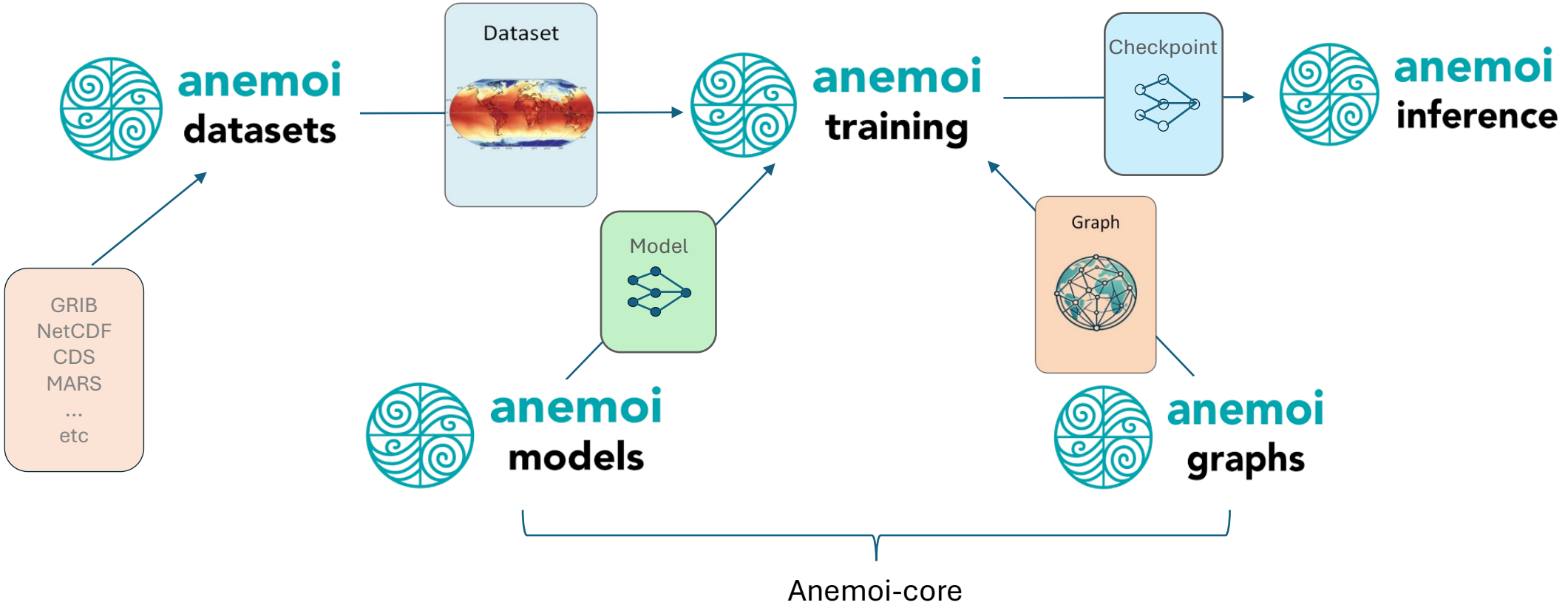
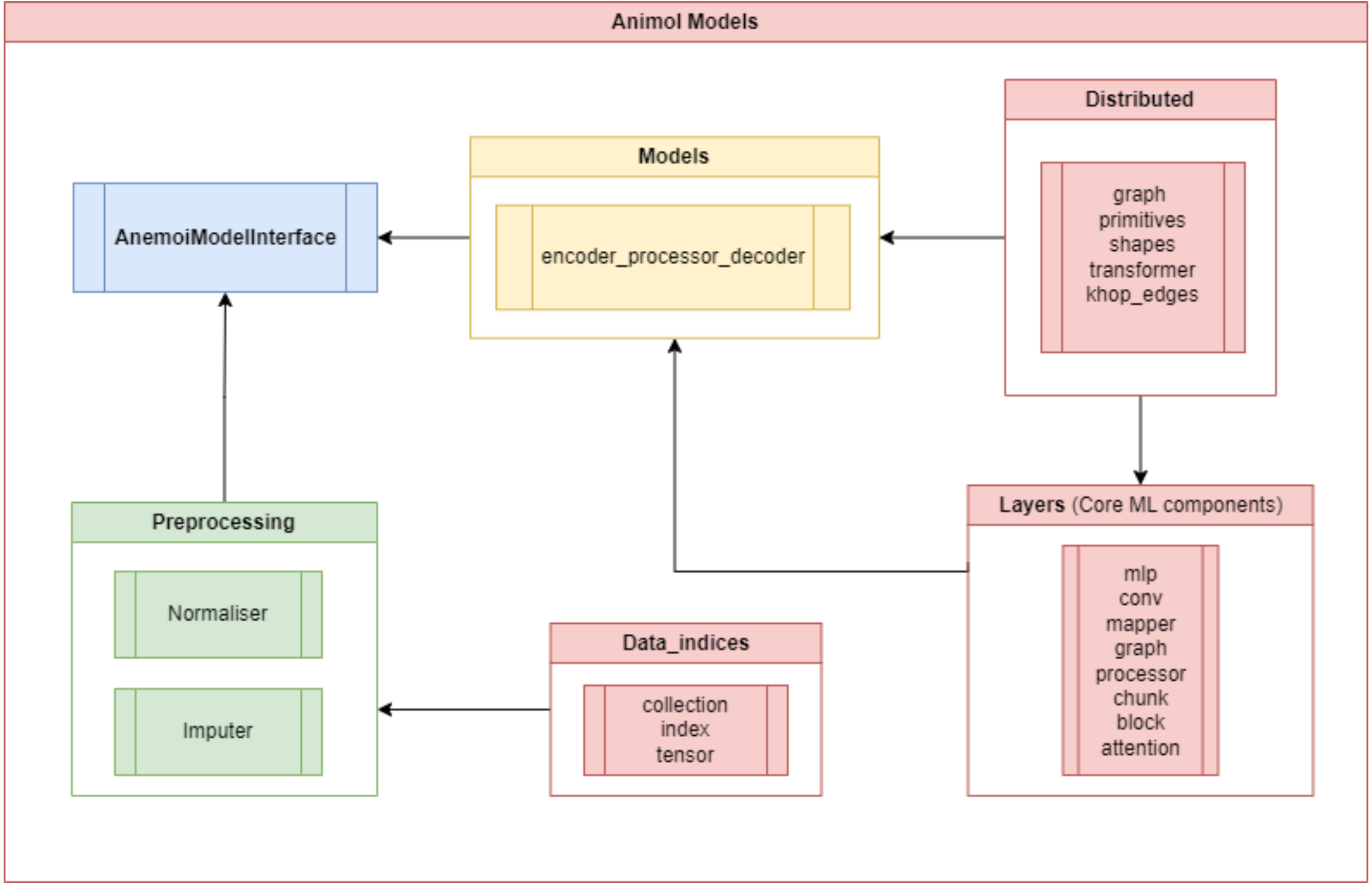
Anemoi Models

