OPTIMAL SEARCH FOR MINIMUM ERROR RATE TRAINING

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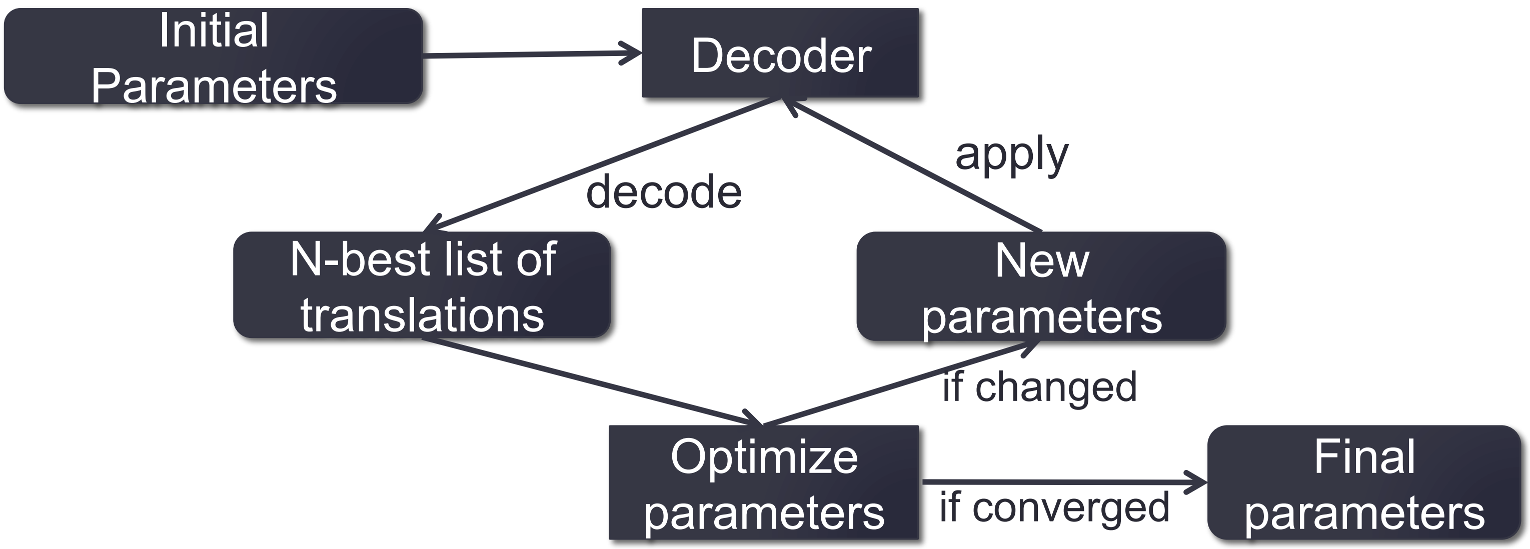
The Claim

- Och’s MERT is not exact
  - I will provide a brief MERT review
- This paper: exact search of MERT search space via linear programming
  - Concurrent optimization of all dimensions
- How does this perform vs. Och’s MERT?

MERT for MT: Primer[1]

- Tune parameter weights to directly optimize evaluation metric



$$\hat{\mathbf{w}} = \arg\min_{\mathbf{w}} \left\{ \sum_{s=1}^{S} E(\mathbf{r}_s, \hat{\mathbf{e}}(\mathbf{f}_s; \mathbf{w})) \right\}$$

$$= \arg\min_{\mathbf{w}} \left\{ \sum_{s=1}^{S} \sum_{n=1}^{N} E(\mathbf{r}_s, \mathbf{e}_{s,n}) \delta(\mathbf{e}_{s,n}, \hat{\mathbf{e}}(\mathbf{f}_s; \mathbf{w})) \right\} \quad \text{s.t.}$$

$$\hat{\mathbf{e}}(\mathbf{f}_s; \mathbf{w}) = \arg \max_{n \in \{1,\ldots,N\}} \{\mathbf{w}^{\mathbf{T}} \mathbf{h}\}_{s,n}$$

