Burattin, A., Bernstein, V., Neurauter, M. et al.
Detection and quantification of flow consistency in business process models
Softw Syst Model (2017). doi:10.1007/s10270-017-0576-y

Detection and quantification of flow consistency in business process models

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This research is supported by Austrian Science Fund: P26609 and P26140.

Table of contents

Process Models and their Representation

- Business process models are useful to
  - Obtain a common understanding of a company business by
    - Facilitating documentation
    - Facilitating communication
  - Enable the discovery of improvement opportunities

Process Models and their Representation

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  - Obtain a common understanding of a company business by
    - Facilitating documentation
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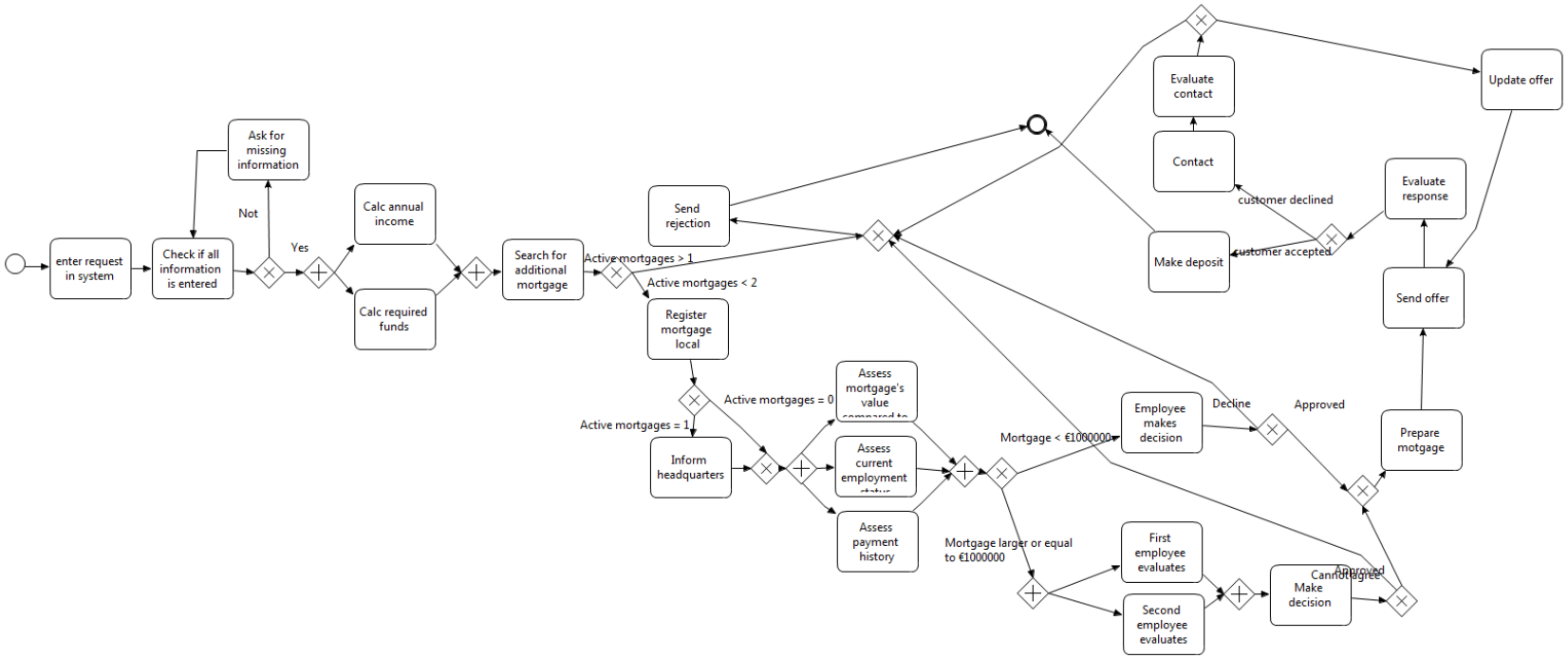
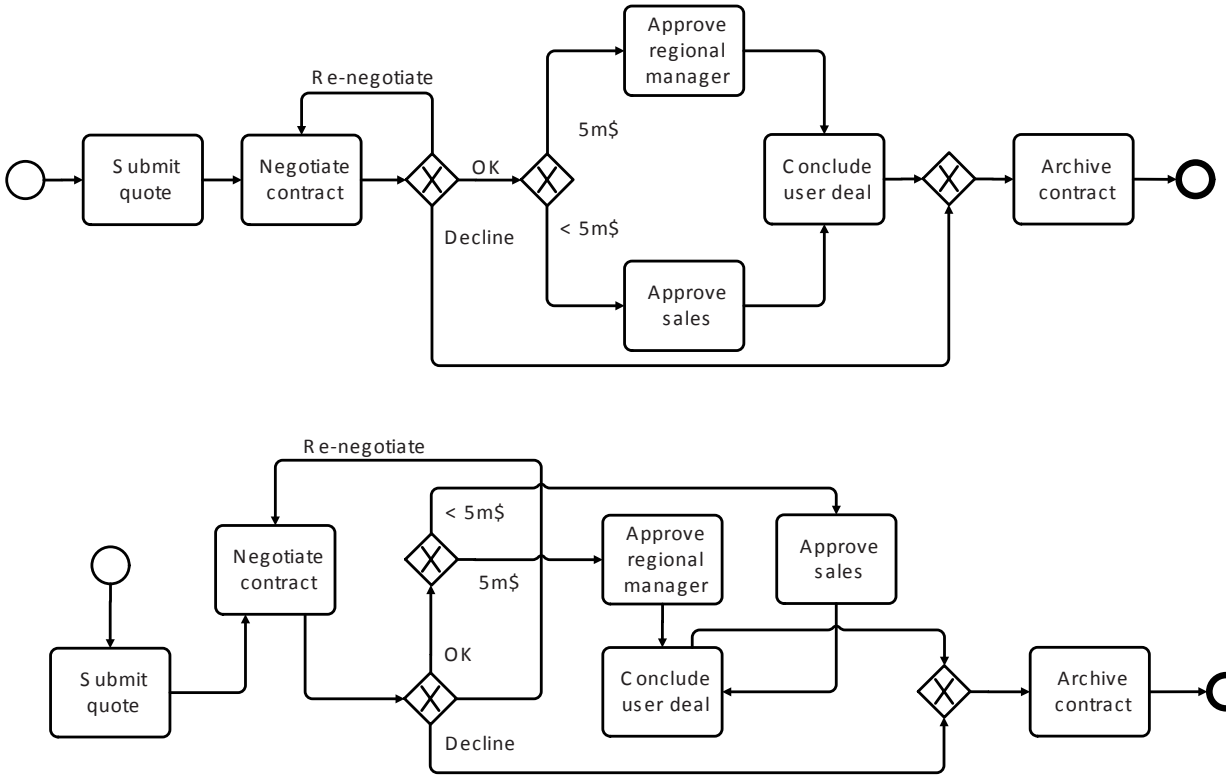
  - Enable the discovery of improvement opportunities
- To serve their purposes, models need to be understood properly



The *Secondary Notation*

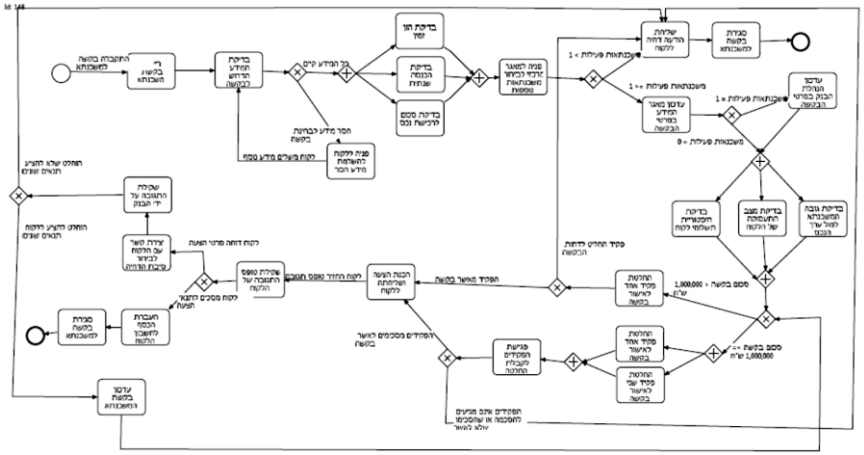
- These two processes have exactly the same semantic:

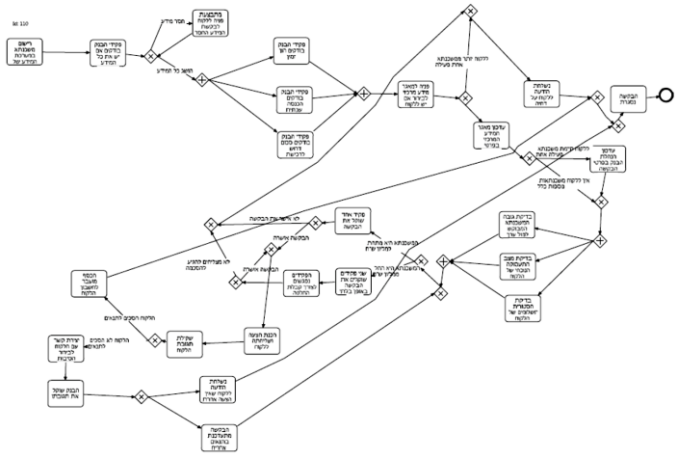


Pictures from "*The Impact of Secondary Notation on Process Model Understanding*". Matthias Schrepfer, Johannes Wolf, Jan Mendling, Hajo A. Reijers

1st study: which layout features are perceived as meaningful

- Two steps study: exploration + validation
- Aim: identify candidate visual features of process models
- Structure of the questionnaire
  - 5 pairs of BPMN models
  - For each pair
    - 7-point Likert scale used to assess models similarity
    - 2 open-ended questions about similarities and differences
  - After the questionnaire, discussions with subject (recorded and transcribed) to gather additional information about the answers





1st study: which layout features are perceived as meaningful

- Subjects
  - Exploration: 15 undergraduate students
    - All subjects with similar knowledge (coming from same educational background)
  - Validation: 7 modeling experts from different countries
- Analysis and findings
  - Only open-ended questions were used to elicit categories/features
  - We manually mapped all statements into clusters
  - Only clusters with at least 2 items were considered
  - Saturation reached by the fourth interview (no new categories after that)

Edges-related features elicited

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"Change the edges to be straight lines"

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  The angles used in bending points of edges: 90° angles, angles larger than 45°, angles smaller than 45°

"I would improve the angles in this model to be 90° angles"

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- Model's shape

  The general shape of the model refers to the way the model is spread on the canvas. This usually is characterized as a square or rectangle

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"The size of the models is different"

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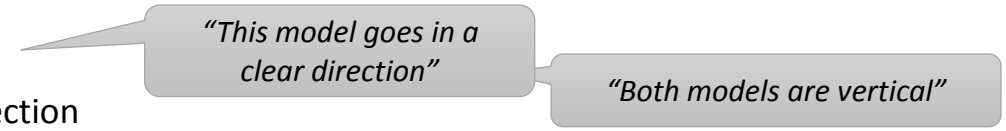

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"This model is clearer because of the alignment of the whole model. It is very aesthetic"

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  Alignment of the elements in the model in relation to each other

Validation with experts

- All identified categories were supported by experts
- Two additional categories were elicited
  - Fixed sizes of activity boxes

    The possibility of having different sizes of the activity boxes for short and long textual descriptions of the activities
  - Implicit versus explicit gateways

    A known property associated with the pragmatic quality of BPMN models

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- We decided to focus on the flow consistency since
  - It is particularly challenging since it involves “high-level concepts” and how such concepts are represented
  - Several ways of computing it, and it is not obvious which approach would most closely reflect human perception

Examples of flow directions

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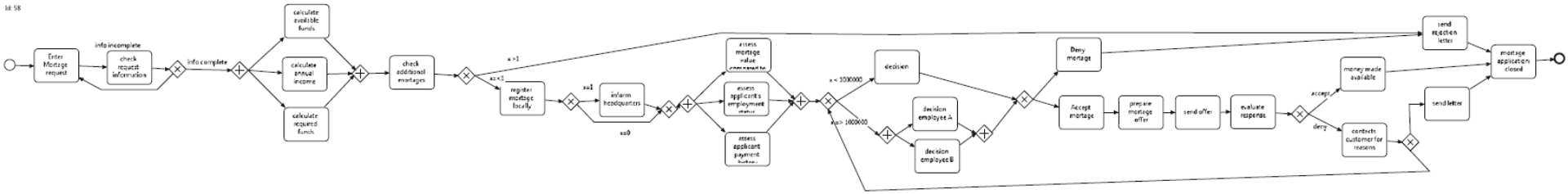

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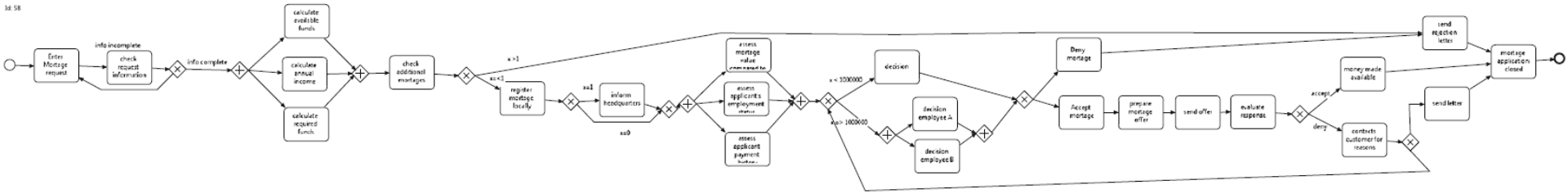

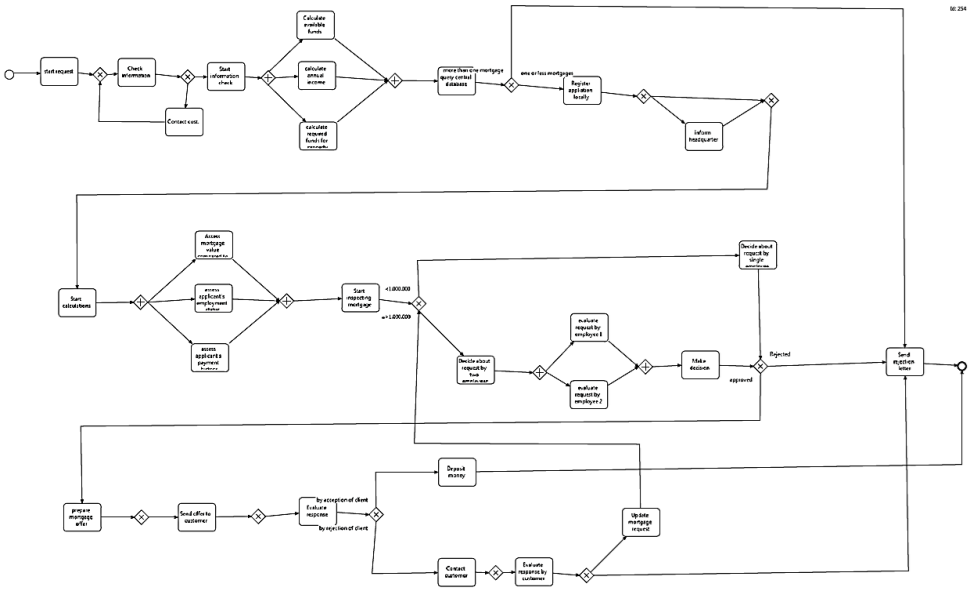

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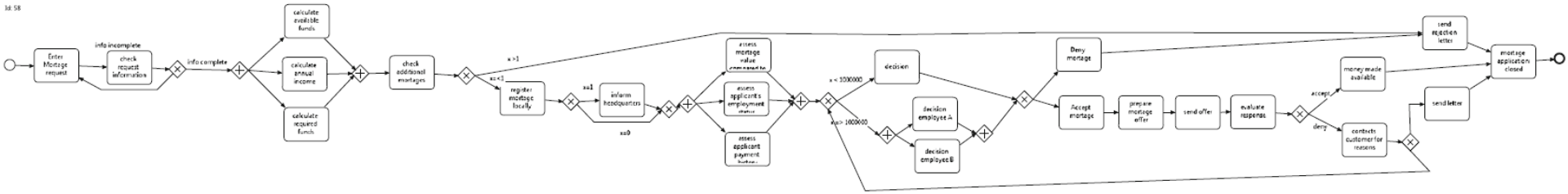