Anemoi in a Nutshell

- Anemoi is an open-source framework to develop **data-driven meteorological forecasting**.
- Anemoi is developed through a **collaborative European initiative**




Animol Models
Distributed
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shapes
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AnemoiModelInterface
Layers (Core ML components)
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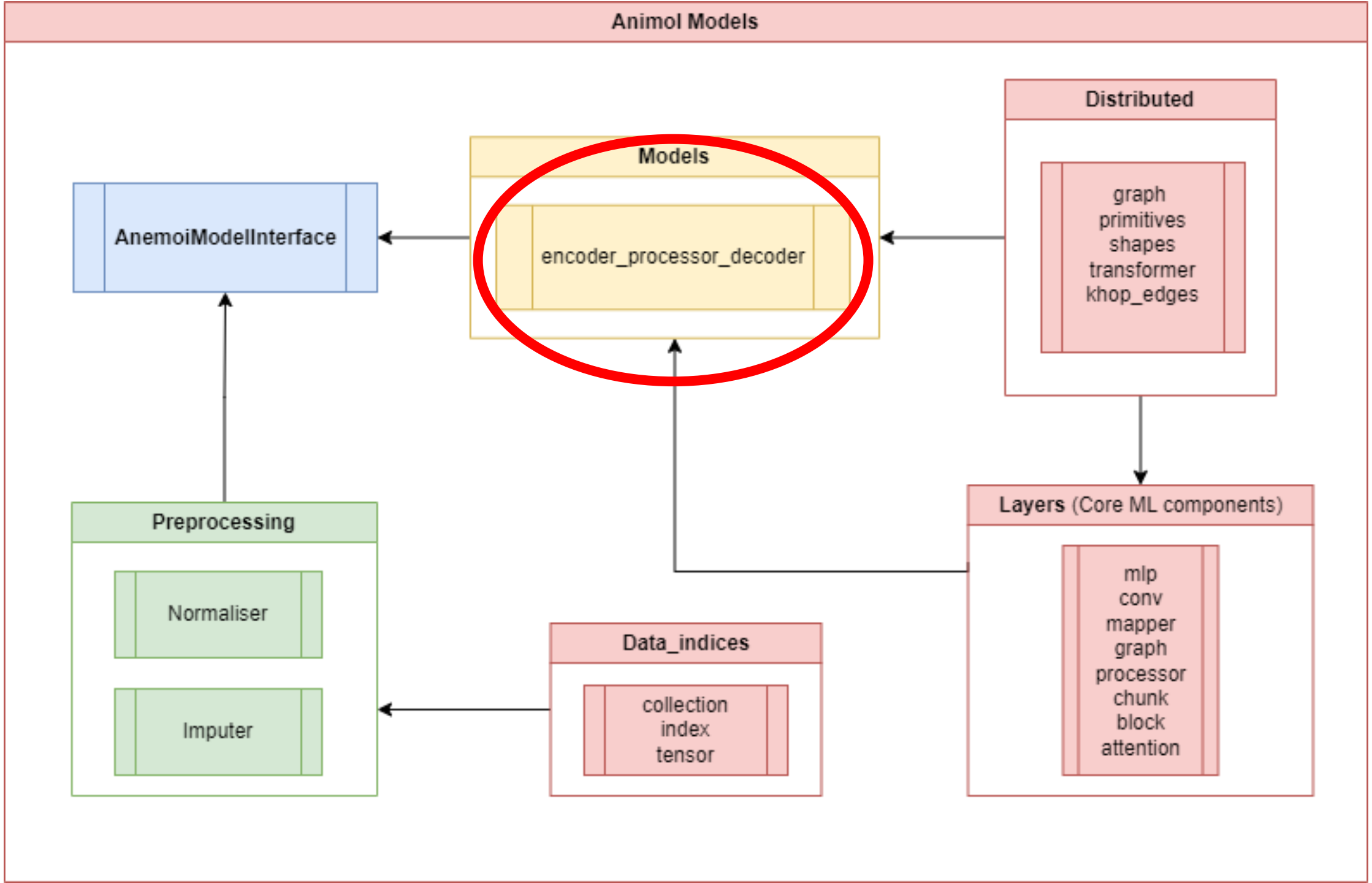
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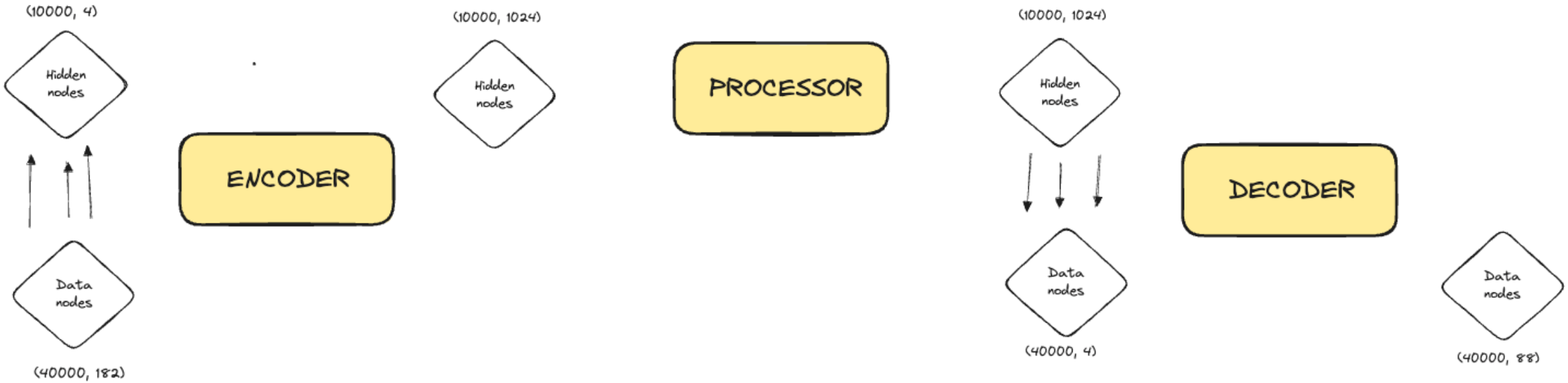
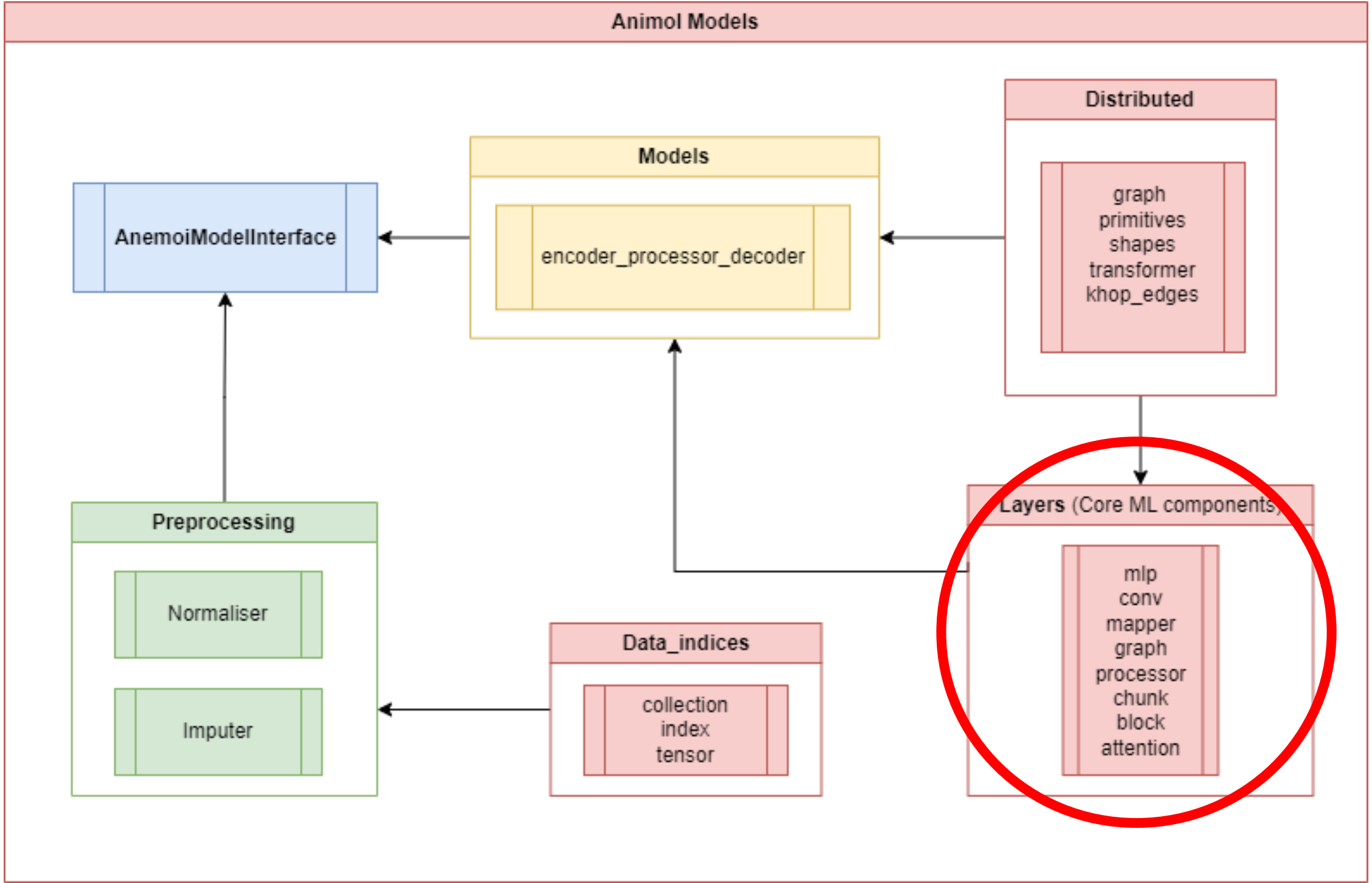

