Final remarks about expressions

- Storage of negative constants

- ▶ class NumConstNode only accepts positive constants
- ▶ a negative constant is stored as a unary minus applied to a positive constant
- ▶ this is a kind of identification constraint to avoid having two ways of representing negative constants: (-2) and $-(2)$

- Widely used constants

- ▶ class DataTree has attributes containing pointers to constants: 0, 1, 2, -1 , NaN, ∞ , $-\infty$, and π
- ▶ these constants are used in many places (in simplification rules, in derivation algorithm...)
- ▶ sub-expression sharing algorithm ensures that these constants will never be duplicated

List of statements

- A statement is represented by an instance of a subclass of the abstract class `Statement`
- Three groups of statements:
 - ▶ initialization statements (parameter initialization with $p = \dots$, `initval`, `histval`, or `endval` block)
 - ▶ shocks blocks (`shocks`, `mshocks`, ...)
 - ▶ computing tasks (`steady`, `check`, `perfect_foresight_solver`, ...)
- Each type of statement has its own class (e.g. `InitValStatement`, `PerfectForesightSolverStatement`, ...)
- The class `ModFile` stores a list of pointers of type `Statement*`, corresponding to the statements of the mod file, in their order of declaration
- Heavy use of polymorphism in the check pass, computing pass, and when writing outputs: abstract class `Statement` provides a virtual method for these 3 actions

Evaluation context

- The ModFile class contains an **evaluation context**
- It is a map associating a numerical value to some symbols
- Filled in with `initval` block values and parameter initializations
- Used during equation normalization (in the block decomposition), for finding non-zero entries in the Jacobian
- Used in testing that trends are compatible with a balanced growth path, for finding non-zero cross partials of equations with respect to trend variables and endogenous variables

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Error checking during parsing

- Some errors in the mod file can be detected during parsing:
 - ▶ syntax errors
 - ▶ use of undeclared symbols in model block, initval block. . .
 - ▶ use of a symbol incompatible with its type (e.g. parameter in initval, local variable used both in model and outside model)
 - ▶ multiple shock declarations for the same variable
- But some other checks can only be done when parsing is completed. . .

Check pass

- The check pass is implemented through the method `ModFile::checkPass()`
- Performs many checks. Examples include:
 - ▶ check there is at least one equation in the model (except if doing a standalone BVAR estimation)
 - ▶ checks for coherence in statements (e.g. options passed to statements do not conflict with each other, required options have been passed)
 - ▶ checks for coherence among statements (e.g. if `osr` statement is present, ensure `osr_params` and `optim_weights` statements are present)
 - ▶ checks for coherence between statements and attributes of mod file (e.g. `use_dll` is not used with `block` or `bytecode`)

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Transform pass (1/2)

- The transform pass is implemented through the method `ModFile::transformPass(bool nostrict)`
- It makes necessary transformations (notably to the dynamic model, symbol table, and statements list), preparing the `ModFile` object for the computing pass. Examples of transformations include:
 - ▶ creation of auxiliary variables and equations for leads, lags, expectation operator, differentiated forward variables, etc.
 - ▶ detrending of model equations if nonstationary variables are present
 - ▶ decreasing leads/lags of predetermined variables by one period
 - ▶ addition of FOCs of Lagrangian for Ramsey problem
 - ▶ addition of `dsge_prior_weight` initialization before all other statements if estimating a DSGE-VAR where the weight of the DSGE prior of the VAR is calibrated

Transform pass (2/2)

- It then freezes the symbol table, meaning that no more symbols can be created on the `ModFile` object
- Finally, checks are performed on the transformed model. Examples include:
 - ▶ same number of endogenous variables as equations (not done in certain situations, *e.g.* Ramsey, discretionary policy, where checks are done in MATLAB)
 - ▶ correspondence among variables and statements, *e.g.* Ramsey policy, identification, perfect foresight solver, and perfect foresight solver are incompatible with deterministic exogenous variables
 - ▶ correspondence among statements, *e.g.* for DSGE-VAR with `bayesian_irf` option, the number of shocks must be equal to the number of observed variables

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Overview of the computing pass

- Computing pass implemented in `ModFile::computingPass()`
- Creates static model from dynamic one (by removing leads/lags)
- Determines which derivatives to compute
- Then calls `DynamicModel::computingPass()`, which computes:
 - ▶ leag/lag variable incidence matrix
 - ▶ symbolic derivatives w.r.t. endogenous, exogenous, and parameters, if needed
 - ▶ equation normalization + block decomposition
 - ▶ temporary terms
 - ▶ computes equation cross references, if desired
- NB: analogous operations for static model are performed by `StaticModel::computingPass()`
- Asserts that equations declared `linear` are indeed linear (by checking that $\text{Hessian} == 0$)
- Finally, calls `Statement::computingPass()` on all statements

