A CONSTRAINED ADAPTIVE SCAN ORDER APPROACH TO TRANSFORM COEFFICIENT ENTROPY CODING

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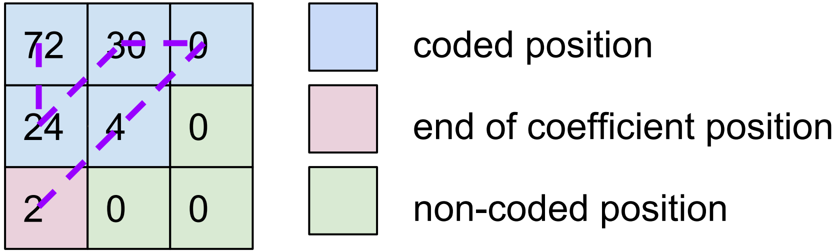
Coding of Transform Block Coefficients

- Use a scan order to code transform block coefficients sequentially.
- Code an end-of-coefficient token after last non-zero coefficient in the scan order.
- The rest of zero coefficients can be skipped.



72	30	0
24	4	0
2	0	0

🟦 coded position

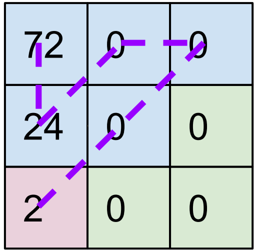
🟪 end of coefficient position

🟩 non-coded position

72 -> 24 -> 30 -> 0 ->4 -> 2 -> eob

Motivation

- Arrange most zero coefficients to the tail.
  - The end-of-coefficient token will allow us to ignore zero coefficients in the tail.
- Transform block statistics are different across different video clips.
  - Using a predefined scan order will waste bits in coding zero coefficients.
  - An adaptive approach is needed.



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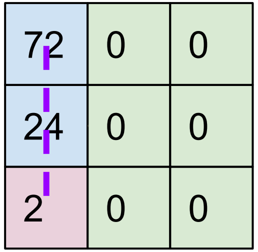
24	0	0
2	0	0



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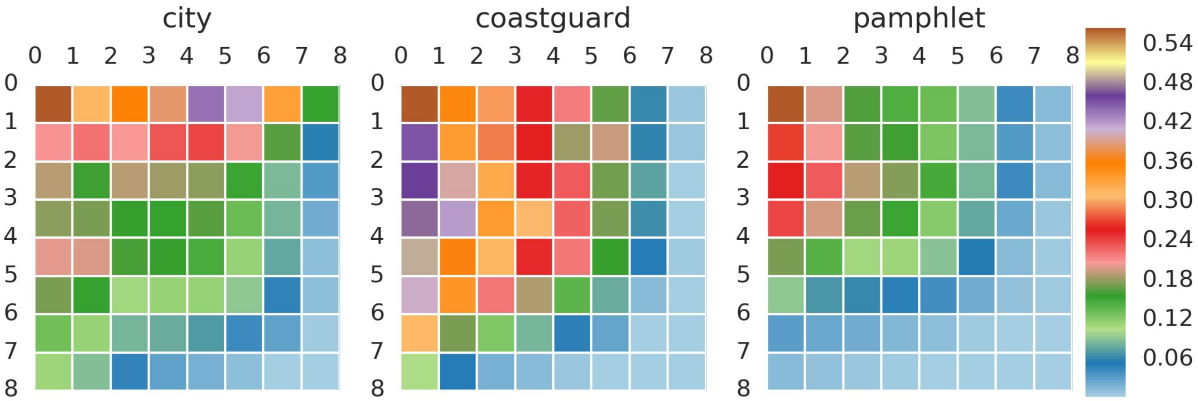
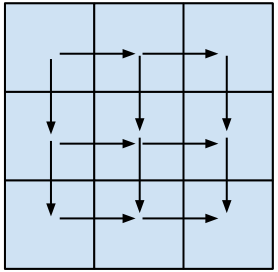


