The SPECIALIST NLP Tools Generating Multiwords from MEDLINE Filters & Matchers

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- Lexical Systems Group: http://umlslex.nlm.nih.gov
- The SPECIALIST NLP Tools: http://specialist.nlm.nih.gov

Table of Contents

What Is a Word?

- Orthographic (space in written text vs. but not in speech)
  - Single words vs. multiwords:
    - [ice-cream] vs. [ice cream]
- Lexical Item (lexeme) – Lexical Record in Lexicon
  - Part of Speech:
    - saw - [noun|singular|E0054443], [verb|infinitive|E0054444]
  - Inflections (grammatical word-forms):
    - 0023681|noun - [dog|singular] vs. [dogs|plural]
  - A special unit of meaning:
    - bank|E0011894 – [financial institution] vs. [margin of a watercourse]
  - Spelling Variants:
    - [color] vs. [colour], [labeled] vs. [labelled]
- Spelling
- …

Single Words vs. Multiwords

- Words include single words and multiwords
- Word boundary – space or tab
- Multiwords are words hat happen to be spelled with a space
- Single words vs. multiwords
  - One word can be represented as a single word or multiword (clubfoot)

Single words	Multiwords
saw	club foot
ice-cream	ice cream
clubfoot	drop-foot gait
club-foot	Horner's syndrome

Lexicon Unigram Coverage – Word Count

- Total word count for MEDLINE (2016): 3,114,617,940
- Lexicon covers > 98% unigrams from MEDLINE

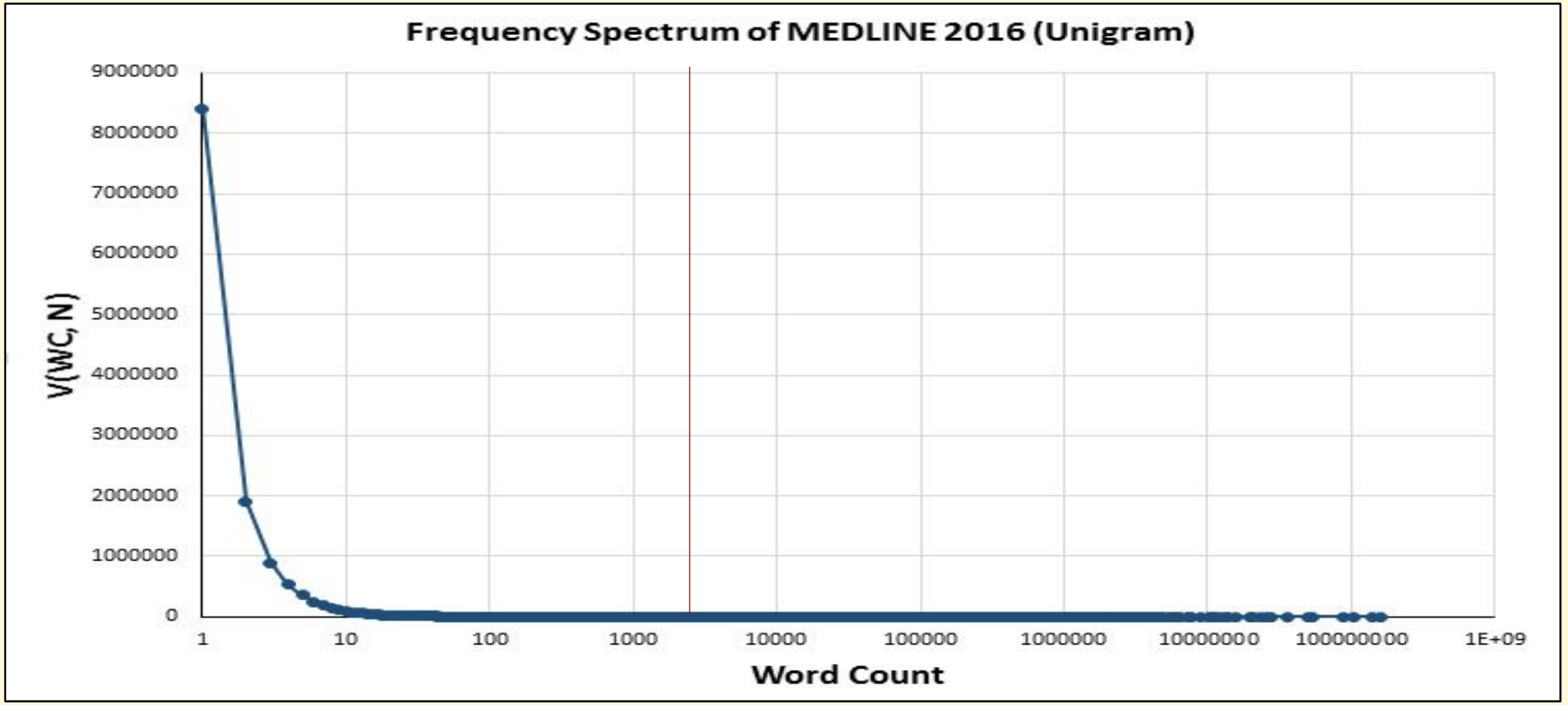
Types	Word Count	Percentage %	Accu. %
LEXICON	2,911,156,308	93.4675%	93.4675%
NUMBER	8,753,120	0.2810%	93.7485%
DIGIT	145,548,882	4.6731%	98.4216%
MULTIWORD	19,148,557	0.6148%	99.0364%
NEW	30,011,073	0.9636%	100.0000%
Total	3,114,617,940		