Model Variables

- In the context of class `ModelTree`, a **variable** is a pair (symbol, lag)
- The symbol must correspond to a variable of type endogenous, exogenous, deterministic exogenous variable, or parameter
- The `SymbolTable` class keeps track of valid symbols, while the `variable_node_map` keeps track of model variables (symbol, lag pairs stored in `VariableNode` objects)
- After the computing pass, the `DynamicModel` class writes the leag/lag incidence matrix:
 - ▶ $\text{max_lag} + \text{max_lead} + 1$ rows (usually 3): the first row indicates $t - 1$ (if applicable), the second row t , and the third row $t + 1$ (if applicable)
 - ▶ one column for every endogenous symbol in order of declaration; NB: includes endogenous auxiliary variables created during the transform pass
 - ▶ elements of the matrix are either 0 (if the variable does not appear in the model) or correspond to the variable's column in the Jacobian of the dynamic model

Static versus dynamic model

- The static model is simply the dynamic model without leads and lags
- Static model used to characterize the steady state
- The Jacobian of the static model is used in the (MATLAB) solver for determining the steady state

Example

- suppose dynamic model is $2x_t \cdot x_{t-1} = 0$
- static model is $2x^2 = 0$, whose derivative w.r.t. x is $4x$
- dynamic derivative w.r.t. x_t is $2x_{t-1}$, and w.r.t. x_{t-1} is $2x_t$
- removing leads/lags from dynamic derivatives and summing over the two partial derivatives w.r.t. x_t and x_{t-1} gives $4x$

Which derivatives to compute?

- In deterministic mode:
 - ▶ static Jacobian w.r.t. endogenous variables only
 - ▶ dynamic Jacobian w.r.t. endogenous variables only
- In stochastic mode:
 - ▶ static Jacobian w.r.t. endogenous variables only
 - ▶ dynamic Jacobian w.r.t. endogenous, exogenous, and deterministic exogenous variables
 - ▶ dynamic Hessian w.r.t. endogenous, exogenous, and deterministic exogenous variables
 - ▶ possibly dynamic 3rd derivatives (if `order option ≥ 3`)
 - ▶ possibly dynamic Jacobian and/or Hessian w.r.t. parameters (if `identification` or `analytic derivs` needed for estimation and `params_derivs_order > 0`)
- For Ramsey policy: the same as above, but with one further order of derivation than declared by the user with `order option` (the derivation order is determined in the check pass, see `RamseyPolicyStatement::checkPass()`)

Derivation algorithm (1/2)

- Derivation of the model implemented in `ModelTree::computeJacobian()`, `ModelTree::computeHessian()`, `ModelTree::computeThirdDerivatives()`, and `ModelTree::computeParamsDerivatives()`
- Simply call `ExprNode::getDerivative(deriv_id)` on each equation node
- Use of polymorphism:
 - ▶ for a constant or variable node, derivative is straightforward (0 or 1)
 - ▶ for a unary, binary, trinary op nodes and external function nodes, recursively calls method `computeDerivative()` on children to construct derivative

Derivation algorithm (2/2)

Optimizations

- Caching of derivation results
 - ▶ method `ExprNode::getDerivative(deriv_id)` memorizes its result in a member attribute (`derivatives`) the first time it is called
 - ▶ the second time it is called (with the same argument), it simply returns the cached value without recomputation
 - ▶ caching is useful because of sub-expression sharing
- Efficiently finds symbolic derivatives equal to 0
 - ▶ consider the expression $x + y^2$
 - ▶ without any computation, you know its derivative w.r.t. z is zero
 - ▶ each node stores in an attribute (`non_null_derivatives`) the set of variables which appear in the expression it represents ($\{x, y\}$ in the example)
 - ▶ this set is computed in `prepareForDerivation()`
 - ▶ when `getDerivative(deriv_id)` is called, immediately returns zero if `deriv_id` is not in that set

Temporary terms (1/2)

- When the preprocessor writes equations and derivatives in its outputs, it takes advantage of sub-expression sharing
- In MATLAB static and dynamic output files, equations are preceded by a list of **temporary terms**
- These terms are variables containing expressions shared by several equations or derivatives
- Using these terms greatly enhances the computing speed of the model residual, Jacobian, Hessian, or third derivative

Example

The equations:

```
residual(0)=x+y^2-z^3;  
residual(1)=3*(x+y^2)+1;
```

Can be optimized in:

```
T1=x+y^2;  
residual(0)=T1-z^3;  
residual(1)=3*T1+1;
```

