

LogicMP: A Neuro-symbolic Approach for Encoding First-order Logic Constraints

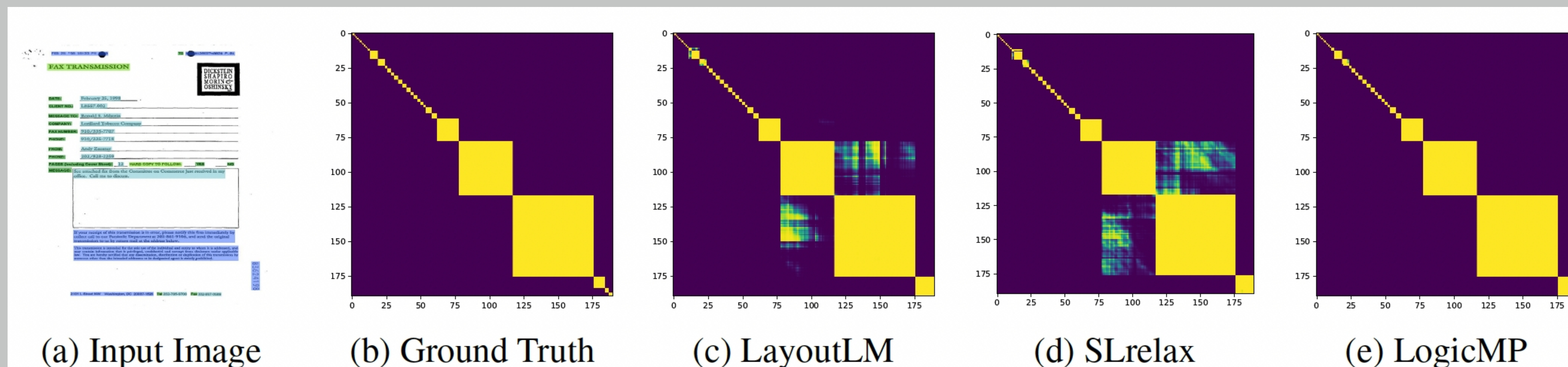


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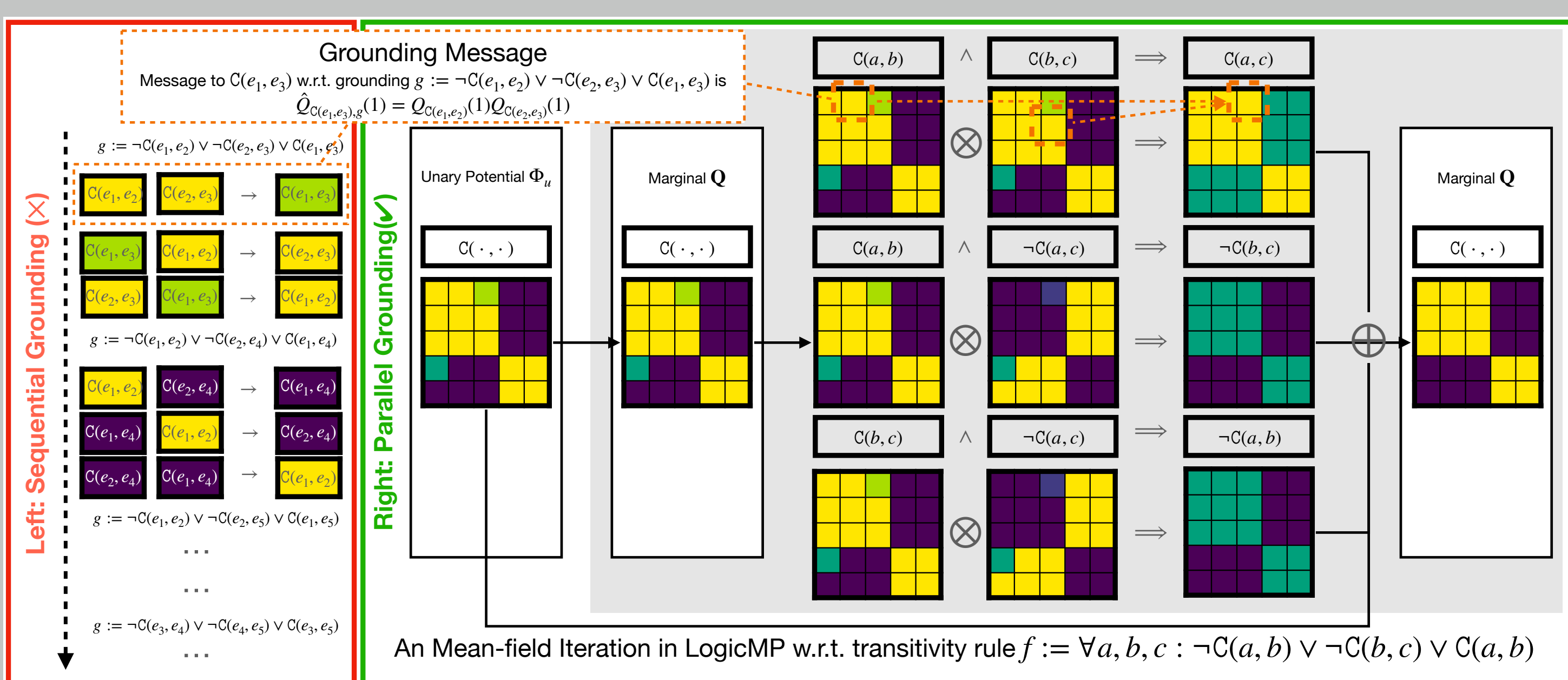
An Example of Encoding First-order Logic Constraints.