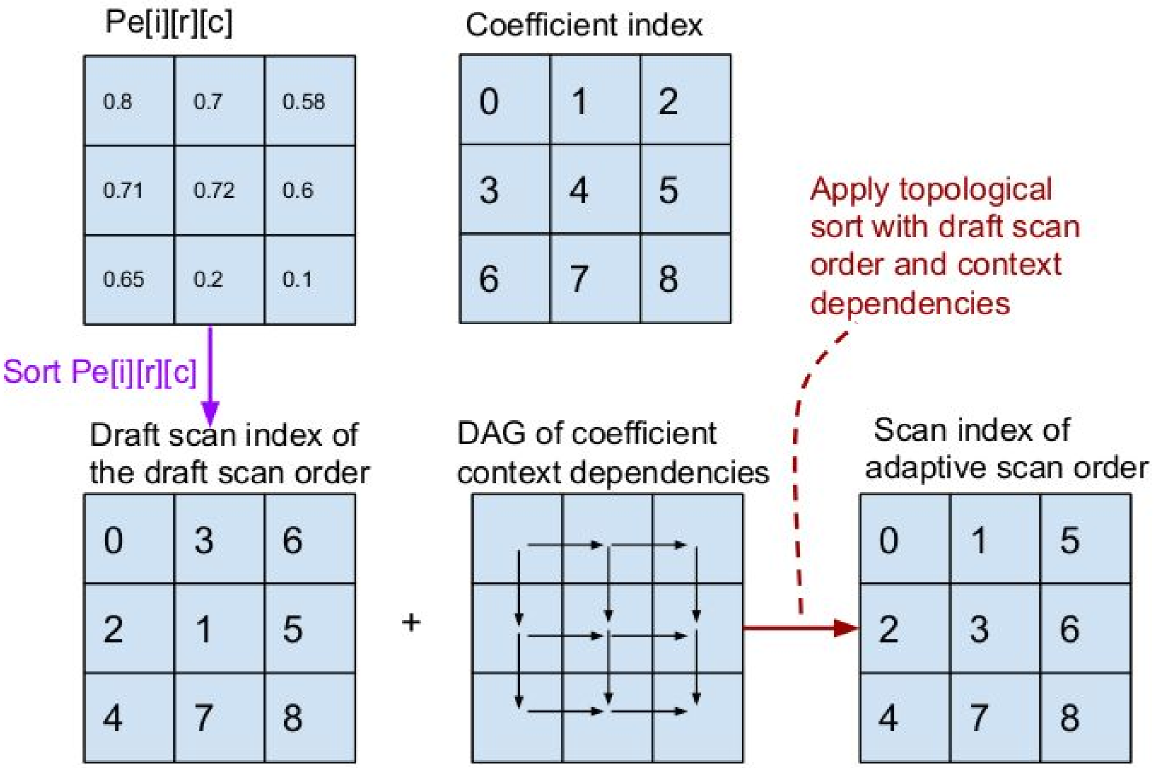
Context Dependency

- How about we design an adaptive scan order merely by sorting the non-zero probabilities of positions in transform blocks?
- The above/left coefficient context dependency is applied in entropy coding to exploit the remaining inter-coefficient correlations.
- The scan order obtained from sorting the non-zero probabilities may have conflict with the context dependency.



Topological Sort - Example

- By applying topological sort, one can generate a scan order that mostly follows the descending order of non-zero probabilities without violating the context dependency.



Pe[i][r][c]

0.8	0.7	0.58
0.71	0.72	0.6
0.65	0.2	0.1

Coefficient index

0	1	2
3	4	5
6	7	8

Sort Pe[i][r][c]