1. Courtesy of P.Koehn, “Statistical Machine Translation”

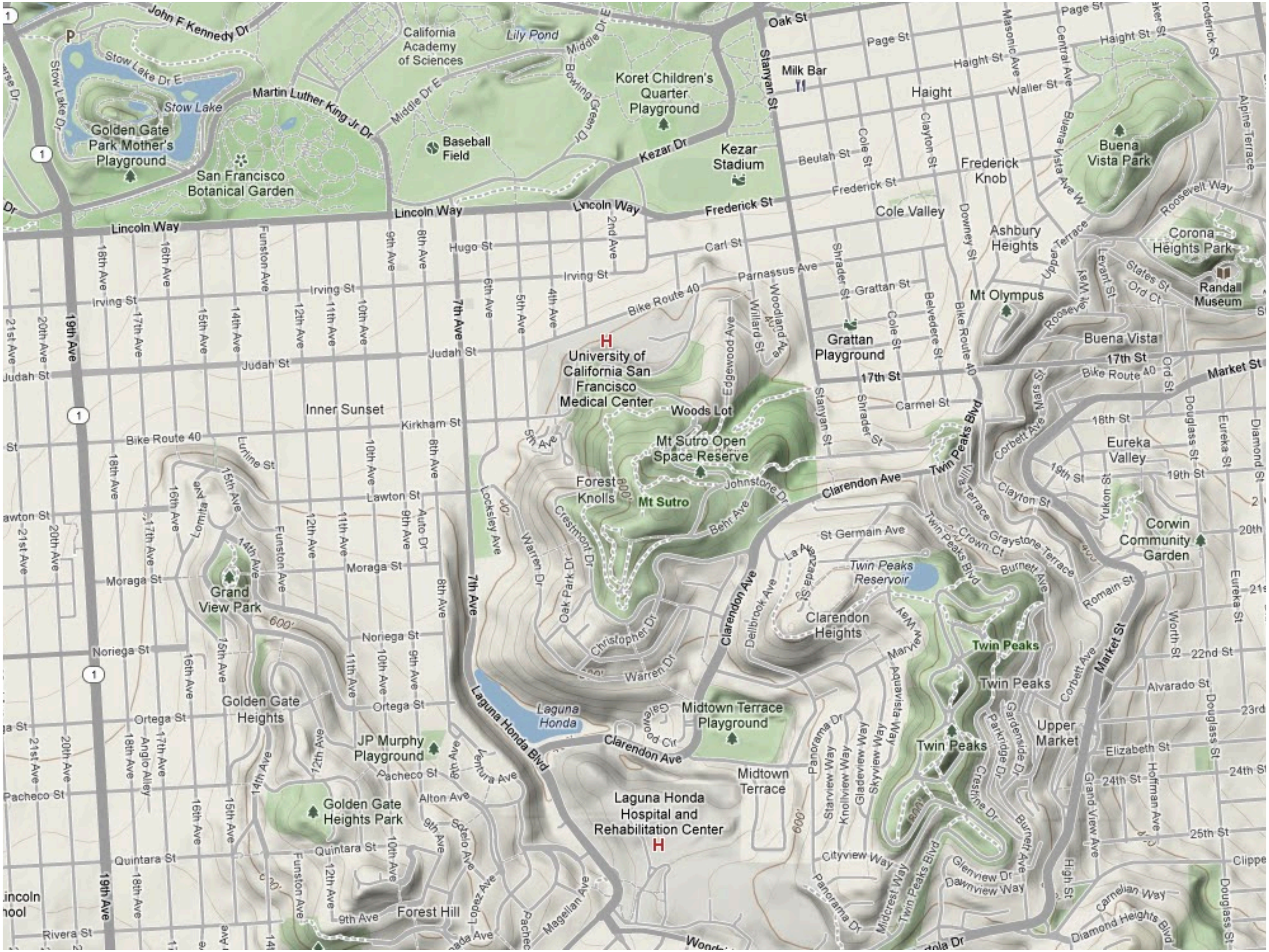
Naïve MERT

- Non-convex, unsmooth: Powell search
  - Multiple starting points used
- Log-linear formulation: $p(x) = \exp\left\{\sum_{i=1}^{N} \lambda_i h_i(x)\right\}$
- Best translation:

$$x^*(\lambda_1, \ldots, \lambda_n) = \arg\max_x \exp\left\{\sum_{i=1}^{N} \lambda_i h_i(x)\right\} \Rightarrow$$

$$x^*(\lambda_c) = \overbrace{\arg\max_x \exp\{\lambda_c h_c(x) + u(x)\}}^{\text{translation line}} \quad \text{where } u(x) = \sum_{i \neq c} \lambda_i h_i(x)$$

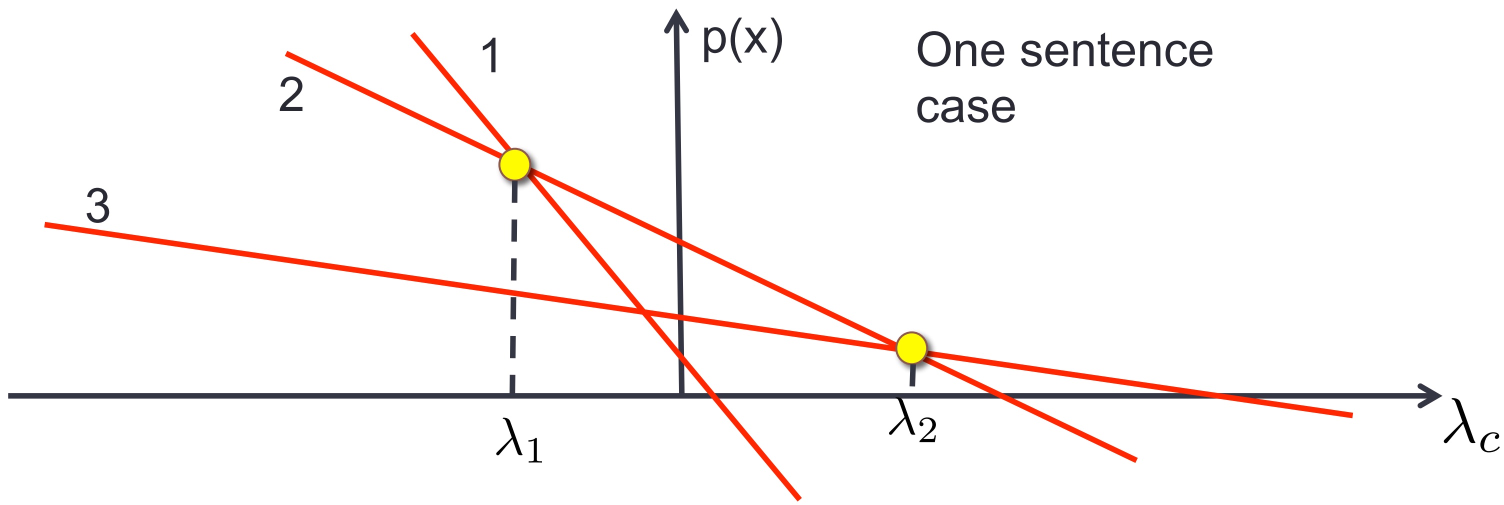
- How to explore parameter space?
  - Grid: trade-off between speed & accuracy
  - Finite approximation