(10000, 4)
Hidden nodes
Data nodes
(40000, 182)
ENCODER
(10000, 1024)
Hidden nodes
PROCESSOR
(10000, 1024)
Hidden nodes
Data nodes
(40000, 4)
DECODER
Data nodes
(40000, 88)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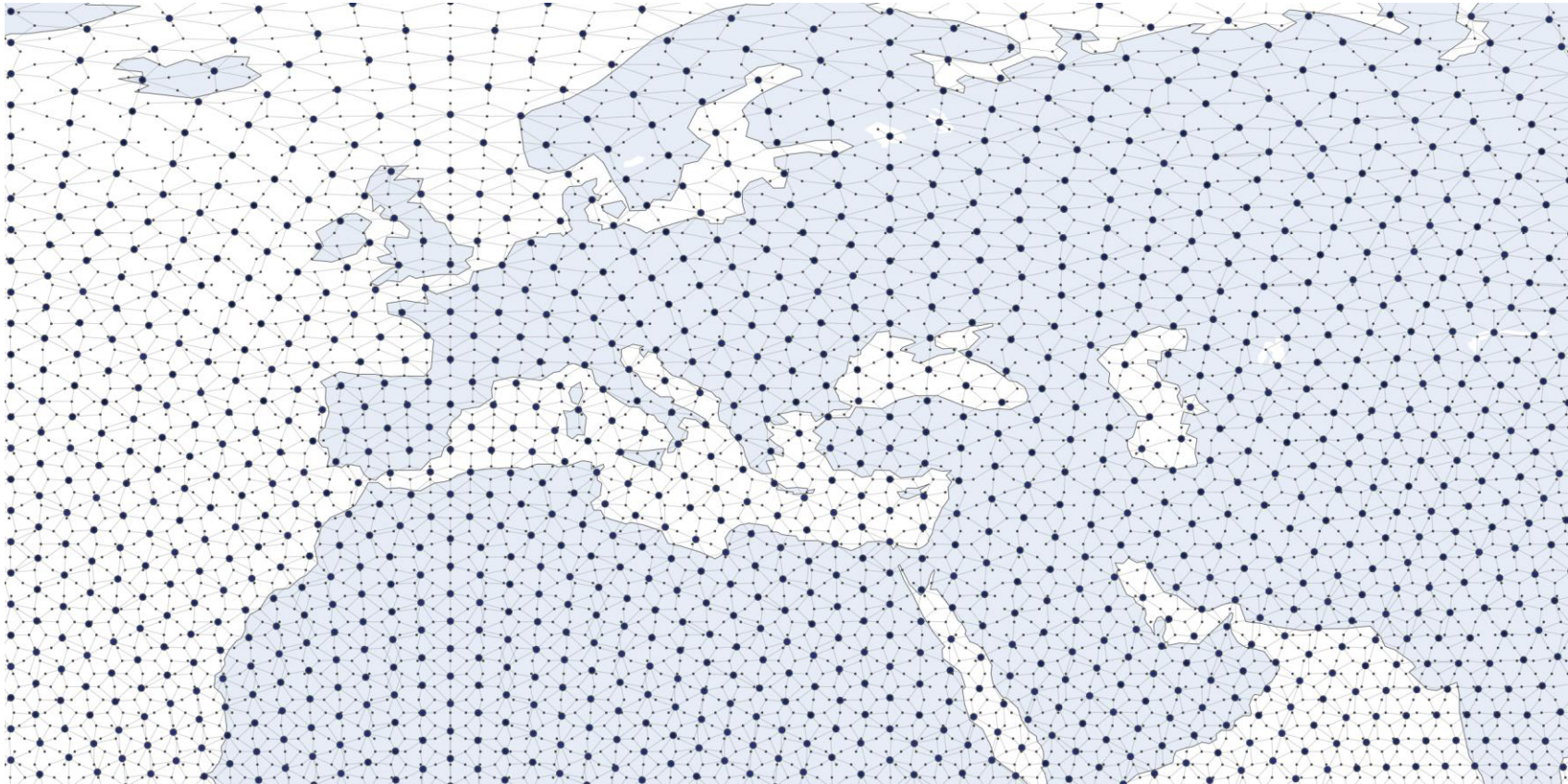
How to build an encoder processor decoder?

