Data Structure for a `PIHA` Object

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`GLOBAL_PIHA`, a `PIHA` object, obtained after the conversion from a C/E system consists of the following fields:

`Hyperplanes`	: List of threshold hyperplanes in the C/E system
`NAR`	: Number of hyperplanes on analysis boundary
`InitialContinuousSet`	: Set of initial continuous states
`InitialDiscreteSet`	: Set of initial discrete states
`Cells`	: List of cells in the continuous state space partition
`InitialCells`	: List of cells which overlaps with the initial continuous set
`Locations`	: List of hybrid automaton locations
`InitialConditions`	: List of initial locations
`InitialLocation_Cells`	: List of initial locations and cells
`CLOCKBlocks`	: List of clock blocks in the C/E system
`SCSBlocks`	: List of switch continuous system blocks in the C/E system
`PTHBlocks`	: List of polyhedral threshold blocks in the C/E system
`FSMBlocks`	: List of finite state machine blocks in the C/E system
`use_sd`	: Flag to indicate whether to perform sample-data difference equation analysis to any SCSB.

The detail of each field is described below.

1. `Hyperplanes`

   `Hyperplanes` is a cell array of `hyperplane` structures, describing threshold hyperplanes from all PTHBs and the analysis region (AR). Each `hyperplane` structure, `GLOBAL_PIHA.Hyperplanes{i}`, consists of the following fields.

pthb : -1 if the i^{th} hyperplane belongs to the analysis region (AR). Otherwise, it is the index to the parent PTHB in GLOBAL_PIHA.PTHBlocks. That is, this hyperplane belongs to the analysis region or the PTHB described by GLOBAL_PIHA.PTHBlocks{GLOBAL_PIHA.Hyperplanes{i}.pthb}.

index : The index of the hyperplane within the parent PTHB or the analysis region (AR)

c, d : Vector and constant pair representing the hyperplane, i.e., GLOBAL_PIHA.Hyperplanes{i}.c*x = GLOBAL_PIHA.Hyperplanes{i}.d.

2. NAR

NAR is the number of hyperplanes on the analysis region boundary. The first NAR hyperplanes in the GLOBAL_PIHA.Hyperplanes list, i.e. GLOBAL_PIHA.Hyperplanes{1:GLOBAL_PIHA.NAR}, are the hyperplanes from the analysis region.

3. InitialContinuousSet

InitialContinuousSet is a cell array of linearcon objects with parameters CE, dE, CI, and dI representing the initial continuous set, i.e.,

```
 GLOBAL_PIHA.InitialContinuousSet{1}.CE*x = GLOBAL_PIHA.InitialContinuousSet{1}.dE,
GLOBAL_PIHA.InitialContinuousSet{1}.CI*x <= GLOBAL_PIHA.InitialContinuousSet{1}.dI.
```

Note, there one only one element in this cell array.

4. InitialDiscreteSet

InitialDiscreteSet is a cell array of initial discrete states. Each element, InitialDiscreteSet{j}, is a vector of state indices for FSMBs in GLOBAL_PIHA.FSMBlocks list. Typically, there is only one element in the array. GLOBAL_PIHA.InitialDiscreteSet{1}(i)=k means that the initial state in the FSMB described by GLOBAL_PIHA.FSMBlocks{i} is the k^{th} state in it, i.e. GLOBAL_PIHA.FSMBlocks{i}.states{k}.

5. Cells

Cells is a cell array of cells in the partition of the continuous state space. Each cell, Cells{i}, is a structure of the following format

boundary : A vector of indices to hyperplanes in GLOBAL_PIHA.Hyperplanes list that composes the boundary of this cell. The boundary hyperplanes are GLOBAL_PIHA.Hyperplanes{boundary}.

hpflags : A vector of the same length as the GLOBAL_PIHA.Hyperplanes list. Each element, hpflags(j), is a boolean flag indicating the side of the j^{th} hyperplane in GLOBAL_PIHA.Hyperplanes list in which the cell lies. Specifically,

- 1 ⟶ this cell satisfies
  GLOBAL_PIHA.Hyperplanes{j}.c*x <= GLOBAL_PIHA.Hyperplanes{j}.d
- 0 ⟶ this cell satisfies
  GLOBAL_PIHA.Hyperplanes{j}.c*x >= GLOBAL_PIHA.Hyperplanes{j}.d

pthflags : A vector of the same length as the GLOBAL_PIHA.PTHBlocks list (simulink diagram). Each element, pthflags(j), is a flag indicating the output value of the j^{th} PTHB in the GLOBAL_PIHA.PTHBlocks list for any x in this cell.