Draft scan index of the draft scan order

0	3	6
2	1	5
4	7	8

+

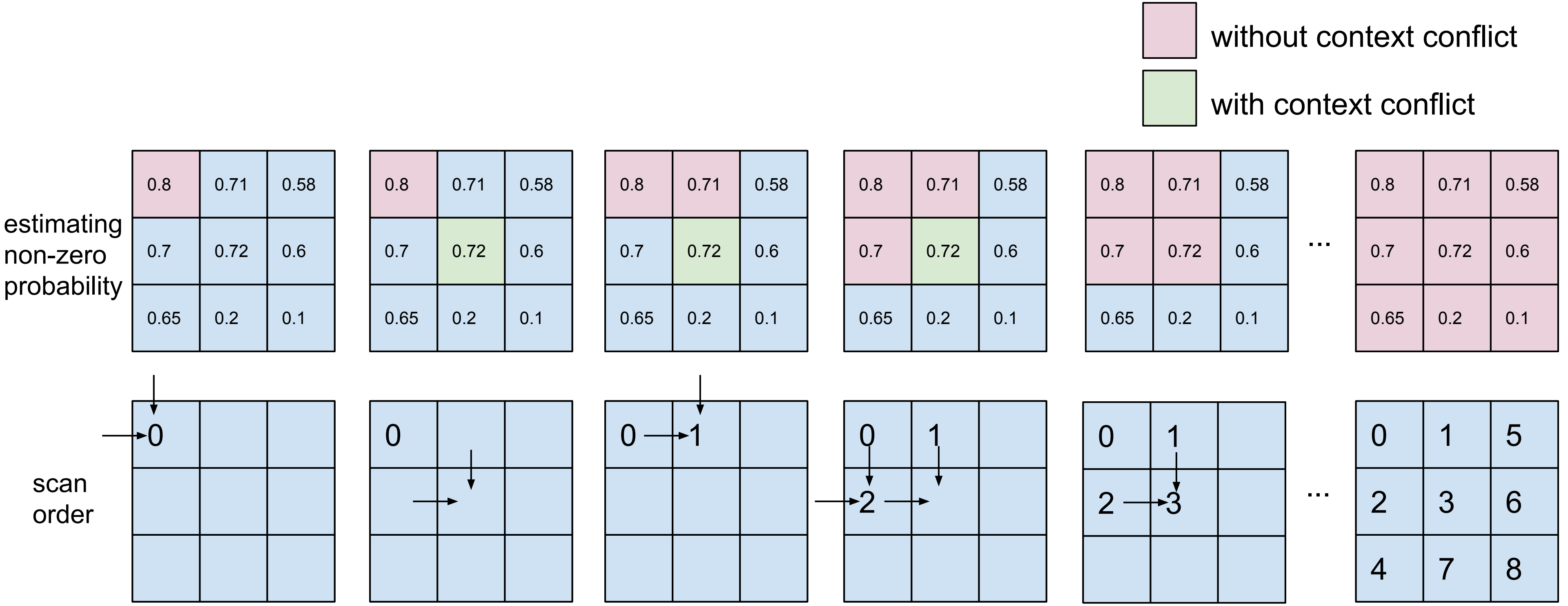
DAG of coefficient context dependencies

Apply topological sort with draft scan order and context dependencies

Scan index of adaptive scan order

0	1	5
2	3	6
4	7	8

Topological Sort - Resolve Context Conflict



🟥 without context conflict

🟩 with context conflict

estimating non-zero probability

0.8	0.71	0.58
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...

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scan order

0		

0		

0	1	

0	1	
2		

0	1	
2	3	

...