- Encoders/decoders use Mappers.
  - Map from one grid to another.
  - 3 to choose from:
    - GNN (message passing)
    - **GraphTransformer**
    - Transformer



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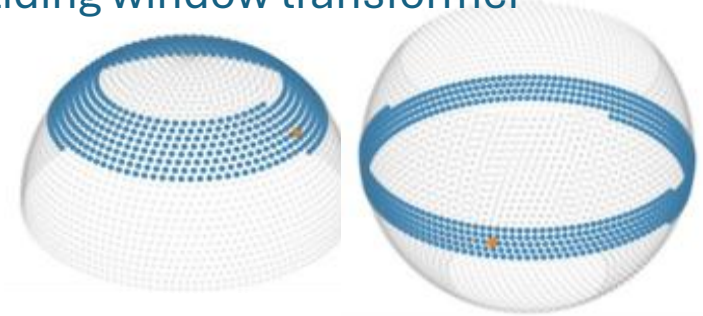
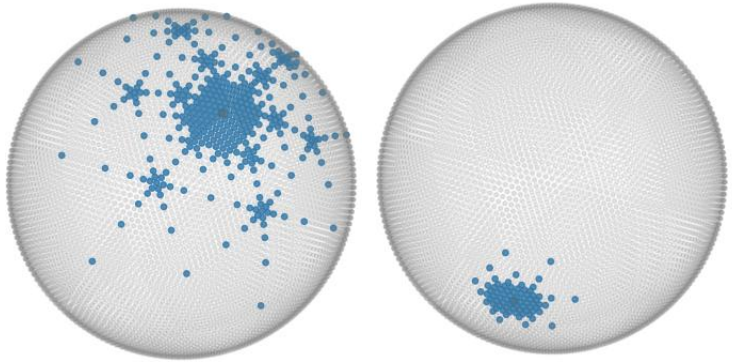
How to build an encoder processor decoder?

- Processors layers to build the processor.
  - Operate on fixed grid.
  - 3 to choose from:
    - GNN (message passing)
    - **GraphTransformer**
    - **Transformer**