John F Kennedy Dr
California Academy of Sciences
Lily Pond
Middle Dr E
Stow Lake Dr E
Stow Lake Dr
Stow Lake
Golden Gate Park Mother's Playground
San Francisco Botanical Garden
Martin Luther King Jr Dr
Baseball Field
Bowling Green Dr
Koret Children's Quarter Playground
Kezar Dr
Kezar Stadium
Oak St
Page St
Haight St
Stanyan St
Milk Bar
Haight
Waller St
Masonic Ave
Central Ave
Buena Vista Ave W
Buena Vista Park
Alpine Terrace
Beulah St
Cole St
Clayton St
Frederick Knob
Frederick St
Lincoln Way
Cole Valley
Ashbury Heights
Roosevelt Way
Corona Heights Park
Randall Museum
Upper Terrace
Levant St
States St
Ord Ct
Hugo St
Carl St
Irving St
Parnassus Ave
Shrader St
Grattan St
Downey St
Mt Olympus
Bike Route 40
Woodland Ave
Willard St
Edgewood Ave
Belvedere St
Grattan Playground
Buena Vista
17th St
Market St
Judah St
University of California San Francisco Medical Center
Carmel St
Woods Lot
Inner Sunset
Kirkham St
Mt Sutro Open Space Reserve
18th St
Eureka Valley
Twin Peaks Blvd
Corbett Ave
Douglass St
Eureka St
Diamond St
Lawton St
Forest Knolls
Mt Sutro
Johnstone Dr
Clarendon Ave
19th St
Clayton St
Yukon St
Behr Ave
Crestmont Dr
St Germain Ave
Crown Ct
Graystone Terrace
Corwin Community Garden
20th St
Moraga St
Grand View Park
Twin Peaks Reservoir
Burnett Ave
Romain St
Warren Dr
Oak Park Dr
Clarendon Heights
Noriega St
Christopher Dr
Dellbrook Ave
Marview Way
Twin Peaks
Market St
22nd St
Worth St
Alvarado St
Golden Gate Heights
Ortega St
Laguna Honda Blvd
Laguna Honda
Midtown Terrace Playground
Galewood Cir
Aquavista Way
Gardenside Dr
Parkridge Dr
Upper Market
23rd St
JP Murphy Playground
Pacheco St
Ventura Ave
Clarendon Ave
Midtown Terrace
Panorama Dr
Starview Way
Knollview Way
Gladeview Way
Skyview Way
Elizabeth St
24th St
Hoffman Ave
Alton Ave
Golden Gate Heights Park
Laguna Honda Hospital and Rehabilitation Center
Crestline Dr
Grand View Ave
Quintara St
Funston Ave
Cityview Way
25th St
Clipper
Lopez Ave
Glenview Dr
Dawnview Way
Midcrest Way
Carnelian Way
High St
Lincoln School
Forest Hill
Magellan Ave
Diamond Heights Blvd
Rivera St
Lomita Ave
Lurline St
Locksley Ave
Auto Dr
Anglo Alley
Sotelo Ave
19th Ave
7th Ave
9th Ave
8th Ave
2nd Ave
4th Ave
5th Ave
6th Ave
10th Ave
11th Ave
12th Ave
14th Ave
15th Ave
16th Ave
17th Ave
18th Ave
20th Ave
21st Ave
600'