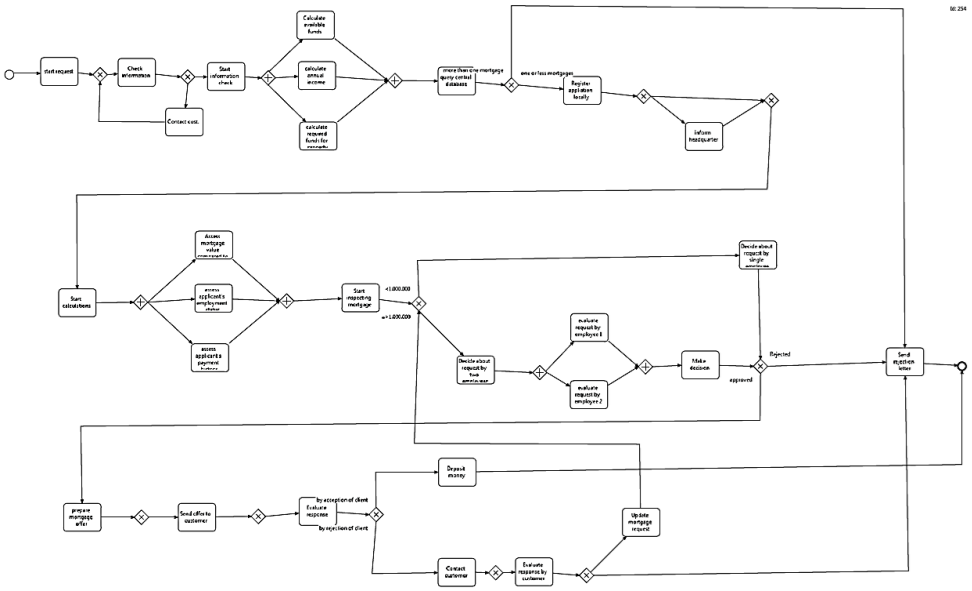

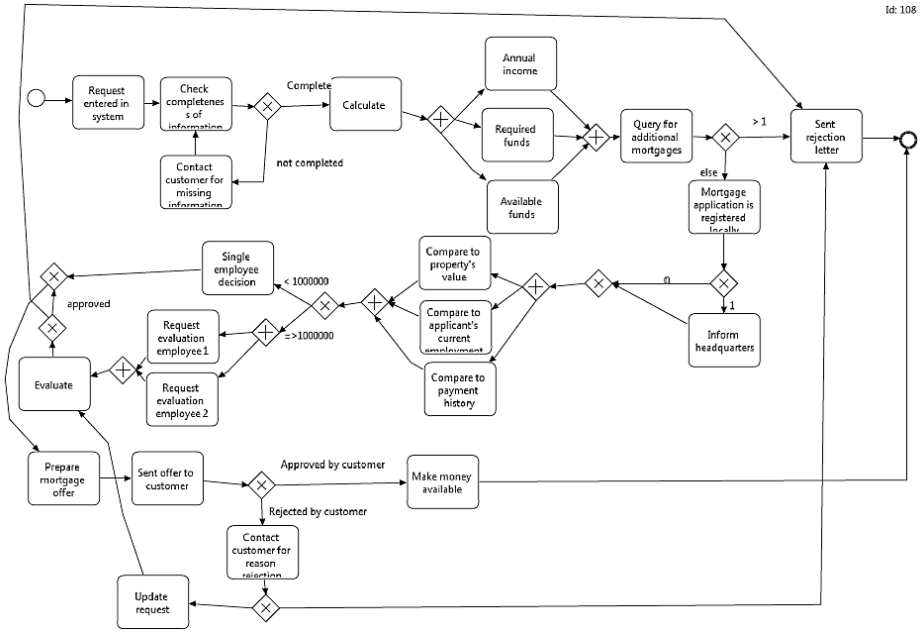

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- Provide a metric quantifying the consistency of the flow
  - *"The extent to which the layout of a process model reflects the temporal logical ordering of the process"*
- The metric should mimic as much as possible human perception of the consistency of the flow

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Based on global features, such as "the three lines" (cf. model in previous slide)

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The consistency of the flow is a "global feature"
More similar to human perception

Cons
Very difficult to capture global patters

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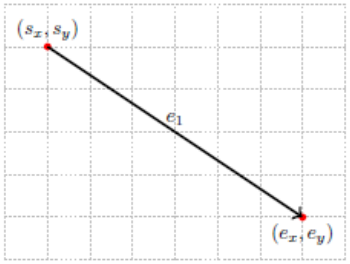

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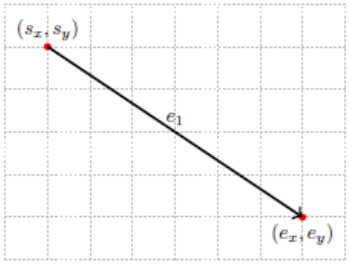
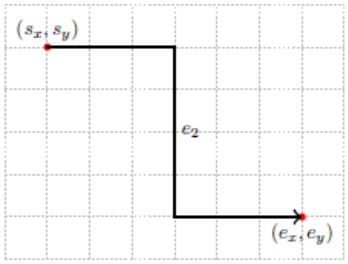
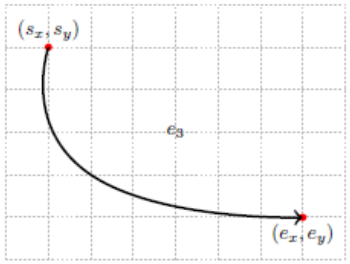
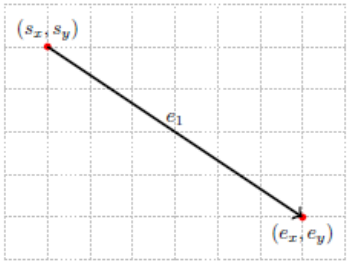


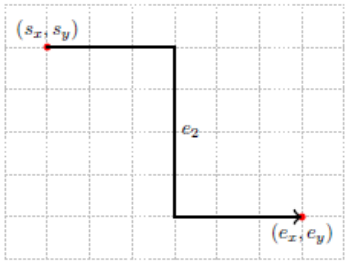


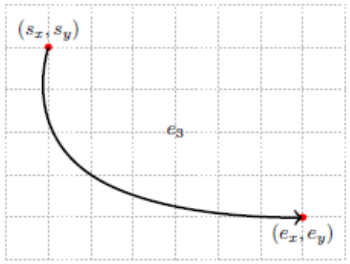


Assumptions made

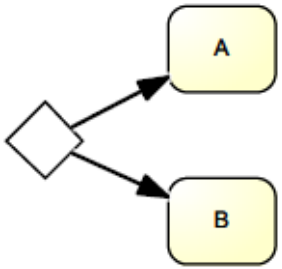
- We consider the graphical representation of BPMN models
- Only start/end points of edges are considered

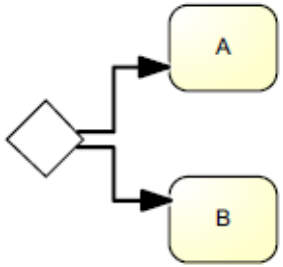


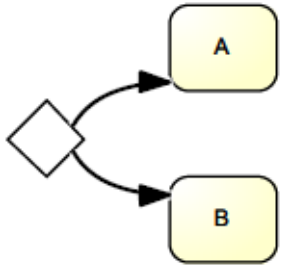




- From our point of view, these fragments are equivalent







First two metric: M-E1 and M-E2

- These metrics consider the direction of each edge

First two metric: M-E1 and M-E2

- These metrics consider the direction of each edge

Input: $G = (V, E, L_V, L_E)$: graph with the representation of the process;
Direction: a function to obtain the direction(s) of an edge

```
/* Define the directions, and initialize one counter for each
   direction                                                    */
freqs[North] ← 0
freqs[East] ← 0
freqs[South] ← 0
freqs[West] ← 0
/* Iterate through all edges to populate freqs                 */
for e ∈ E do
    /* Contribution of the edge to each direction              */
    dirs_e ← Direction(e) /* dirs is a set with all directions the
       edge e is pointing to                                    */
    for d ∈ {North, East, South, West} do
        /* If the direction d is one of edge's direction, then
           increment the corresponding counter                  */
        if d ∈ dirs_e then
            freqs[d] ← freqs[d] + 1 /* The same edge is allowed to
               belong to more than one direction                */
        end
    end
end
/* Obtain the cost of the predominant direction                */
predominant ← max {freqs[North], freqs[East], freqs[South], freqs[West]}
/* Return the final consistency score, assuming the graph has
   at least one edge (and therefore |E| > 0                     */
return predominant/|E|
```