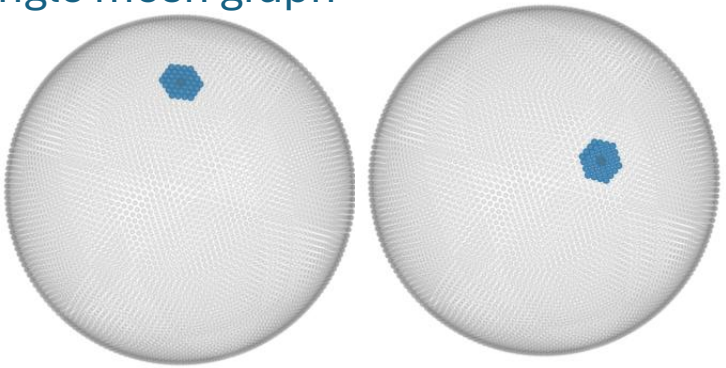
Sliding window transformer



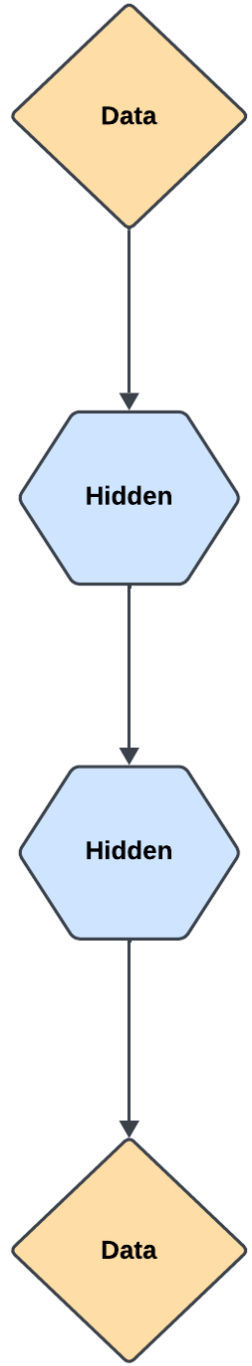
Multi mesh graph

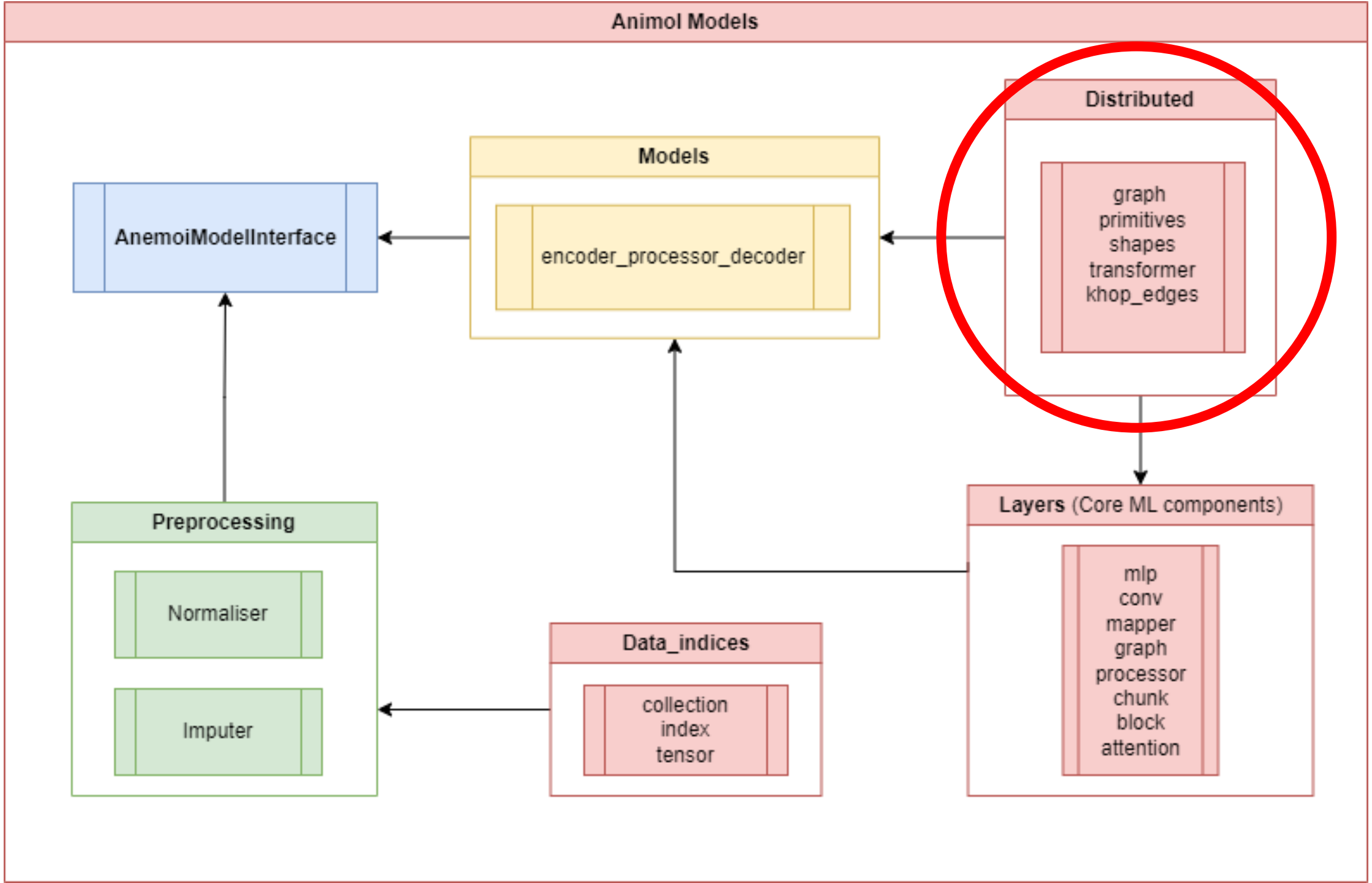


Single mesh graph



```yaml
encoder:
  _target_: anemoi.models.layers.mapper.GraphTransformerForwardMapper
  trainable_size: ${model.trainable_parameters.data2hidden}
  sub_graph_edge_attributes: ${model.attributes.edges}
  num_chunks: 4
  mlp_hidden_ratio: 4 # GraphTransformer or Transformer only
  num_heads: 16 # GraphTransformer or Transformer only
  qk_norm: False
  cpu_offload: ${model.cpu_offload}
  layer_kernels: ${model.layer_kernels}
  shard_strategy: "edges"
processor:
  _target_: anemoi.models.layers.processor.GraphTransformerProcessor
  trainable_size: ${model.trainable_parameters.hidden2hidden}
  sub_graph_edge_attributes: ${model.attributes.edges}
  num_layers: 16
  num_chunks: 4
  mlp_hidden_ratio: 4 # GraphTransformer or Transformer only
  num_heads: 16 # GraphTransformer or Transformer only
  qk_norm: False
  cpu_offload: ${model.cpu_offload}
  layer_kernels: ${model.layer_kernels}
decoder:
  _target_: anemoi.models.layers.mapper.GraphTransformerBackwardMapper
  trainable_size: ${model.trainable_parameters.hidden2data}
  sub_graph_edge_attributes: ${model.attributes.edges}
  num_chunks: 4
  mlp_hidden_ratio: 4 # GraphTransformer or Transformer only
  num_heads: 16 # GraphTransformer or Transformer only
  initialise_data_extractor_zero: False
  qk_norm: False
  cpu_offload: ${model.cpu_offload}
  layer_kernels: ${model.layer_kernels}
  shard_strategy: "edges"
```

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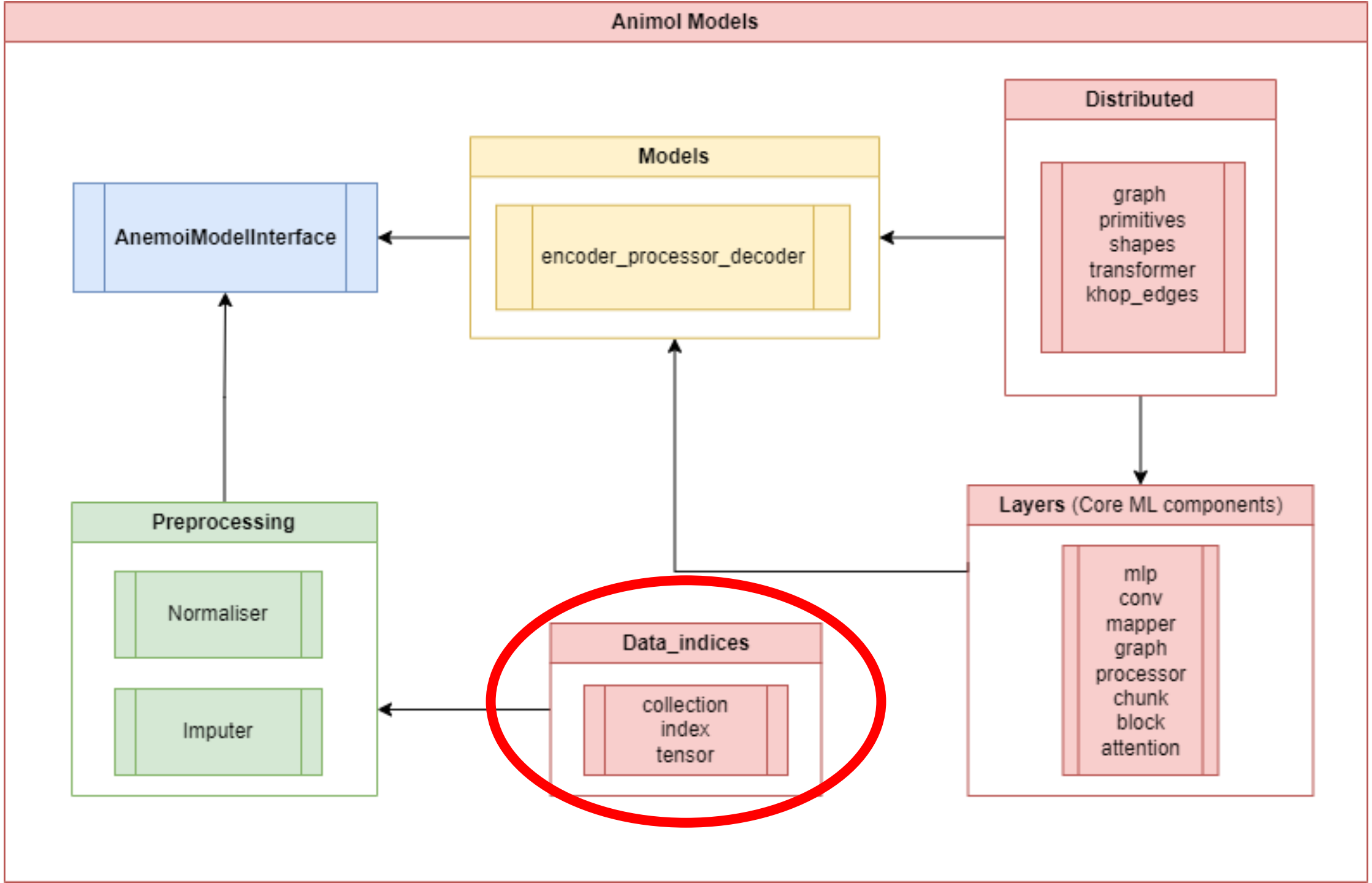
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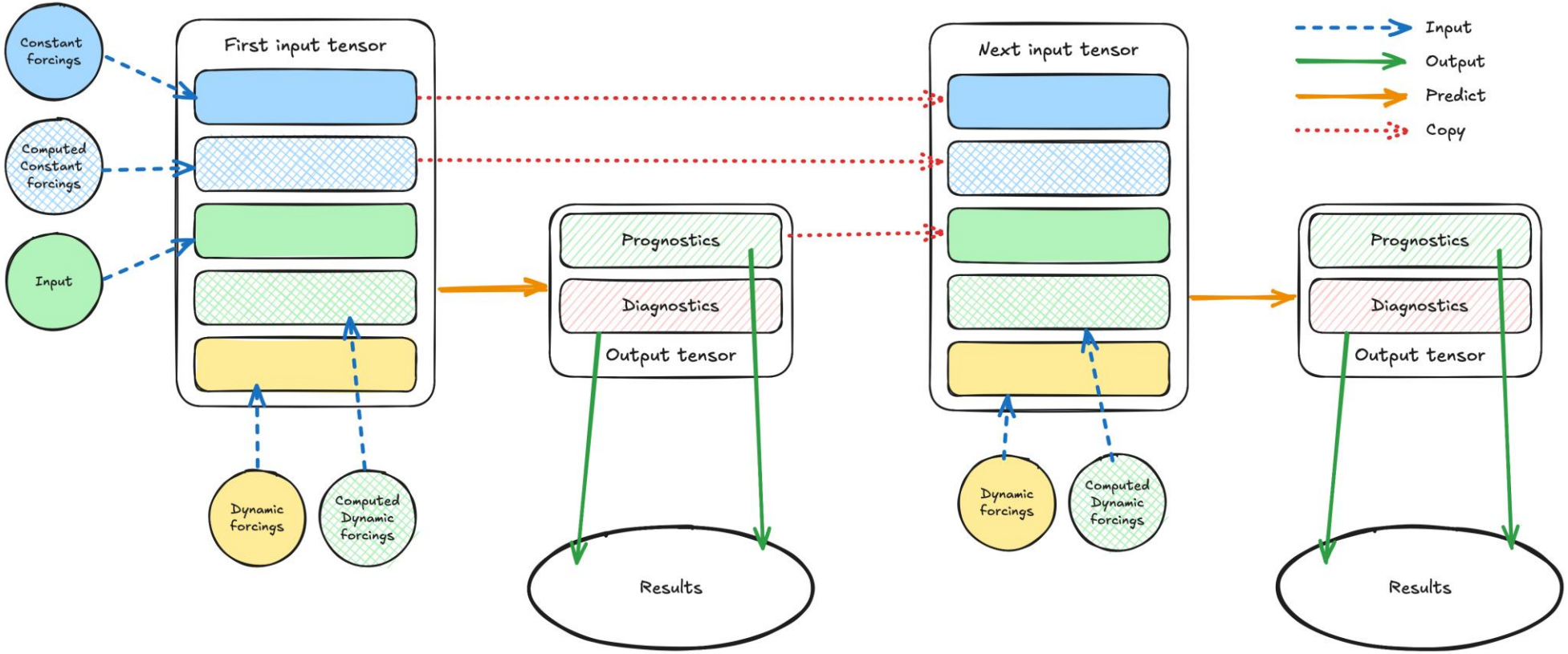
How to index the big array?