Task: Given the input image and input tokens, the task is to develop a function to predict whether two tokens coexist in a block.
Rule: If tokens i and j are in the same block and tokens j and k are also together, then tokens i and k should be in the same block.
Rule: $\forall i, j, k : c(i, j) \wedge c(j, k) \implies c(i, k)$.



An example of using LogicMP in the image segmentation problem.

LogicMP: the first fully differentiable neuro-symbolic approach capable of encoding FOLCs for arbitrary neural networks



Overview of LogicMP.

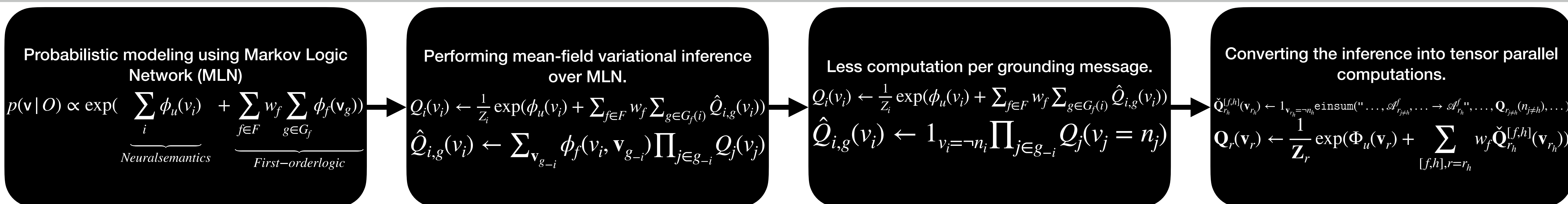
Algorithm 2 PyTorch-like Code for LogicMP with Transitivity Rule

```
# logits: torch.Tensor, size=[batchsize, nentities, nentities, 2]
# niterations: int, number of iterations

cur_logits = logits.clone()
for i in range(niterations):
    Q = softmax(cur_logits, dim=-1)
    cur_logits = logits.clone()
    # Message Aggregation for Implication \forall a, b, c: C(a, b) \wedge C(b, c) \implies C(a, c)
    msg_to_ac = einsum('kab, kbc->kac', Q[...], Q[...])
    # Message Aggregation for Implication \forall a, b, c: C(a, b) \wedge \neg C(a, c) \implies \neg C(b, c)
    msg_to_bc = - einsum('kab, kac->kbc', Q[...], Q[...])
    # Message Aggregation for Implication \forall a, b, c: C(b, c) \wedge \neg C(a, c) \implies \neg C(a, b)
    msg_to_ab = - einsum('kbc, kac->kab', Q[...], Q[...])
    msg = msg_to_ac + msg_to_bc + msg_to_ab
    cur_logits[..., 1] += msg * weight
# Returns cur_logits
```

Pseudo Code for the Example.

Approach Details



Experiments

Task: Given the input image and input tokens, the task is to develop a function to predict whether two tokens coexist in a block.
Rule: If tokens i and j are in the same block and tokens j and k are also together, then tokens i and k should be in the same block.

Results over Document Images.

Methods	full	long
LayoutLM-BIOES [14]	80.1	33.7
LayoutLM-SpanNER [4]	74.0	22.0
LayoutLM-SPADE [6]	80.1	43.5
LayoutLM-Pair [12]	82.0	46.7
LayoutLM-Pair w/ SL [13]	-	-
LayoutLM-Pair w/ SPL [1]	-	-
LayoutLM-Pair w/ SLrelax	82.0	47.8
LayoutLM-Pair w/ LogicMP	83.3	50.1
LayoutLM-Pair w/ SLrelax+LogicMP	83.4	50.3

Task: Given the relational facts, the task is to develop a function to predict whether a latent fact is true.
Rule: Rules of family/school/academic relations.

Results over Relational Graphs.

Method	Kinship					UW-CSE					Cora				
	S1	S2	S3	S4	S5 avg.	A.	G.	L.	S.	T. avg.	S1	S2	S3	S4	S5 avg.
MCMC [9]	.53	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BP/Lifted BP [10]	.53	.58	.55	.55	.56	.01	.01	.01	.01	.01	-	-	-	-	-
MC-SAT [8]	.54	.60	.55	.55	-	.03	.05	.06	.02	.02	.04	-	-	-	-
HL-MRF [2]	1.0	1.0	1.0	1.0	-	.06	.09	.02	.04	.03	.05	-	-	-	-
ExpressGNN	.56	.55	.49	.53	.55	.01	.01	.01	.01	.01	.37	.66	.21	.42	.55
ExpressGNN w/ GS [15]	.97	.97	.99	.99	.99	.09	.19	.14	.06	.09	.11	.62	.79	.46	.57
ExpressGNN w/ LogicMP	.99	.98	1.0	1.0	1.0	.26	.30	.42	.25	.28	.30	.80	.88	.72	.83

Task: Given the text sequence, the task is to develop a function to predict the sequence labels.
Rule: adjacent rules and list rule.

Results over Text.

Methods	F1
BLSTM [5]	89.98
BLSTM (lex) [3]	90.77
BLSTM w/ CRF [7]	90.94
BLSTM w/ CRF (mean field) [11]	91.07
BLSTM w/ SL [13]	-
BLSTM w/ SPL [1]	-
BLSTM w/ SLrelax	90.38
BLSTM w/ LogicDist (adj) [5]	p: 89.80, q: 91.11
BLSTM w/ LogicDist (adj+list) [5]	p: 89.93, q: 91.18
BLSTM w/ LogicMP (adj)	91.25
BLSTM w/ LogicMP (adj+list)	91.42

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