Temporary terms (2/2)

- Expression storage in the preprocessor implements maximal sharing, but this is not optimal for the MATLAB output files, because creating a temporary variable also has a cost (in terms of CPU and of memory)
- Computation of temporary terms implements a trade-off between:
 - ▶ cost of duplicating sub-expressions
 - ▶ cost of creating new variables
- Algorithm uses a recursive cost calculation, which marks some nodes as being “temporary”
- *Problem*: redundant with optimizations done by the C/C++ compiler (when Dynare is in DLL mode)
⇒ compilation very slow on big models

The special case of Ramsey model

- For most statements, the method `computingPass()` is a no-op...
- ...except for `planner_objective` statement, which serves to declare planner objective when doing optimal policy under commitment
- Class `PlannerObjectiveStatement` contains an instance of `ModelTree` which stores the objective function (i.e. only one equation in the tree)
- During the computing pass, triggers the computation of the first and second order (static) derivatives of the objective

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Output overview

- Implemented in `ModFile::writeOutputFiles()`
- If mod file is `mymodel.mod`, all created filenames will begin with `mymodel`
- Main output file is `mymodel.driver`, containing:
 - ▶ general initialization commands
 - ▶ symbol table output (from `SymbolTable::writeOutput()`)
 - ▶ lead/lag incidence matrix (from `DynamicModel::writeDynamicMFile()`)
 - ▶ call to MATLAB functions corresponding to the statements of the mod file (written by calling `Statement::writeOutput()` on all statements through polymorphism)
- Subsidiary output files:
 - ▶ for the static model (residuals, temporary terms, derivatives)
 - ▶ for the dynamic model (residuals, temporary terms, derivatives)
 - ▶ one for the auxiliary variables in the dynamic model (if relevant)
 - ▶ one for the steady state file (if relevant)
 - ▶ for the planner objective and Lagrange multipliers (static residuals and derivatives, if relevant)
 - ▶ one each for the static and dynamic parameter derivatives (if required)

Model output files

Three possible output types:

- MATLAB/Octave mode: static and dynamic files in MATLAB
- Julia mode: static and dynamic files in Julia
- DLL mode:
 - ▶ static and dynamic files in C++ source code (with corresponding headers)
 - ▶ compiled through `mex` to allow execution from within MATLAB
- Sparse DLL mode:
 - ▶ static file in MATLAB
 - ▶ two possibilities for dynamic file:
 - ★ by default, a C++ source file (with header) and a binary file, to be read from the C++ code
 - ★ or, with `no_compiler` option, a binary file in custom format, executed from MATLAB through `simulate DLL`
 - ★ the second option serves to bypass compilation of C++ file which can be very slow

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- 9 Proposed Changes**

Proposed changes with addition of Julia support (1/2)

- ❶ Julia output is provided upon parsing of `mod` file, everything else done in Julia
 - ▶ Pros: very few changes to the preprocessor
 - ▶ Cons: repeated code (same checks, transformations, computations done in preprocessor and Julia); potential code divergence/two parallel projects
- ❷ Dump preprocessor altogether: do everything with Julia
 - ▶ Pros: simple to distribute, move away from C++ (no contributions, requires more expertise)
 - ▶ Cons: MATLAB/Octave users must also download Julia, a big project, speed (?)

Proposed changes with addition of Julia support (2/2)

- ③ Create libraries out of the preprocessor
 - ▶ Pros: Dynare interaction similar across HLPs, preprocessor used as is
 - ▶ Cons: difficult for outsiders to contribute, big project, not much benefit in speed when compared to...
- ④ Write `mod` file from HLP then call preprocessor; option to output JSON file representing `ModFile` object at every step of the preprocessor
 - ▶ Pros: Dynare interaction similar across HLPs, preprocessor used as is, minimal amount of work, easy incremental step, allows users to support any given HPL given the JSON output
 - ▶ Cons: unnecessary processing when certain changes made in host language, keeps defaults of current preprocessor, speed (?)
- ⑤ Other ideas?

Using HLP mod file objects (1/2)



Using HLP mod file objects (2/2)

- Allows interactivity for all HLPs; requires only
 - ▶ A definition of a mod file class in the HLP
 - ▶ A library function that converts an HLP mod file object to a `mod` file
- Allows users to use Dynare with any HPL. Standard JSON output can be read in any HPL; user can use it construct desired HPL objects and work with model in their language of preference
- Easy first step
- No divergence of codebase: don't need to repeat code (checks, transformations, etc.) across platforms
- Creates `mod` files that can be used on other host language platforms
- Adds one more HLP library to distribute
- Need to design/implement classes that will store processed Dynare `mod` file in various HLPs