- Anemoi datasets, we built a big array.
- But we may use data differently.
- **Prognostic** (in and out), **forcing** (in), and **diagnostic** (out).
- Need code to understand how to get data in and out of the tensor.



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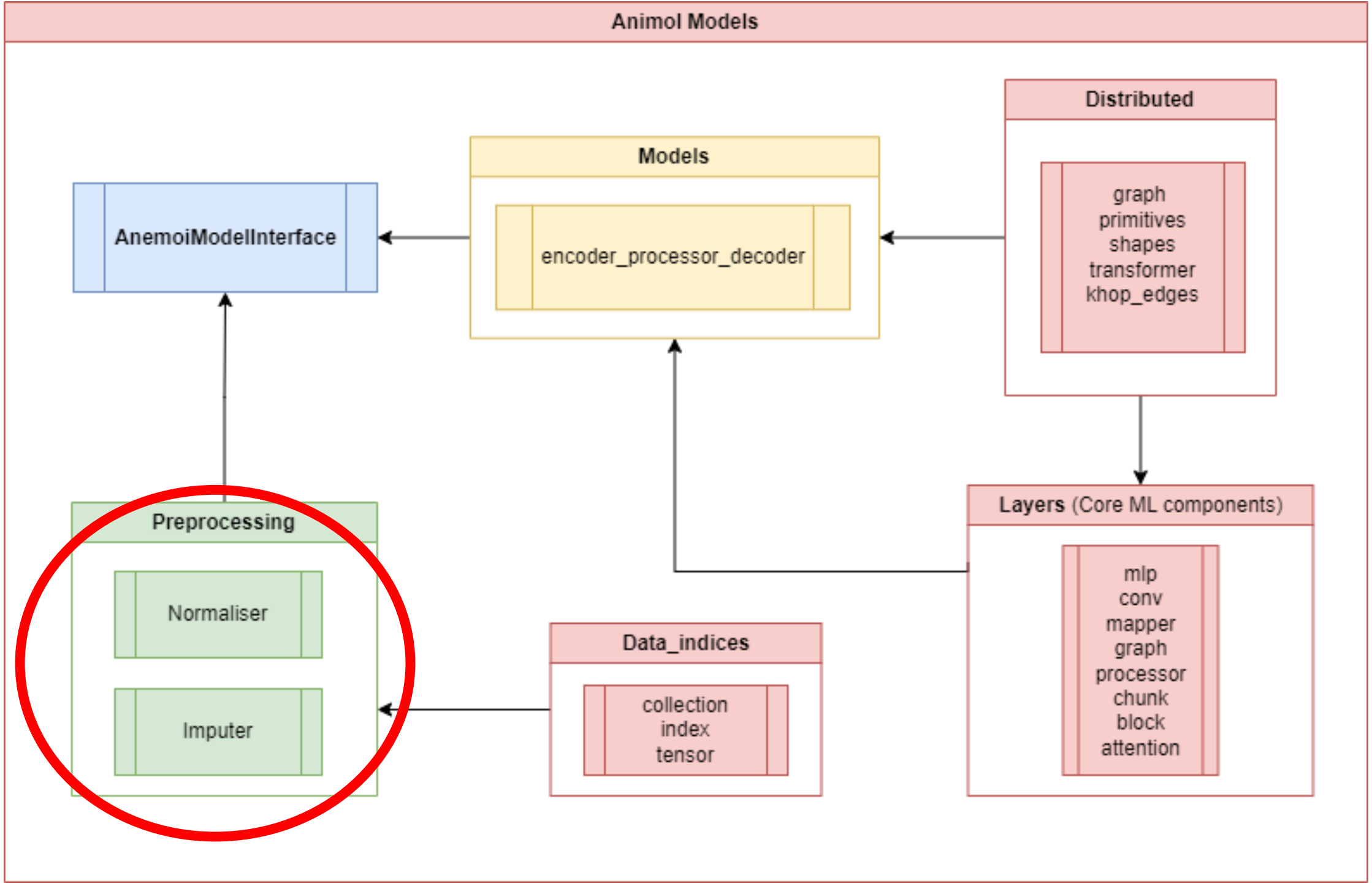
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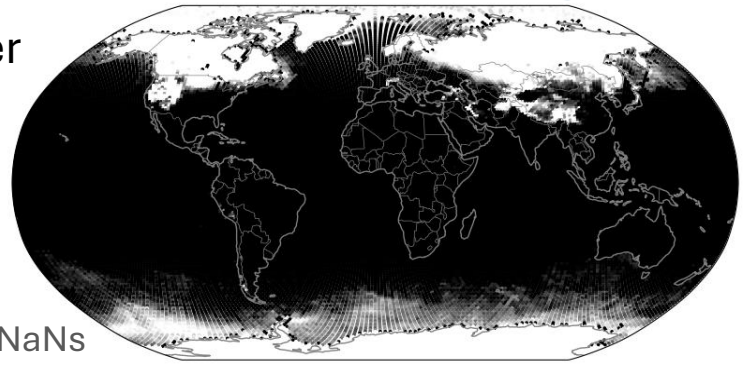
Normaliser