Och's Trick

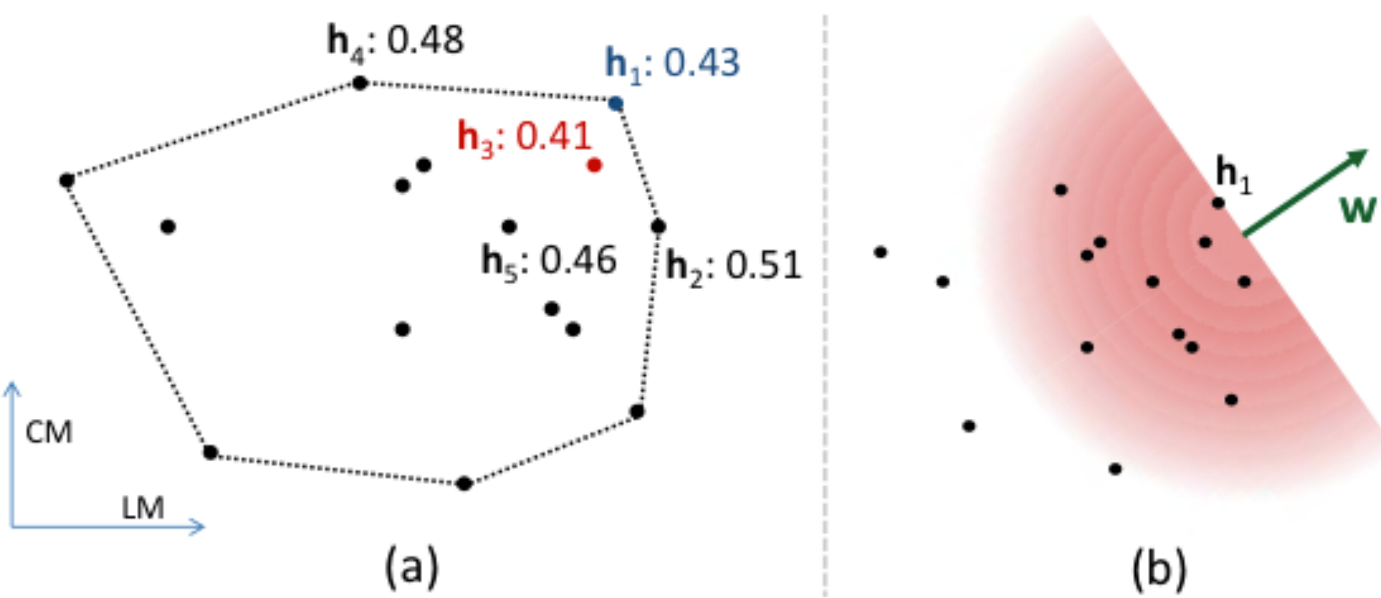
- Translation ranking only changes at intersections of translation lines!



- Multiple sentences:
  - aggregate intersections across sentences
  - For each intersection point, compute error (re-rank and select 1-best)
  - Return interval with best error score

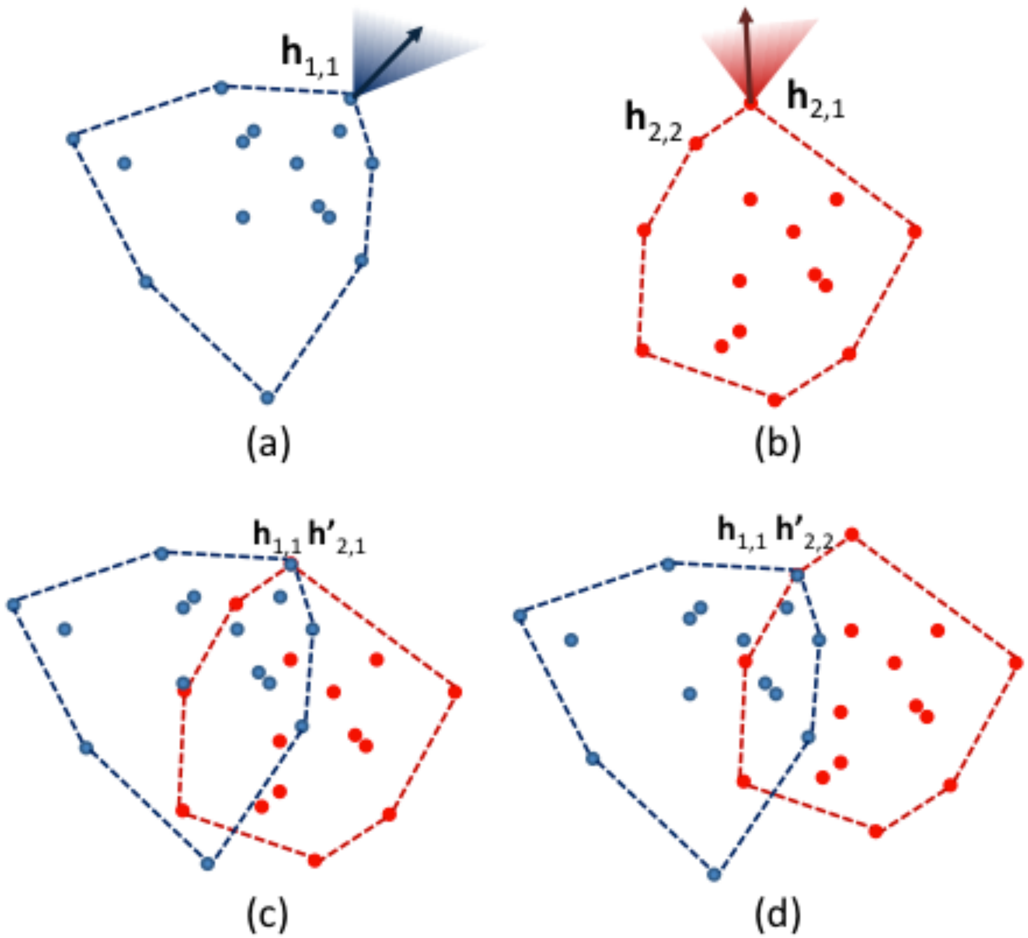
LP-MERT: one sentence case

- Och's MERT: great, but optimizing one parameter at a time?
  - Search over a larger subspace of parameter combos, not just line search
- Build convex hull of n-best list, iterate through extreme points
  - CH construction algorithms exponential in dimension
- Resort to LP with interior point methods (poly in dimension) to find extreme points



And more than 1 sentence?