- 0 ⟶ the PTHB described by GLOBAL_PIHA.PTHBlocks{j} outputs 0 is the continuous state x is in this cell and 1 otherwise.
- 1 ⟶ the PTHB described by GLOBAL_PIHA.PTHBlocks{j} outputs 1 if the continuous state x in this cell and 0 otherwise.
- -1 ⟶ the output of the PTHB described by GLOBAL_PIHA.PTHBlocks{j} is not used to evaluate whether the continuous state x is in this cell or not.

6. InitialCells

   InitialCells is a vector of indices to the cells in the GLOBAL_PIHA.Cells list that overlaps with the initial continuous set. That is, GLOBAL_PIHA.Cells{GLOBAL_PIHA.InitialCells(i,:)} are the cells that overlaps with the i^{th} initial continuous set described by GLOBAL_PIHA.InitialContinuousSeti.

7. Locations

   Locations is a cell array of location structures. Each element, Locations{i}, with the following format

   transitions : A cell array of transition structures describing all state transitions from this location. Each element, transitions{j}, consists of the following fields.

id : An ID assigned by Stateflow to this transition

expression : The string lablled to this transition in the stateflow model, including the guard condition and the settings of the output events

clock : 1 if there is a clock event in the guard condition. 0, otherwise

idx : The index to the FSMB in which the state varies under this transition. That is, the transition triggers the state change in the FSMB described by GLOBAL_PIHA.FSMBlocks{GLOBAL_PIHA.Locations{i}.transitions{j}.idx}

source : The index to the state in GLOBAL_PIHA.FSMBlocks{GLOBAL_PIHA.Locations{i}.transitions{j}.idx} before this state transition. That is GLOBAL_PIHA.FSMBlocks{GLOBAL_PIHA.Locations{i}.transitions{j}.idx}.states{GLOBAL_PIHA.Locations{i}.transitions{j}.source} is the state before this transition.

destination : The index to the state in GLOBAL_PIHA.FSMBlocks{GLOBAL_PIHA.Locations{i}.transitions{j}.idx} after this state transition. That is, GLOBAL_PIHA.FSMBlocks{GLOBAL_PIHA.Locations{i}.transitions{j}.idx}.states{GLOBAL_PIHA.Locations{i}.transitions{j}.destination} is the state after this transition.

destination_name : The name of the state in GLOBAL_PIHA.FSMBlocks{GLOBAL_PIHA.Locations{i}.transitions{j}.idx} after this transition `reset_flag` : 1 if this state transition affects the output event from `GLOBAL_PIHA.FSMBlocks{GLOBAL_PIHA.Locations{i}.transitions{j}.idx}`. 0, otherwise.

`reset_scs_index` : The array of indices to the SCSBs in which the state reset will be triggered by the output event from `GLOBAL_PIHA.FSMBlocks{GLOBAL_PIHA.Locations{i}.transitions{j}.idx}`. That is, the output event triggers the state resets in `GLOBAL_PIHA.SCSBlocks{GLOBAL_PIHA.Locations{i}.transitions{j}.reset_scs_index}`

`guard` : The index to the `cell` that contains all continuous states satisfying the guard condition for this state transition. That is, the `cell` `GLOBAL_PIHA.Cells{GLOBAL_PIHA.Locations{i}.transitions{j}.guard}` contains all continuous states that satisfy the guard condition for this transition.

`guard_cell_event_flags` : The cell array of boolean vectors to indicate if the output from the PTHB appears in the guard condition.

- `guard_cell_event_flags{1}(i)=1` ⟶ the output of the PTHB described by `GLOBAL_PIHA.PTHBlocks{i}` is in the guard condition
- `guard_cell_event_flags{1}(i)=1` ⟶ the output of the PTHB described by `GLOBAL_PIHA.PTHBlocks{i}` is in the guard condition

`guard_compl` : The index to the `cell` that contains all continuous states not satisfying the guard condition. That is, the `cell` `GLOBAL_PIHA.Cells{GLOBAL_PIHA.Locations{i}.transitions{j}.guard}` contains all continuous states that don't satisfy the guard condition for this transition.