- Apply the statistics to normalise the data.
  - Could be in the training code.
  - But it living in the model helps with inference.
- Options:
  - Mean-std
  - Std
  - Max
  - Min-max
  - None

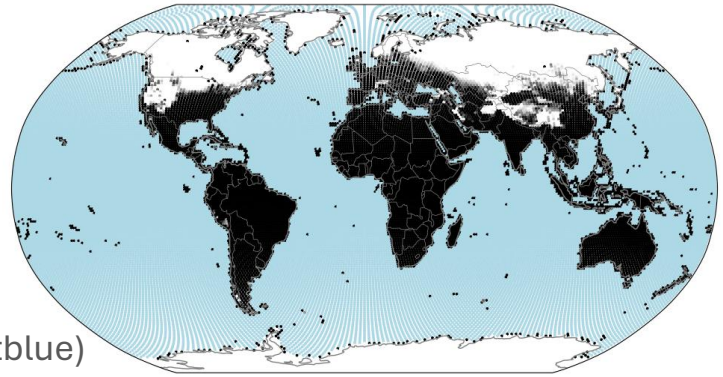
```yaml
normalizer:
  default: "mean-std"

  # Remap cp statistics to those of tp when using FractionBounding. This ensures
  # that cp, as a fraction of tp, remains consistent with tp's scale and statistics.
  # NOTE: This remap should only be applied if FractionBounding is enabled for cp.
  # remap:
  #   cp: tp

  # Standardization applied to tp and cp variables. Ensure that if cp is bounded
  # as a fraction of tp, both variables are normalized using these shared statistics.
  # "Std" normalization is preferred here over "mean-std" to avoid shifting of the
  # zero value in the normalized space.
  std:
  - "tp"
  # - "cp"

  min-max:
  max:
  - "sdor"
  - "slor"
  - "z"
  none:
  - "cos_latitude"
  - "cos_longitude"
  - "sin_latitude"
  - "sin_longitude"
  - "cos_julian_day"
  - "cos_local_time"
  - "sin_julian_day"
  - "sin_local_time"
  - "insolation"
  - "lsm"
```

Dealing with missing values

Snow Cover over ocean



Without masking NaNs



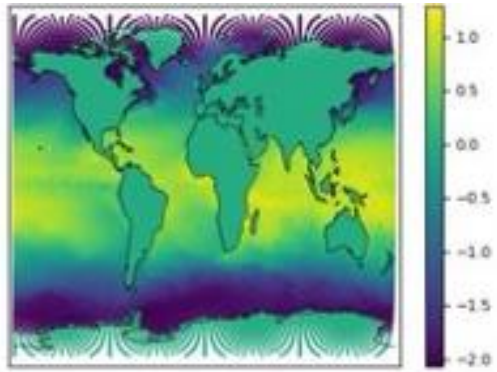
Masking NaNs (lightblue)

In training: NaNs are replaced by values and **masked in the loss function with zeros**

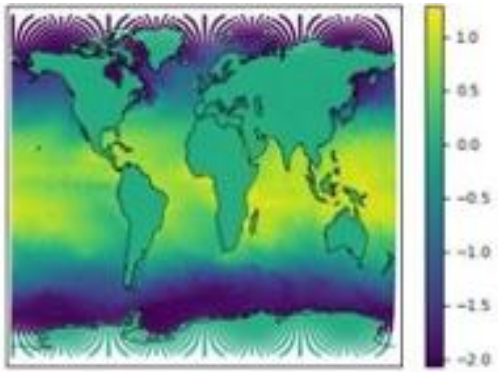
At inference: the model **'predicts'** values **in the masked areas** – these are **removed** in a **post-processing** step

Sea Surface Temperature over land

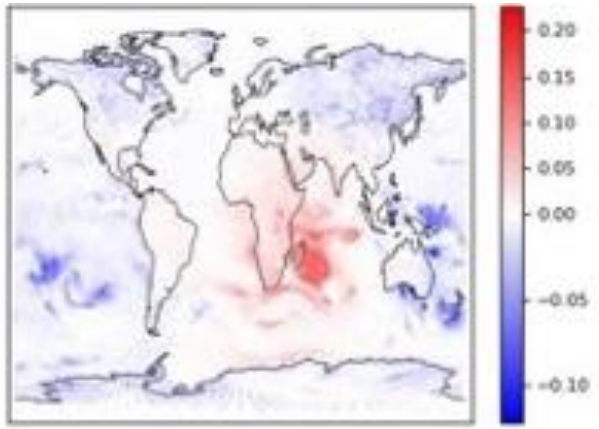
Target



Predicted field

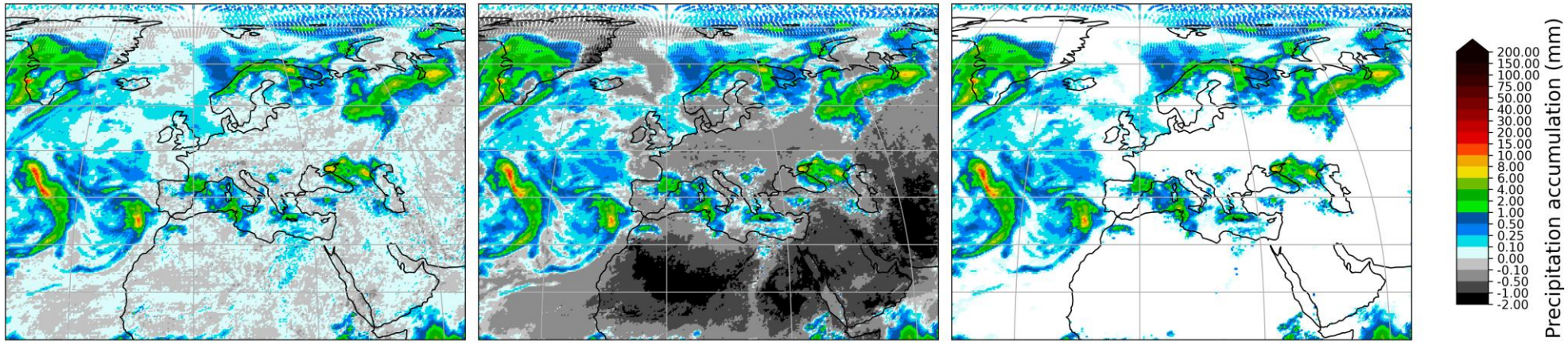


Predicted Increment



- *Additional issues caused when NaNs move! This was the case with waves fields.*