First two metric: M-E1 and M-E2

- These metrics consider the direction of each edge

Input: $G = (V, E, L_V, L_E)$: graph with the representation of the process;
Direction: a function to obtain the direction(s) of an edge

```
/* Define the directions, and initialize one counter for each
   direction                                                    */
1  freqs[North] ← 0
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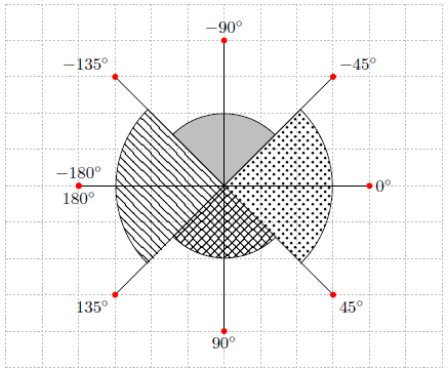
3  freqs[South] ← 0
4  freqs[West] ← 0
/* Iterate through all edges to populate freqs                  */
5  for e ∈ E do
       /* Contribution of the edge to each direction           */
6      dirs_e ← Direction(e) /* dirs is a set with all directions the
          edge e is pointing to                                 */
7      for d ∈ {North, East, South, West} do
           /* If the direction d is one of edge's direction, then
              increment the corresponding counter               */
8          if d ∈ dirs_e then
9              freqs[d] ← freqs[d] + 1 /* The same edge is allowed to
                  belong to more than one direction             */
10         end
11     end
12 end
/* Obtain the cost of the predominant direction                 */
13 predominant ← max {freqs[North], freqs[East], freqs[South], freqs[West]}
/* Return the final consistency score, assuming the graph has
   at least one edge (and therefore |E| > 0                     */
14 return predominant/|E|
```

M-E1

Direction specification providing 1 direction per edge



First two metric: M-E1 and M-E2

- These metrics consider the direction of each edge

Input: $G = (V, E, L_V, L_E)$: graph with the representation of the process;
Direction: a function to obtain the direction(s) of an edge