- LP Formulation: return 0 if interior point
- Naïve approach: enumerate all possible hypothesis combinations across all sentences
- Smarter approach: merging convex hulls to maintain convexity
- Extreme point determination: $O(NS)$ # points vs. $O(N^S)$



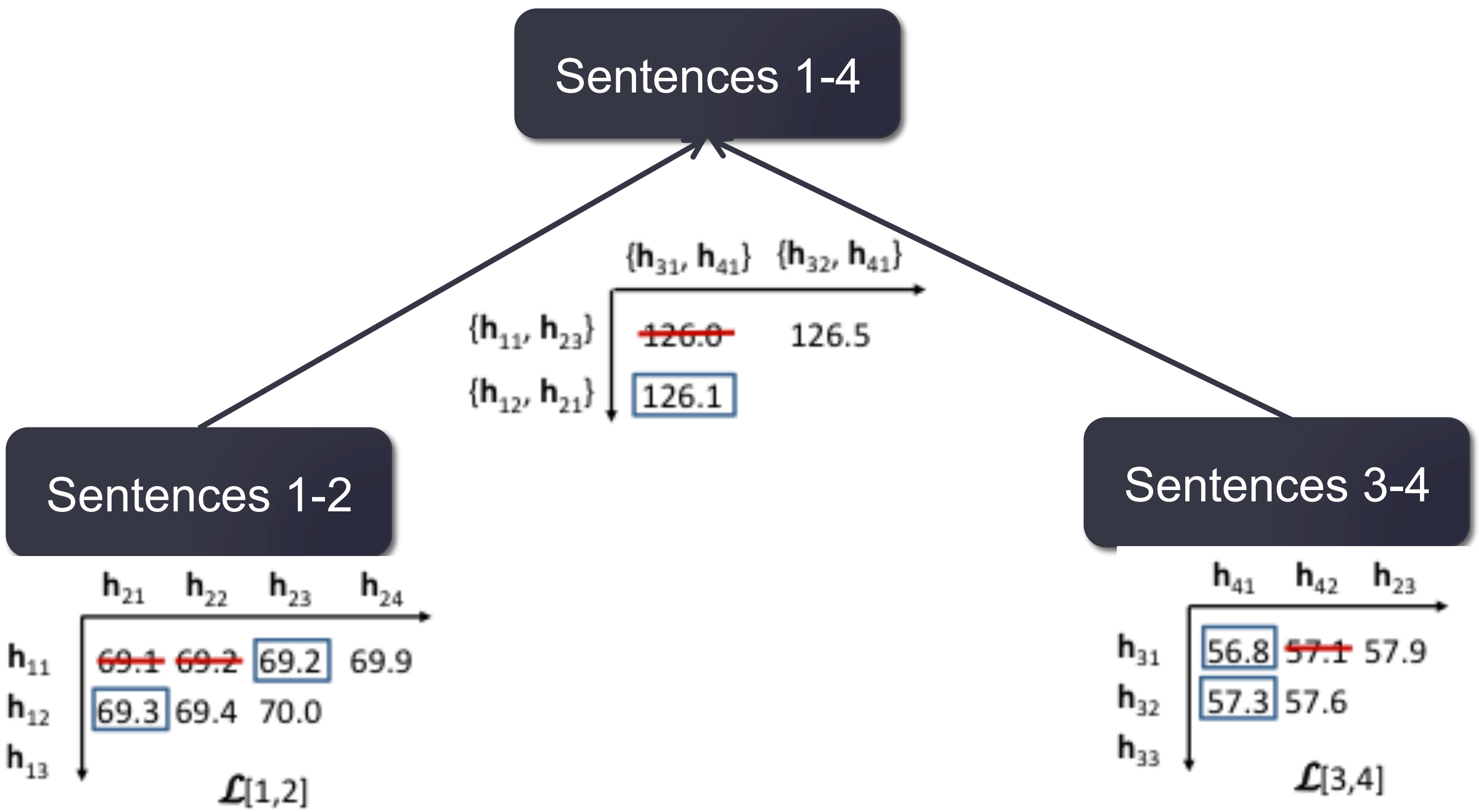
Other Tricks and Speedups

- Takes $O(NS)$ points to determine if a point is extreme. Need to do this for $O(N^S)$ possible combinations
- Trick 1: lazy enumeration (ordering of combos)
- However, not quite enough