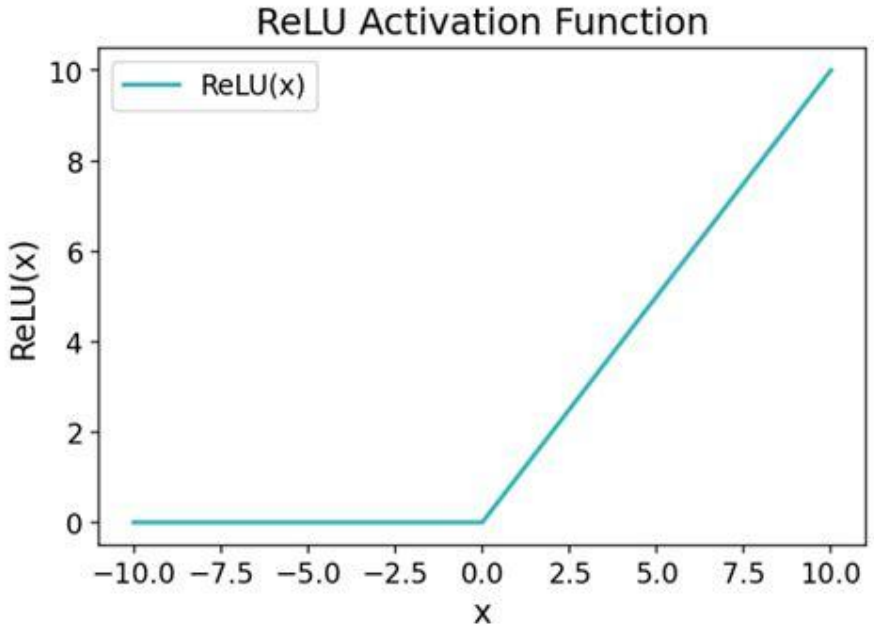
Bounding – a missing piece of the model diagram!



Previous AIFS

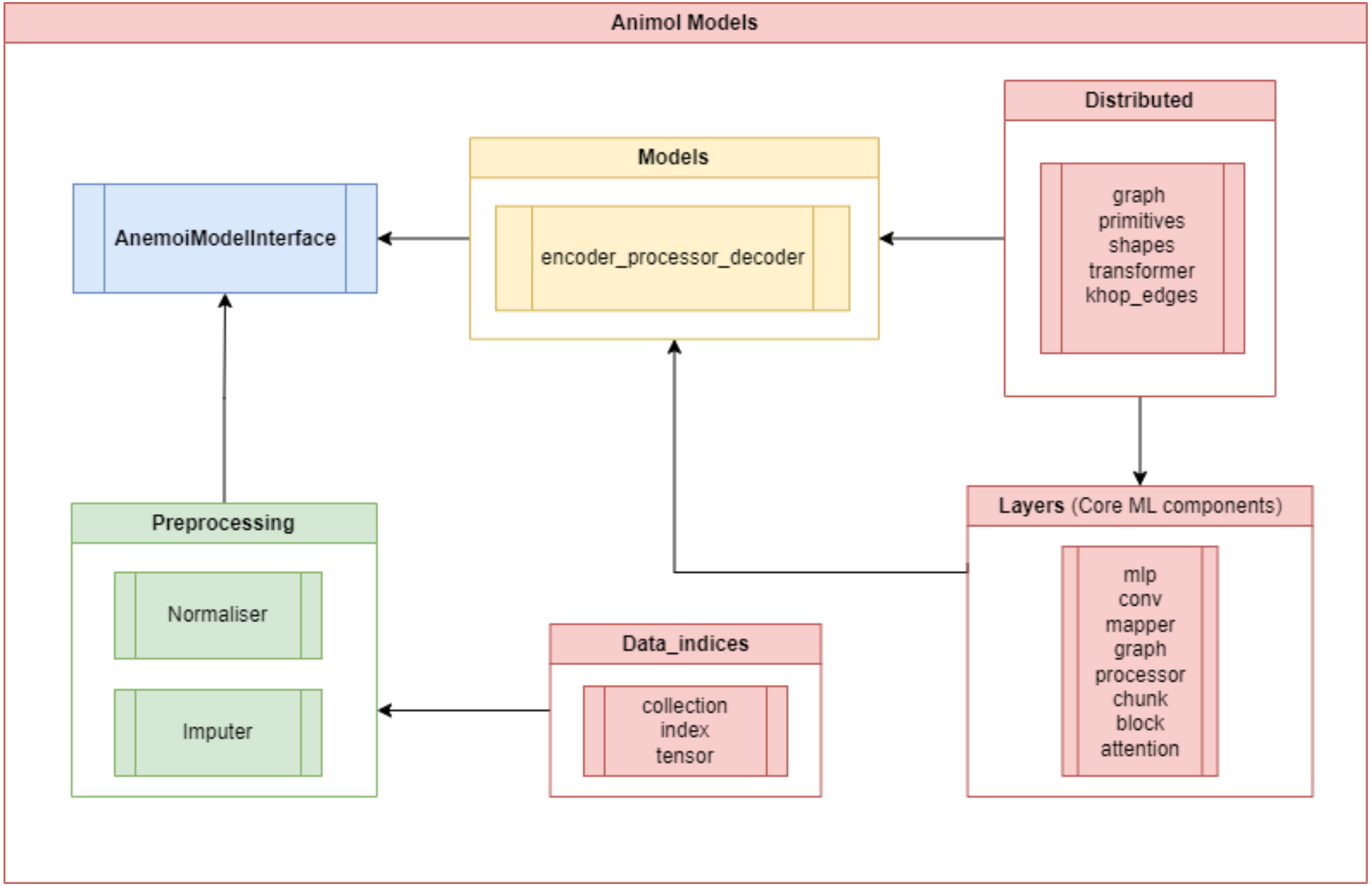
Input to bounding layer

New AIFS




```yaml
bounding: #These are applied in order

# Bound tp (total precipitation) with a Relu bounding layer
# ensuring a range of [0, infinity) to avoid negative precipitation values.
- _target_: anemoi.models.layers.bounding.ReluBounding #[0, infinity)
  variables:
  - tp

# [OPTIONAL] Bound cp (convective precipitation) as a fraction of tp.
# This guarantees that cp is physically consistent with tp by restricting cp
# to a fraction of tp [0 to 1]. Uncomment the lines below to apply.
# NOTE: If this bounding strategy is used, the normalization of cp must be
# changed to "std" normalization, and the "cp" statistics should be remapped
# to those of tp to ensure consistency.

# - _target_: anemoi.models.layers.bounding.FractionBounding # fraction of tp
#   variables:
#   - cp
#   min_val: 0
#   max_val: 1
#   total_var: tp
```

Questions?



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