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/* Define the directions, and initialize one counter for each
   direction                                                    */
1  freqs[North] ← 0
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3  freqs[South] ← 0
4  freqs[West] ← 0
/* Iterate through all edges to populate freqs                  */
5  for e ∈ E do
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          edge e is pointing to                                 */
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                  belong to more than one direction             */
10         end
11     end
12 end
/* Obtain the cost of the predominant direction                 */
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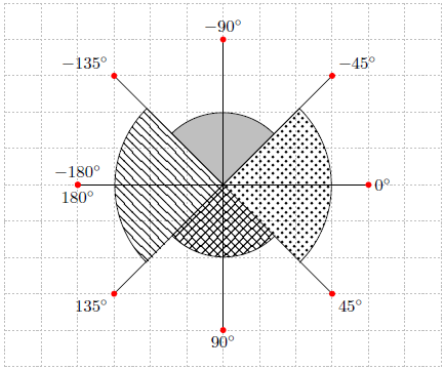
/* Return the final consistency score, assuming the graph has
   at least one edge (and therefore |E| > 0                     */
14 return predominant/|E|
```

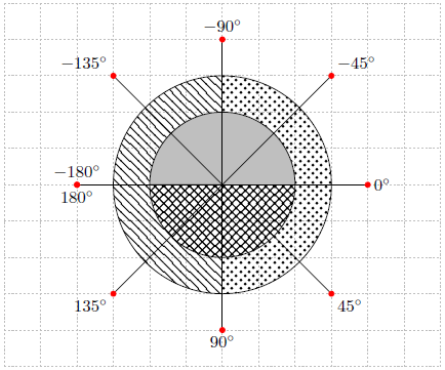
M-E1

Direction specification providing 1 direction per edge



M-E2

Direction specification providing 2 direction per edge



Metric M-BP

- This approach is instead based on Behavioral Profiles

Input: $G = (V, E, L_V, L_E)$:

1 $t_{strict} \leftarrow 0$
2 $correct_{\text{East}} \leftarrow 0$
3 $correct_{\text{South}} \leftarrow 0$
4 $BP \leftarrow \text{BehavioralProfiles}(G)$ /* Compute all behavioral relations */
5 **foreach** $bp \in BP$ **do**
6 **if** $\#_{relation}(bp) = \rightarrow$ **then** /* Only strict order relations */
  /* Extract the coordinates of the central points of the source and target nodes */
7 $(s_x, s_y) \leftarrow L_V(\#_{source}(bp))$
8 $(t_x, t_y) \leftarrow L_V(\#_{target}(bp))$
9 **if** $s_x < t_x$ **then** /* Check for the East direction */
10 $correct_{\text{East}} \leftarrow correct_{\text{East}} + 1$
11 **end**
12 **if** $s_y < t_y$ **then** /* Check for the South direction */
13 $correct_{\text{South}} \leftarrow correct_{\text{South}} + 1$
14 **end**
15 $t_{strict} \leftarrow t_{strict} + 1$
16 **end**
17 **end**
18 **return** $\max\{correct_{\text{East}}, correct_{\text{South}}\} / t_{strict}$ /* Final consistency score as the dominant direction, divided by the total number of strict relations */

Metric M-BP

- This approach is instead based on Behavioral Profiles

Input: $G = (V, E, L_V, L_E)$:

1 $t_{strict} \leftarrow 0$
2 $correct_{\text{East}} \leftarrow 0$
3 $correct_{\text{South}} \leftarrow 0$
4 $BP \leftarrow \text{BehavioralProfiles}(G)$ /* Compute all behavioral relations */
5 **foreach** $bp \in BP$ **do**
6 **if** $\#_{relation}(bp) = \rightarrow$ **then** /* Only strict order relations */