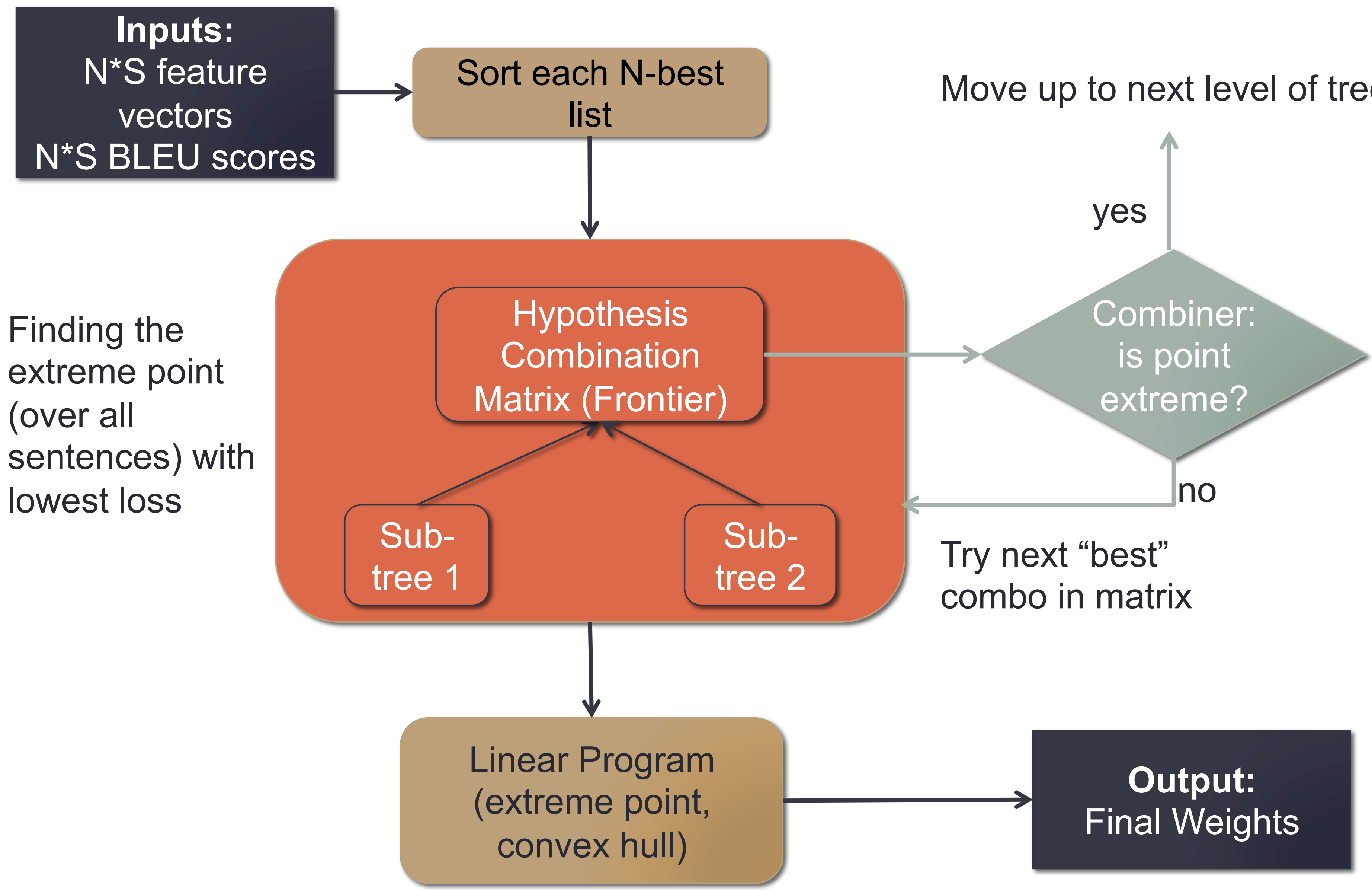
Sentence 1	Sentence 2	Sentence 3	Sentence 4
Where are you ?	Hello	Pizza with coke	That's sick bro !
Where is you ?	Good Day	Pizza with drink	That brother ill
Where are I ?	Hello	Pizza coke	That is ill brother
Who are you ?	Hi	Pizza with coke	Brother ill that

Binary lazy enumeration

- Use divide-and-conquer:

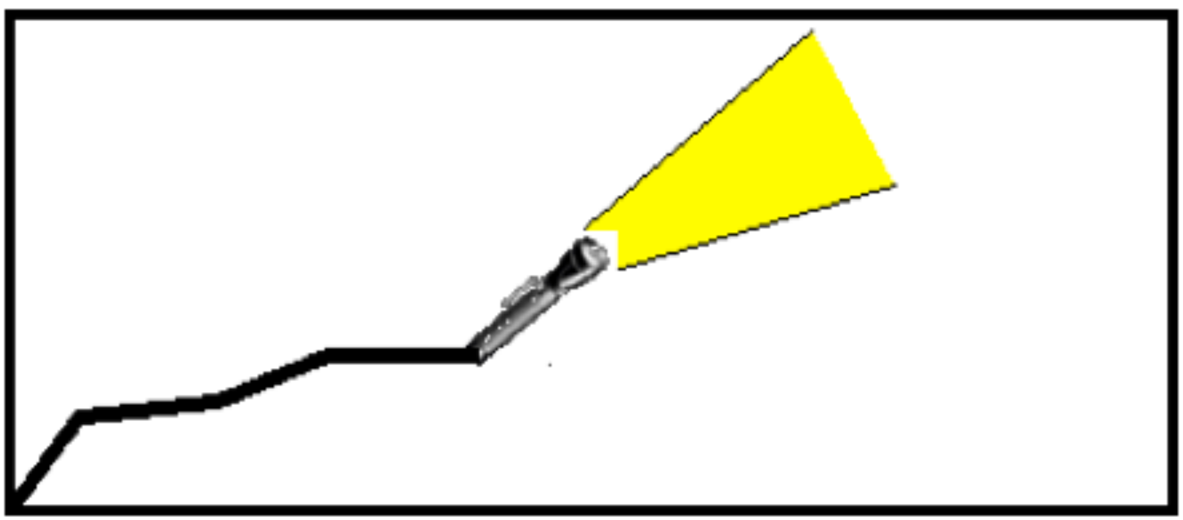


Final Algorithm



Approximations that we need

- Cosine similarity check (with reference vector):
  $\cos(\hat{\mathbf{w}}, \mathbf{w_0}) \geq t$
- Beam search: prune with respect to current best parameter vector (when combining, check model score)



Experimental Setup

- Tree-to-string model
- 13 features in total
  - Standard PM and LM features, re-ordering, function word insertion/deletion, insertion/deletion counts, target length
- N-best size = 100
  - Same combined N-best lists
- WMT 2010 English → German (1.6 million sentence pairs)
  - 2009 test: tuning
  - 2010 test: test
  - One reference translation

The D&C Speedup

length	tested comb.	total comb.	order
8	639,960	1.33×10^{20}	$O(N^8)$
4	134,454	2.31×10^{10}	$O(2N^4)$
2	49,969	430,336	$O(4N^2)$
1	1,059	2,624	$O(8N)$

Table 1: Number of tested combinations for the experiments of Fig. 5. LP-MERT with $S = 8$ checks only 600K full combinations on average, much less than the total number of combinations (which is more than 10^{20}).

Dependence on dimension

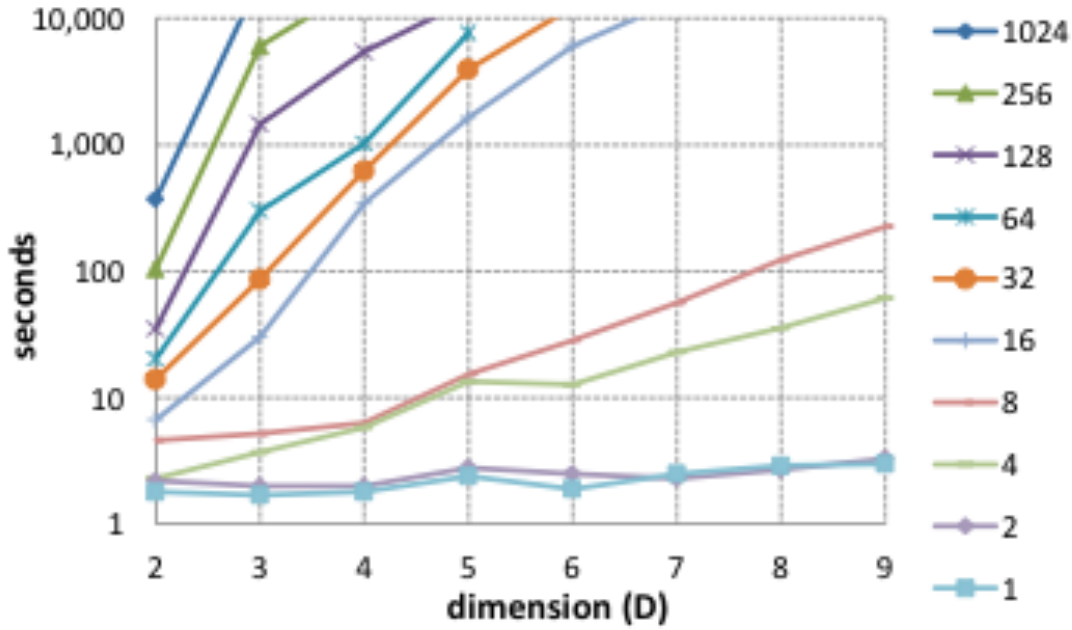


Figure 6: Effect of the number of features (runtime on 1 CPU of a modern computer). Each curve represents a different number of tuning sentences.