0	1	5
2	3	6
4	7	8

Estimation of Non-zero Probabilities of Transform Coefficients

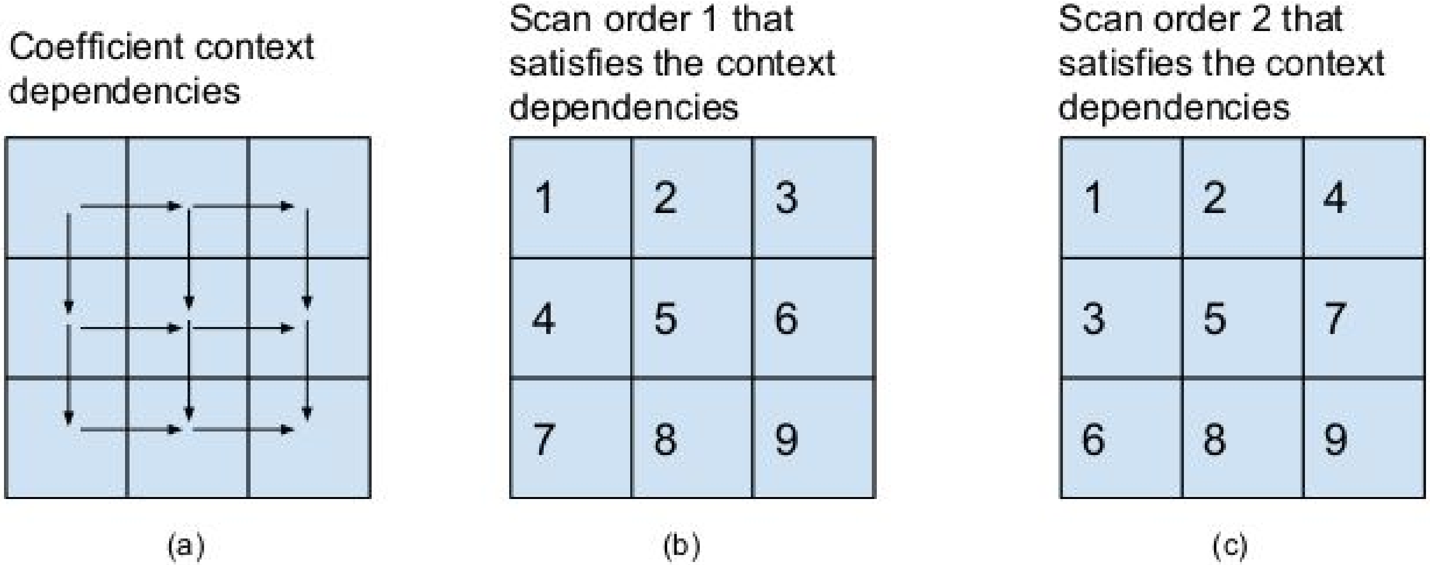
- The cost of transmitting non-zero probabilities or the adaptive scan order from encoder to decoder is impractically large
- Moving window estimation
    - Estimate non-zero probabilities of transform block coefficients for i-th frame.
    - Non-zero coefficient counts and number of transform blocks
        - $C[i-1][r][c]$
        - $M \rightarrow$ number of transform blocks
    - Observed non-zero probabilities
        - $P c [i-1][r][c] = C[i-1][r][c]/M$
        - per-frame update
    - Estimating non-zero probabilities
        - $P e [i][r][c] = (1 - k) * P e [i-1][r][c] + k * P c [i-1][r][c]$
        - per-frame update

Performance

- Coding gains (BDRate) over predefined scan order scheme on VP9
    - Low-resolution dataset
        - 40 videos with resolutions of 240p, SIF or CIF
        - 1.04%
    - Mid-resolution dataset
        - 23 videos with resolutions of 480p or 4CIF
        - 0.93%
    - High-resolution dataset
        - 38 videos with resolutions 720p, 1080p or XGA
        - 1.13%
- Encoder/decoder Time
    - Encoder: non-observable
    - Decoder: +1%

Q & A

Context Dependency - A Sparse but Strict Constraint



Coefficient context dependencies

(a)

Scan order 1 that satisfies the context dependencies

1	2	3
4	5	6
7	8	9

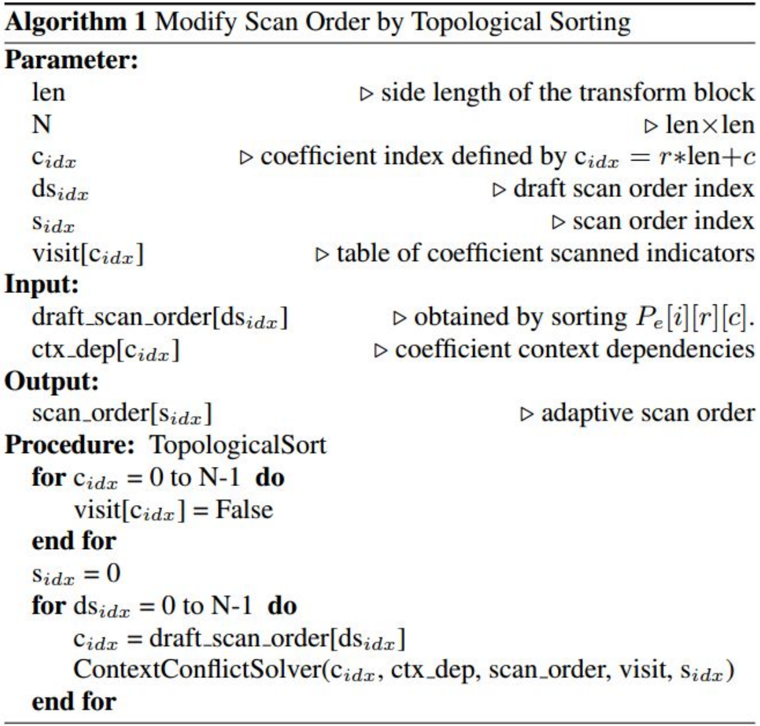
(b)