  /* Extract the coordinates of the central points of the source and target nodes */
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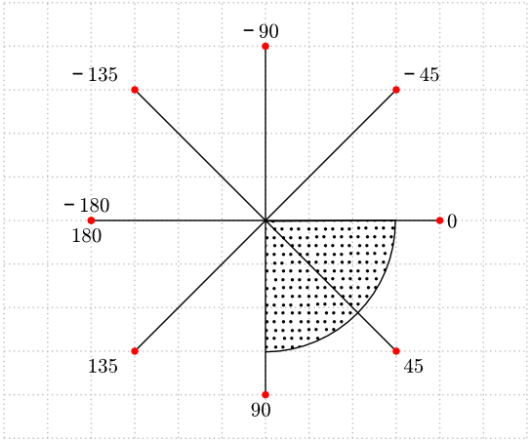
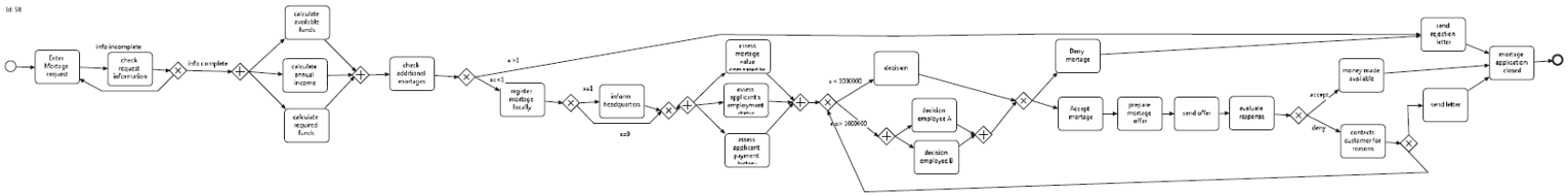
8 $(t_x, t_y) \leftarrow L_V(\#_{target}(bp))$
9 **if** $s_x < t_x$ **then** /* Check for the East direction */
10 $correct_{\text{East}} \leftarrow correct_{\text{East}} + 1$
11 **end**
12 **if** $s_y < t_y$ **then** /* Check for the South direction */
13 $correct_{\text{South}} \leftarrow correct_{\text{South}} + 1$
14 **end**
15 $t_{strict} \leftarrow t_{strict} + 1$
16 **end**
17 **end**
18 **return** $\max\{correct_{\text{East}}, correct_{\text{South}}\} / t_{strict}$ /* Final consistency score as the dominant direction, divided by the total number of strict relations */

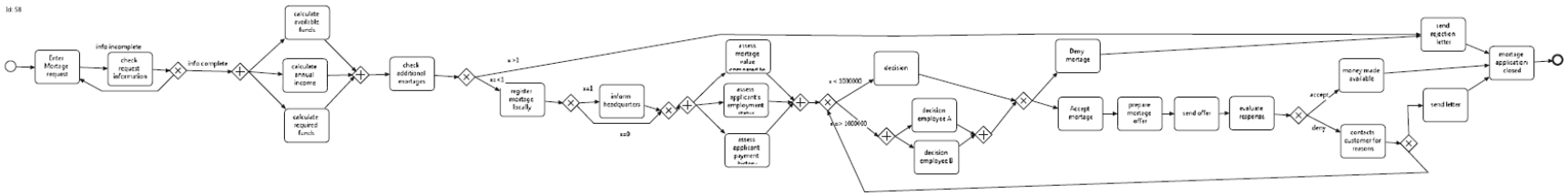
Angular representation of “south-east”



Example of metric computations

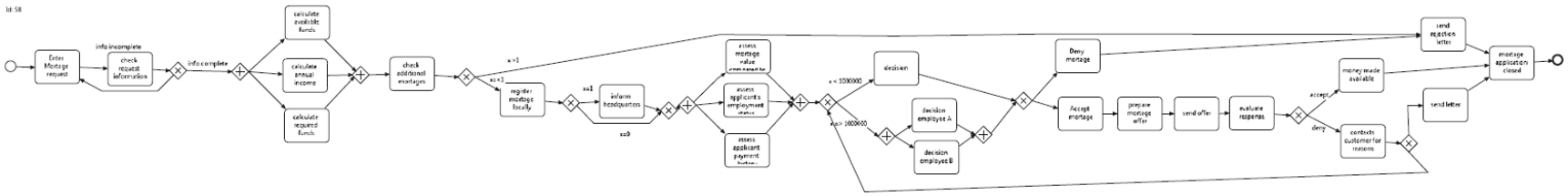


Example of metric computations



- M-E1
  - Edge north: 1
  - Edges east: 48
  - Edges west: 2
  - Edges south: 0
  - Final score: 48/51 = **0.941**

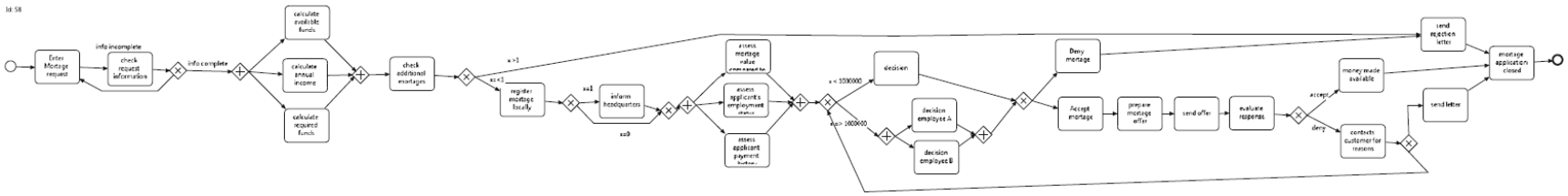
Example of metric computations



- M-E1
  - Edge north: 1
  - Edges east: 48
  - Edges west: 2
  - Edges south: 0
  - Final score: 48/51 = **0.941**

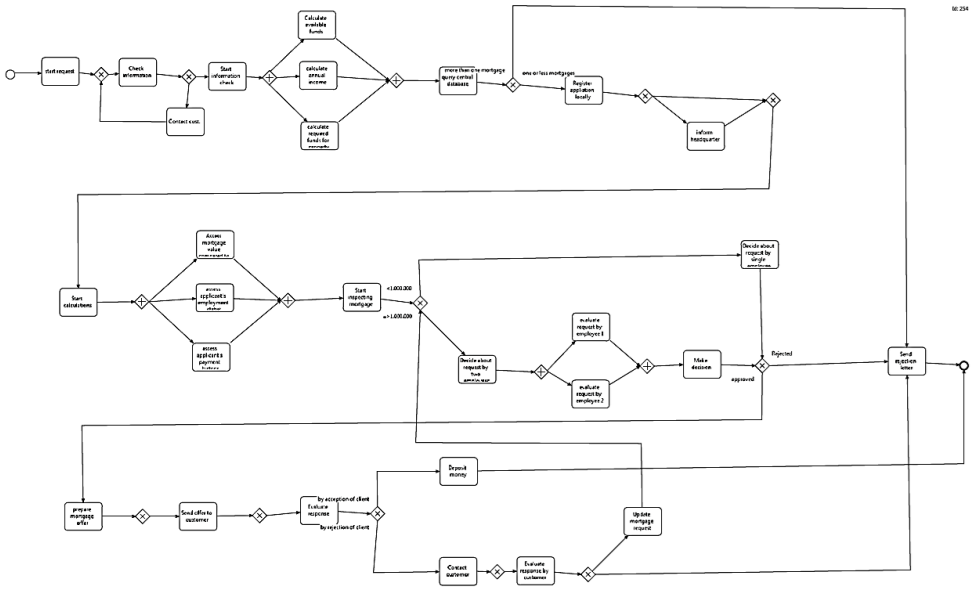
- M-E2
  - Edge north: 28
  - Edges east: 49
  - Edges west: 2
  - Edges south: 23
  - Final score: 49/51 = **0.960**

Example of metric computations

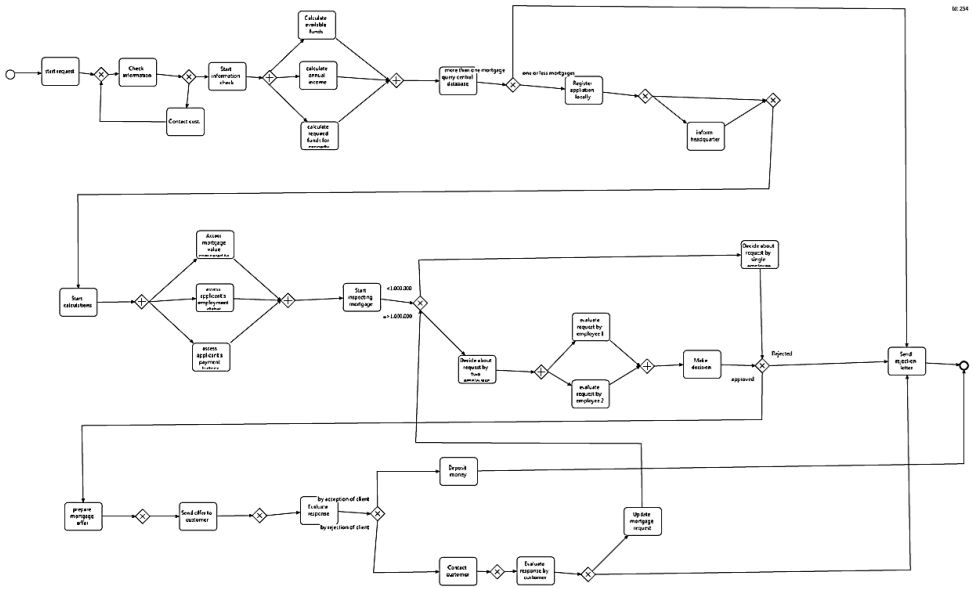


- M-E1
  - Edge north: 1
  - Edges east: 48
  - Edges west: 2
  - Edges south: 0
  - Final score: 48/51 = **0.941**
- M-BP
  - Strict relations: 43
  - Pointing south-east: 40
  - Final score: 40/43 = **0.930**
- M-E2
  - Edge north: 28
  - Edges east: 49
  - Edges west: 2
  - Edges south: 23
  - Final score: 49/51 = **0.960**

Example of metric computations (cont.)

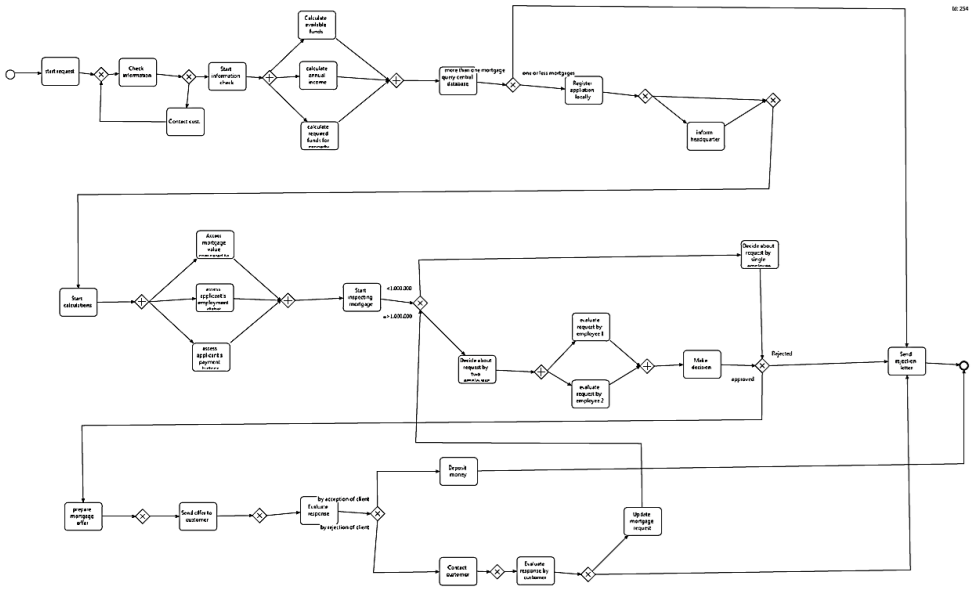


Example of metric computations (cont.)



- M-E1
  - Edge north: 1
  - Edges east: 50
  - Edges west: 2
  - Edges south: 4
  - Final score: 50/59 = **0.847**

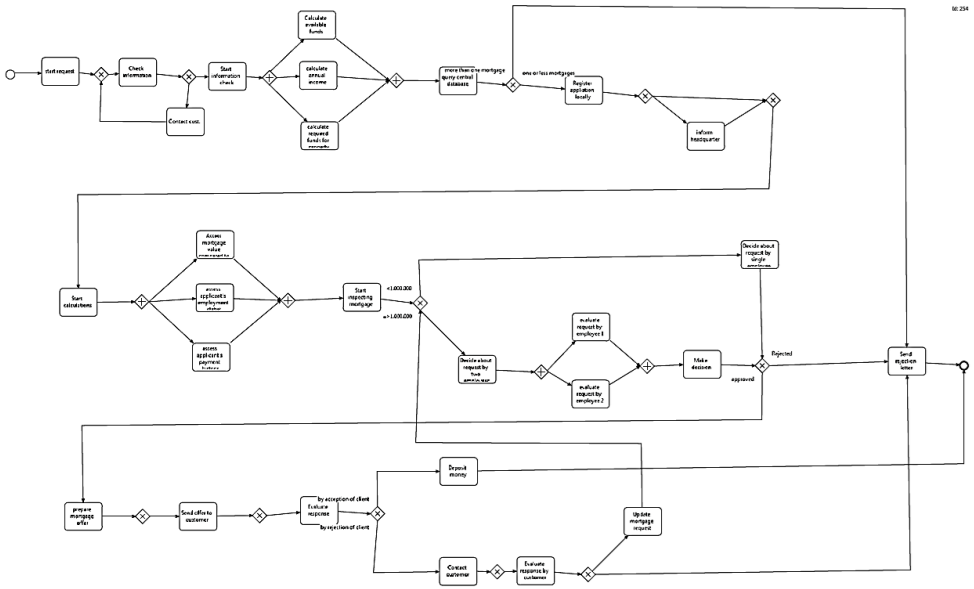
Example of metric computations (cont.)



- M-E1
  - Edge north: 1
  - Edges east: 50
  - Edges west: 2
  - Edges south: 4
  - Final score: 50/59 = **0.847**

- M-E2
  - Edge north: 28
  - Edges east: 54
  - Edges west: 5
  - Edges south: 31
  - Final score: 54/59 = **0.915**

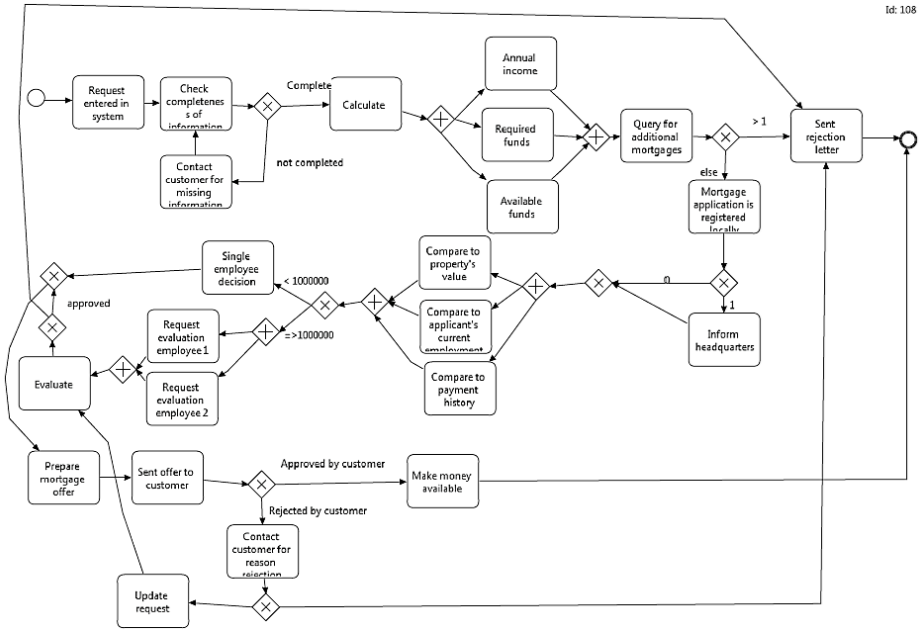
Example of metric computations (cont.)



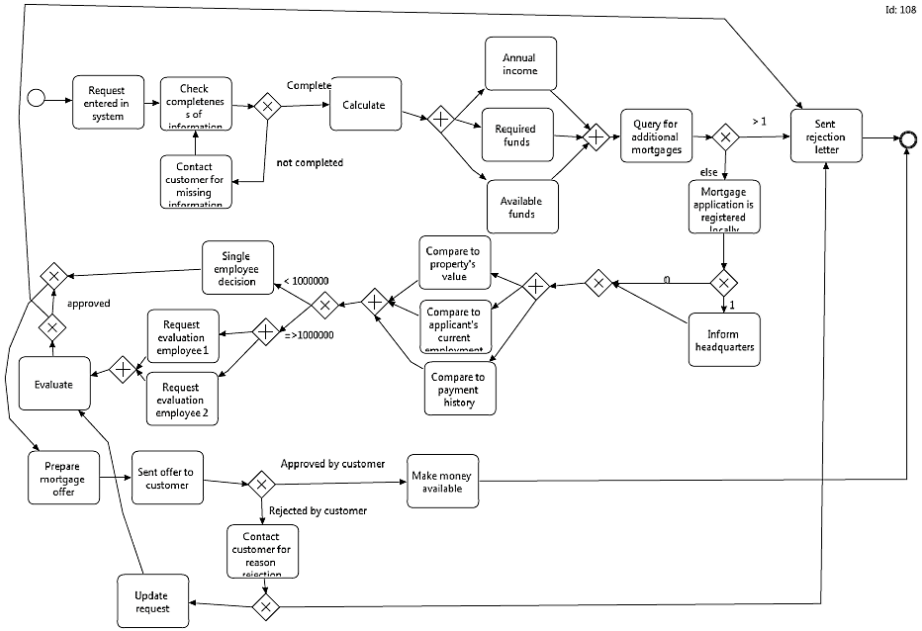
- M-E1
  - Edge north: 1
  - Edges east: 50
  - Edges west: 2
  - Edges south: 4
  - Final score: 50/59 = **0.847**
- M-BP
  - Strict relations: 38