`q` : A vector of discrete state indices (same format as each element of `GLOBAL_PIHA.InitialDiscreteSet`)

`state` : A two dimensional character array containing the discrete state names. `state(j,:)` is the name of the state `GLOBAL_PIHA.FSMBlocks{j}.states{GLOBAL_PIHA.Locations{i}.q(j)}`

`interior_cells` : A vector of indices for cells corresponding to this location. That is, the continuous states in the cells `GLOBAL_PIHA.Cells{GLOBAL_PIHA.Locations{i}.interior_cells}` belong to this location

`orig_interior_cells` : This field has the same meaning as the field `interior_cells` (Note, this field is only used in the file `compute_mapping_SD.m`. It's value is not changed anywhere after it is initialized in `piha.m` to be `GLOBAL_PIHA.Locationsi.interior_cells`.)

8. `InitialConditions`

   `InitialConditions` is a cell array of `initialcondition` structures describing the initial state, including the continuous state and the discrete state. Each element `InitialConditions{j}` consists of the following fields.

`continuousSet` : The `linearcon` object to define the initial set of continuous state.

`initialCells` : The index to the `cell` corresponding to the initial continuous set. All initial continuous states are insides `GLOBAL_PIHA.Cells{GLOBAL_PIHA.InitialConditions.initialCells}`, and all other continuous states are outside this `cell`.

`discreteSet` : A vector of indices to the discrete states in FSMBs. The initial state in the `GLOBAL_PIHA.FSMBlocks{i}` is `GLOBAL_PIHA.FSMBlocks{i}.states{GLOBAL_PIHA.InitialConditions. discreteSet(i)}`

`initialLocation` : The index to the location that containing the initial states. This initial location is `GLOBAL_PIHA.Locations{GLOBAL_PIHA.InitialConditions{1}. initialLocation}`

9. `InitialLocation_Cells`

   `InitialLocation_Cells` is a vector of indices to the initial cells and the corresponding locations. `GLOBAL_PIHA.InitialLocation_Cells(i,length(GLOBAL_PIHA.InitialCells)+j)` is the j^{th} `cell` that overlaps with the i^{th} initial continuous state set. It has the same value as `GLOBAL_PIHA.InitialCells(i,j)`. `GLOBAL_PIHA.InitialLocation_Cells(i,j)` is the index to the corresponding location.

10. `CLOCKBlocks`

    `CLOCKBlocks` is a cell array of VZOH blocks. Each element, `CLOCKBlocks{i}`, is of the following format

    `name` : Name of this VZOH block

    `period` : Vector to define the range of period for the digital controller. `period(1)` is the lower bound and `period(2)` is the upper bound. This allow nondeterminism in the period of the digital controller. When `period(1)==period(2)`, the period of the digital controller is deterministic.

    `jitter` : Vector defining the range of jitter. `jitter(1)` is the lower bound and `jitter(2)` is the upper bound. When `jitter(1)==0` and `jitter(2)==0`, there is no jitter.

    `phase` : Vector defining the range of the shift of the initial sampling time point. `phase(1)` is the lower bound and `phase(2)` is the upper bound. When `phase(1)==0` and `phase(2)==0`, there is no shift of the initial sampling time point.

11. `SCSBlocks`

    `SCSBlocks` is a cell array of switched continuous system blocks. Each element, `SCSBlocks{i}`, has the following format `name` : Name of this SCSB

`nx` : Number of continuous variables

`nz` : Number of state variables in the digital controller

`nup` : Number of output variables from the digital controller

`nu` : Number of discrete inputs from FSMBs

`swfunc` : M-file name of the continuous dynamics

`pacs` : A `linearcon` object defining analysis region for uncertain parameters.

`paradim` : Number of uncertain parameters to analyze

`fsmbindices` : A vector of indices to FSMBs in the `GLOBAL_PIHA.FSMBlocks` field in the order that feeds into the input of this SCSB. That is, the outputs of `GLOBAL_PIHA.FSMBlocks{GLOBAL_PIHA.SCSBlocks{i}.fsmbindices}` are fed to this SCSB.

12. `PTHBlocks`

    `PTHBlocks` is a cell array of polyhedral threshold blocks, each with the following format

    `name` : Name of this PTHB.

    The names of PTHBs can be used as atomic propositions for CTL verifications.

13. `FSMBlocks`

    `FSMBlocks` is a cell array of finite state machine blocks, each with the following format

    `name` : Name of this FSMB.

    `states` : A cell arrayof strings listing the discrete states in this FSMB, by name.

14. `use_sd`

    `use_sd` is a boolean variable, which indicate whether there is a SCSB that requires the sample-data difference equation analysis.