Scan order 2 that satisfies the context dependencies

1	2	4
3	5	7
6	8	9

(c)

Topological Sort - Pseudocode



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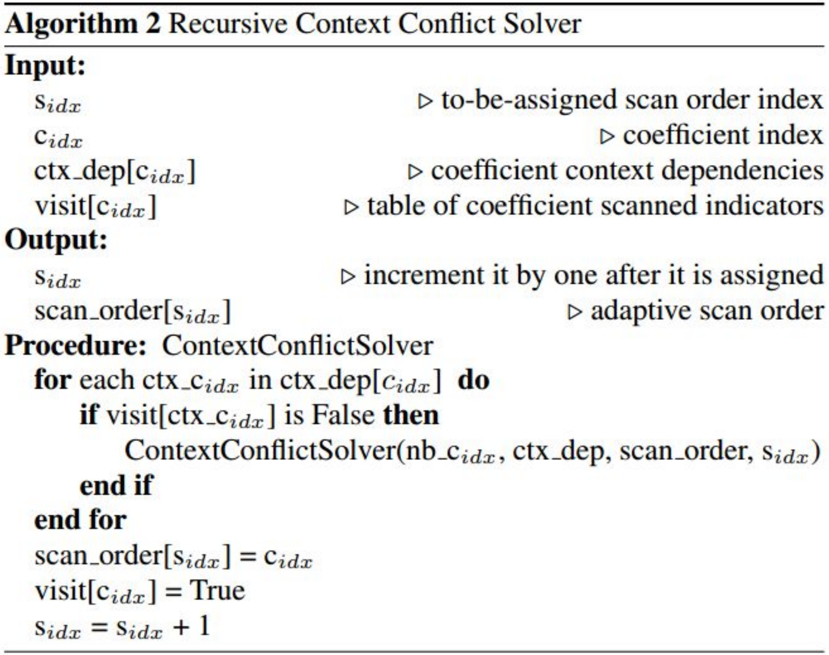
Algorithm 1 Modify Scan Order by Topological Sorting
Parameter:
    len                         ▷ side length of the transform block
    N                           ▷ len×len
    $c_{idx}$                   ▷ coefficient index defined by $c_{idx} = r*len+c$
    $ds_{idx}$                  ▷ draft scan order index
    $s_{idx}$                   ▷ scan order index
    visit[$c_{idx}$]            ▷ table of coefficient scanned indicators
Input:
    draft_scan_order[$ds_{idx}$]   ▷ obtained by sorting $P_e[i][r][c]$.
    ctx_dep[$c_{idx}$]             ▷ coefficient context dependencies
Output:
    scan_order[$s_{idx}$]          ▷ adaptive scan order
Procedure: TopologicalSort
    for $c_{idx}$ = 0 to N-1 do
        visit[$c_{idx}$] = False
    end for
    $s_{idx}$ = 0
    for $ds_{idx}$ = 0 to N-1 do
        $c_{idx}$ = draft_scan_order[$ds_{idx}$]
        ContextConflictSolver($c_{idx}$, ctx_dep, scan_order, visit, $s_{idx}$)
    end for
```



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Algorithm 2 Recursive Context Conflict Solver
Input:
    $s_{idx}$                   ▷ to-be-assigned scan order index
    $c_{idx}$                   ▷ coefficient index
    ctx_dep[$c_{idx}$]          ▷ coefficient context dependencies
    visit[$c_{idx}$]            ▷ table of coefficient scanned indicators
Output:
    $s_{idx}$                   ▷ increment it by one after it is assigned
    scan_order[$s_{idx}$]       ▷ adaptive scan order
Procedure: ContextConflictSolver
    for each ctx_$c_{idx}$ in ctx_dep[$c_{idx}$] do
        if visit[ctx_$c_{idx}$] is False then
            ContextConflictSolver(nb_$c_{idx}$, ctx_dep, scan_order, $s_{idx}$)
        end if
    end for
    scan_order[$s_{idx}$] = $c_{idx}$
    visit[$c_{idx}$] = True
    $s_{idx}$ = $s_{idx}$ + 1
```