  - Pointing south-east: 33
  - Final score: 33/38 = **0.868**

- M-E2
  - Edge north: 28
  - Edges east: 54
  - Edges west: 5
  - Edges south: 31
  - Final score: 54/59 = **0.915**

Example of metric computations (cont.)

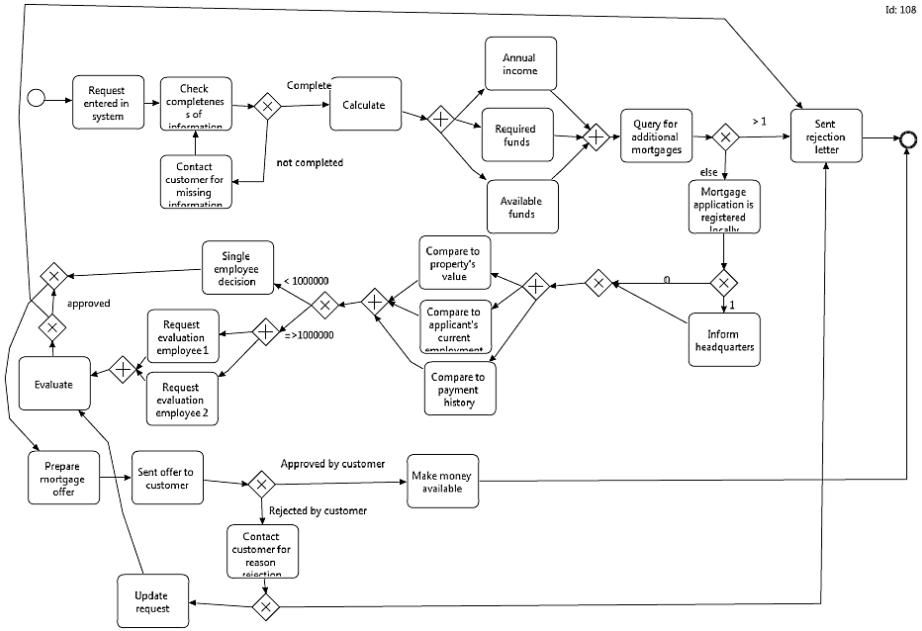


Example of metric computations (cont.)



- M-E1
  - Edge north: 5
  - Edges east: 20
  - Edges west: 17
  - Edges south: 9
  - Final score: 20/51 = **0.392**

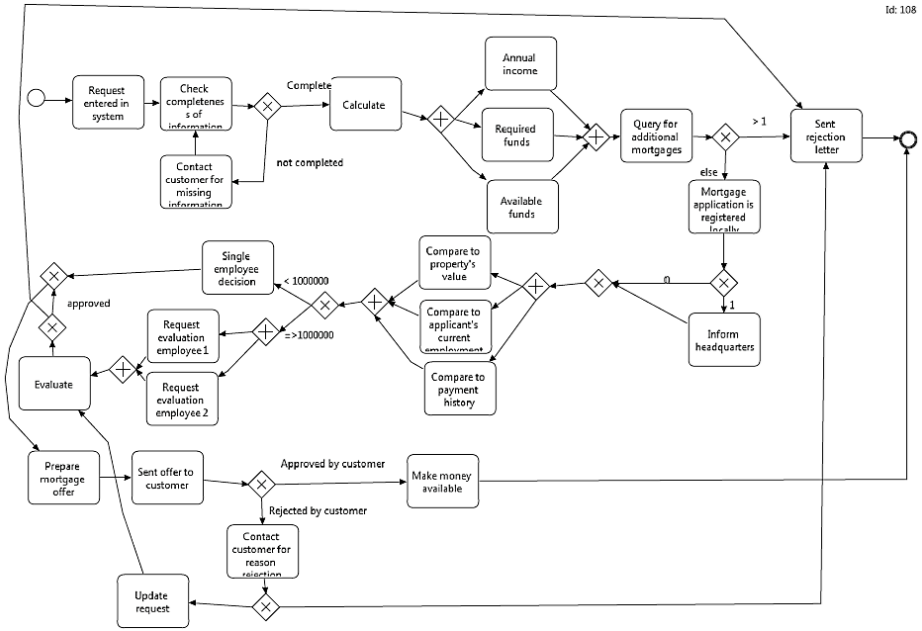
Example of metric computations (cont.)



- M-E1
  - Edge north: 5
  - Edges east: 20
  - Edges west: 17
  - Edges south: 9
  - Final score: 20/51 = **0.392**

- M-E2
  - Edge north: 21
  - Edges east: 27
  - Edges west: 24
  - Edges south: 30
  - Final score: 30/51 = **0.588**

Example of metric computations (cont.)



- M-E1
  - Edge north: 5
  - Edges east: 20
  - Edges west: 17
  - Edges south: 9
  - Final score: 20/51 = **0.392**
- M-BP
  - Strict relations: 37
  - Pointing south-east: 23
  - Final score: 23/37 = **0.622**

- M-E2
  - Edge north: 21
  - Edges east: 27
  - Edges west: 24
  - Edges south: 30
  - Final score: 30/51 = **0.588**

Intermediate results summary

- Results summary on sample models

	M-E1	M-E2	M-BP
Consistent model	0.941	0.960	0.930
Average model	0.847	0.915	0.868
Messy model	0.392	0.588	0.622

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- Experimental evaluation

Intermediate results summary

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Consistent model	0.941	0.960	0.930
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- Experimental evaluation
- Dataset used to answer this question
  - 125 models, all referring to the same process description
  - Data collection: December 2012 at the Eindhoven University of Technology
  - Subjects: students of
    - operations management and logistics
    - business information systems
    - innovation management
    - human-technology interaction
  - Aim: how are these metrics performing with respect to human perception?

First analysis: metrics agreement

- Goal: the extent to which our three metrics agree on the dataset

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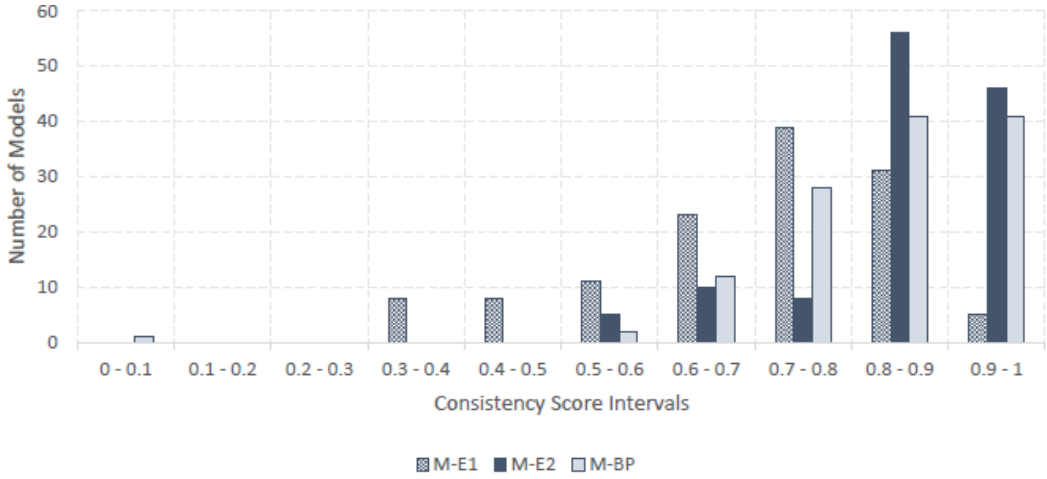
  - Number of models within a consistency score interval



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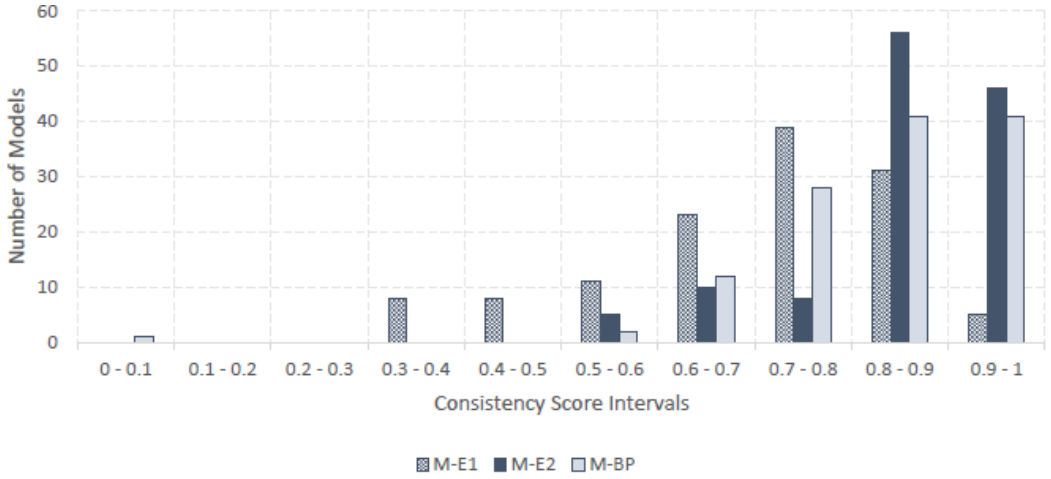
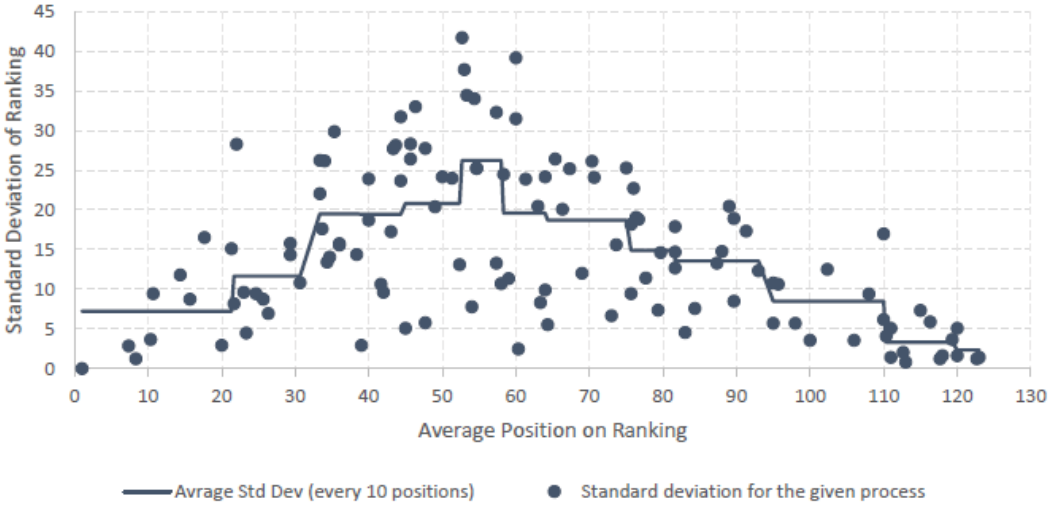


  - Standard deviation of the ranking / average ranking (among the three metrics)



Second analysis: efficiency

- Time required to compute the metrics for one process model
  - Each metric has been compute 5 times for each process (i.e., 5*125 = 625 computations per metric) and the average values are reported