Cosine Similarity Approximation

$$\cos(\hat{\mathbf{w}}, \mathbf{w_0}) \geq 0.84$$

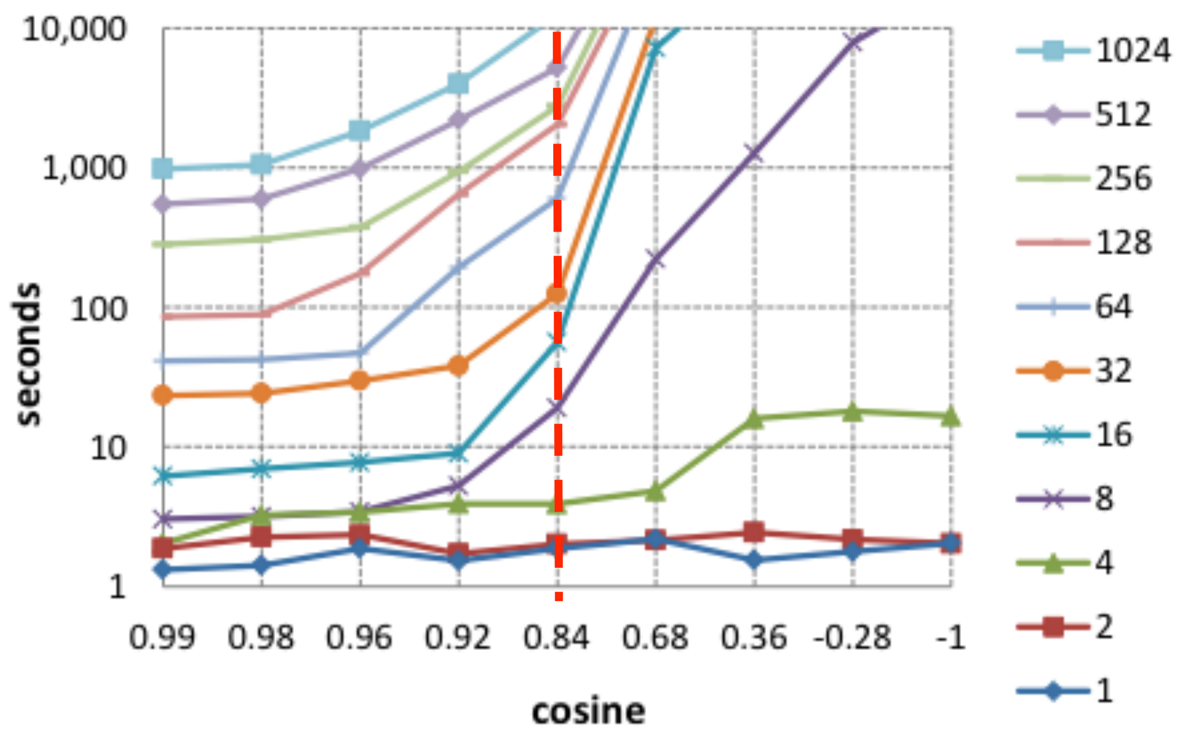
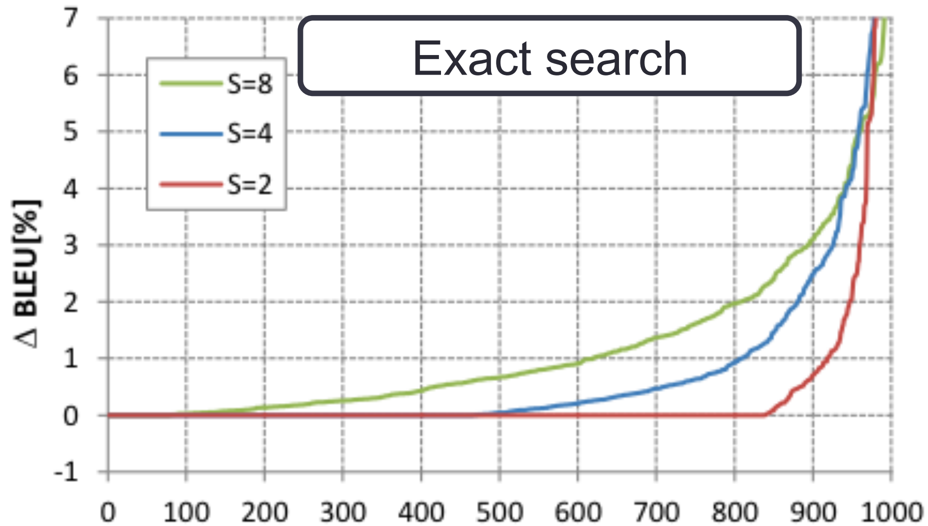


Figure 7: Effect of a constraint on $\mathbf{w}$ (runtime on 1 CPU).

Comparison with 1D-MERT

Assuming LP-MERT finds the "global optimum", 'for S=4, [Powell] makes search errors in 90% of the cases, despite using 20 random starting points'



As S increases, the gap between 1D-MERT and LP-MERT *increases*

With beam (size 1000)

	32	64	128	256	512	1024
1D-MERT	22.93	20.70	18.57	16.07	15.00	15.44
our work	25.25	22.28	19.86	17.05	15.56	15.67
	+2.32	+1.59	+1.29	+0.98	+0.56	+0.23

Table 2: BLEUn4r1[%] scores for English-German on WMT09 for tuning sets ranging from 32 to 1024 sentences.

As S increases, the gap between 1D-MERT and LP-MERT *decreases*

Summary

- End-to-end evaluation (with beam approx. for LP-MERT)
  - Tuning: 0.24 BLEU difference
  - Test: 0.17 BLEU difference
- Exact multi-dimensional MERT
  - LP at the core
  - Divide-and-conquer, lazy enumeration
- Polynomial in dimension, N-best list size
- Exponential in number of sentences
- Approximations used to limit running time
- Bold approach to tackle difficult problem

Questions & concerns that I had…

- End-to-end results do not look significant
- Additional language pairs/datasets would be nice
- As S increases, does the over-performance diminish?
- What can we do to make this algorithm poly(S)?
- LP-MERT + hypergraph MERT → towards MERT 2.0?
- Is direct cost optimization the way forward?

Thank you!