	M-E1	M-E2	M-BP
Average time	0.1533 ms	0.0693 ms	34.4179 ms
Max time	2.0011 ms	0.8164 ms	174.4437 ms
Min time	0.0524 ms	0.0161 ms	2.4495 ms

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Average time	0.1533 ms	0.0693 ms	34.4179 ms
Max time	2.0011 ms	0.8164 ms	174.4437 ms
Min time	0.0524 ms	0.0161 ms	2.4495 ms

- M-BP is the least efficient, since it has to compute the behavioral profiles
  - Still, about 34 ms per model: affective for time-constrained environments too

Third analysis: human assessment

- We selected 14 models from our dataset
  - Sampled according to the distribution of the ranking and standard deviation
  - Two questionnaires (A/B) with models presented in opposite order
  - 7-point Likert scale from “no consistency at all” to “complete consistency”

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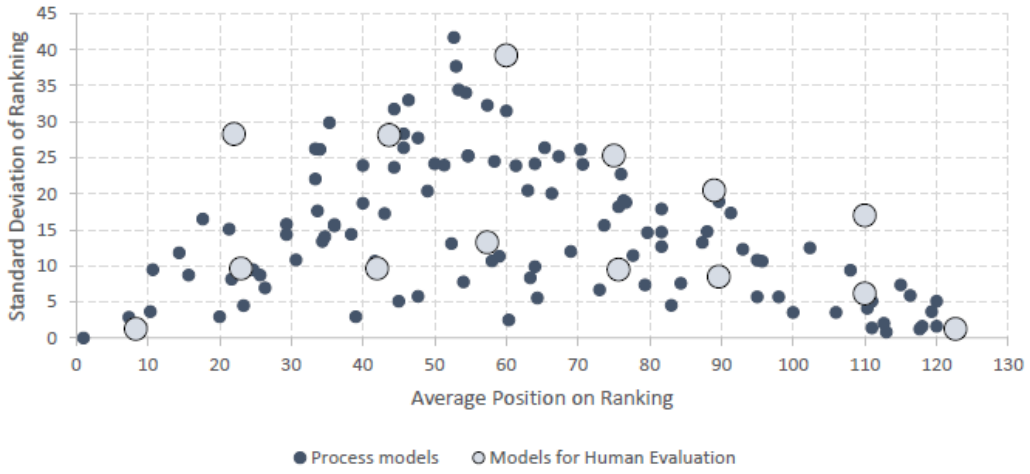

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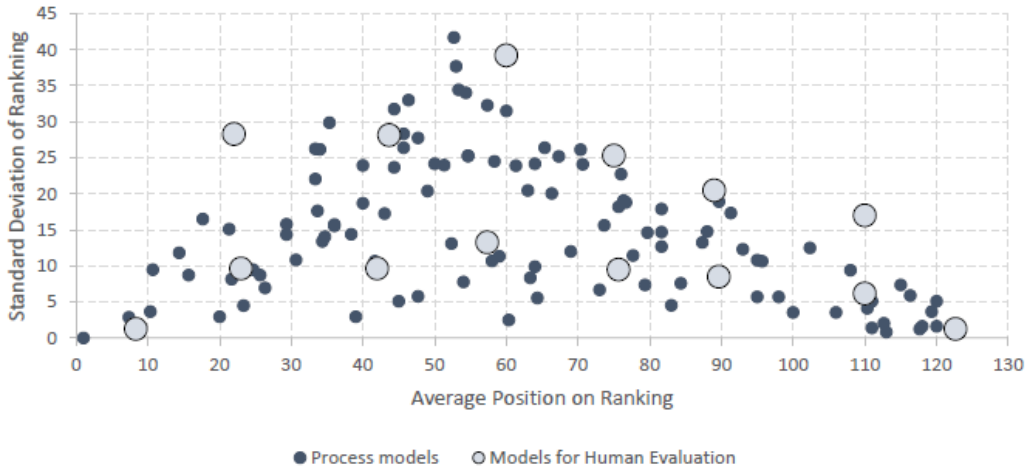

- We asked participants of BPM 2015 (Innsbruck) to evaluate the flow consistency of the models
  - Participants are assumed to be familiar/experts with process modeling
  - We collected 47 evaluations (25 A, 22 B)

Scores obtained

				Human evaluation	
Model	M-E1	M-E2	M-BP	Average score	Standard deviation
Model 1	0.73	0.85	0.68	**0.43**	0.25
Model 2	0.38	0.57	0.57	**0.36**	0.27
Model 3	0.73	0.84	0.83	**0.52**	0.25
Model 4	0.79	0.87	0.85	**0.48**	0.28
Model 5	0.37	0.59	0.78	**0.39**	0.26
Model 6	0.75	0.91	0.92	**0.32**	0.24
Model 7	0.50	0.88	0.95	**0.76**	0.19
Model 8	0.69	0.94	0.91	**0.72**	0.25
Model 9	0.55	0.64	0.70	**0.50**	0.30
Model 10	0.86	0.92	0.93	**0.73**	0.20
Model 11	0.78	0.86	0.71	**0.35**	0.26
Model 12	0.74	0.96	1.00	**0.80**	0.19
Model 13	0.63	0.81	0.81	**0.55**	0.29
Model 14	0.87	0.96	0.97	**0.66**	0.25

Correlations

- We computed correlations of average human score wrt metrics at hand

	Pearson Correlation	Significance
M-E1	0.263	0.364
M-E2	0.567	0.034
M-BP	**0.719**	**0.004**

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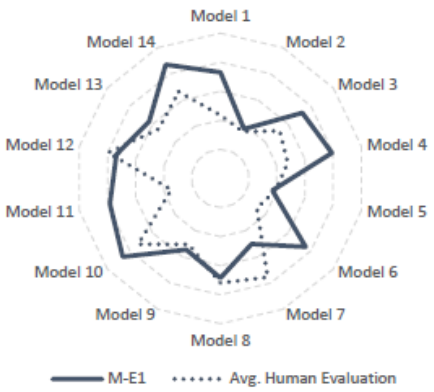

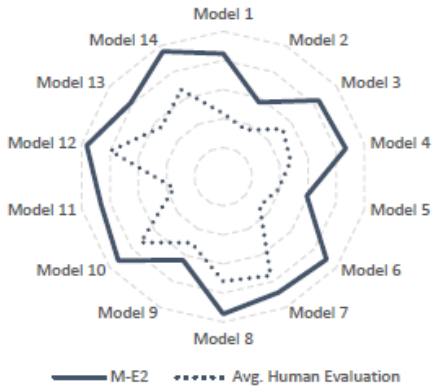

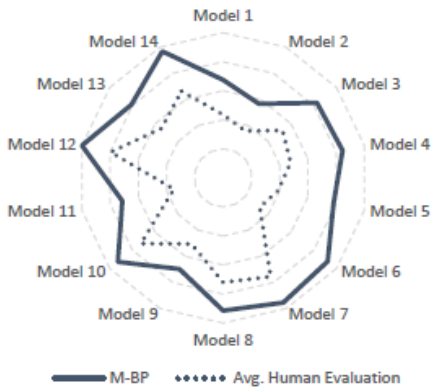

Conclusions and future work

- We showed how we elicited layout features by means of an experiment
- We identified the consistency of the flow as perceived relevant feature
  - We proposed 3 metrics for the quantification of the flow consistency
  - We performed different assessments on our metrics
  - We identify the metric which is the most similar to the human perception

- Possible future work
  - Reuse similar methodology for other layout features
  - Deploy suggestions based on our metrics in real-world modeling environments