Lexicon Unigram Coverage - Unique Word

- Total unique word for MEDLINE (2016): 3,619,854
- Lexicon covers 10.62 % unigrams in MEDLINE

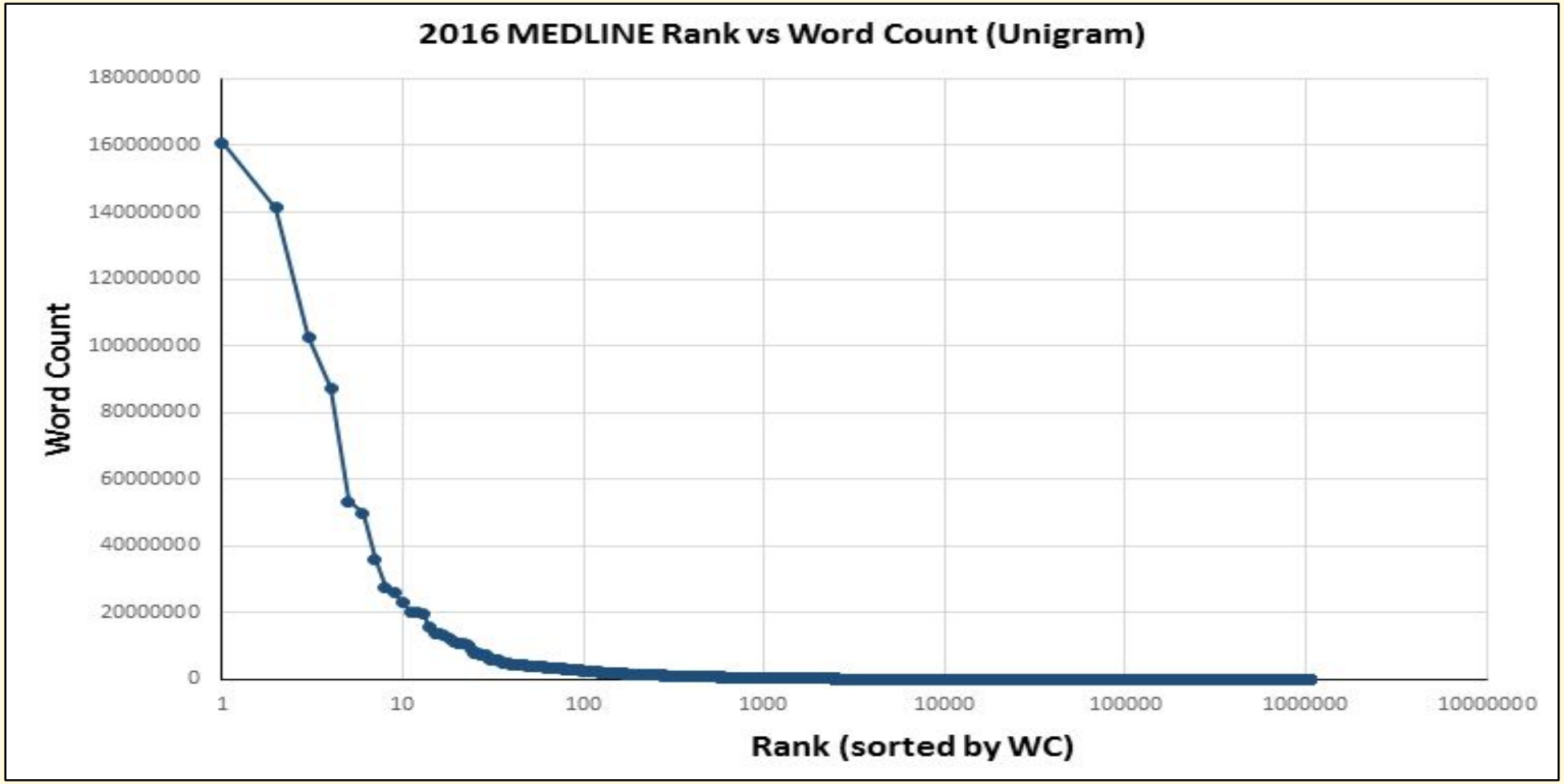
Types	Word Count	Percentage %	Accu. %
LEXICON (S)	296,747	8.1978%	8.1978%
NUMBER	62	0.0017%	8.1995%
DIGIT	87,437	2.4155%	10.6150%
MULTIWORD	43,811	1.2103%	11.8253%
NEW	3,191,797	88.1747%	100.0000%
Total	3,619,854		

Frequency Spectrum of MEDLINE 2016



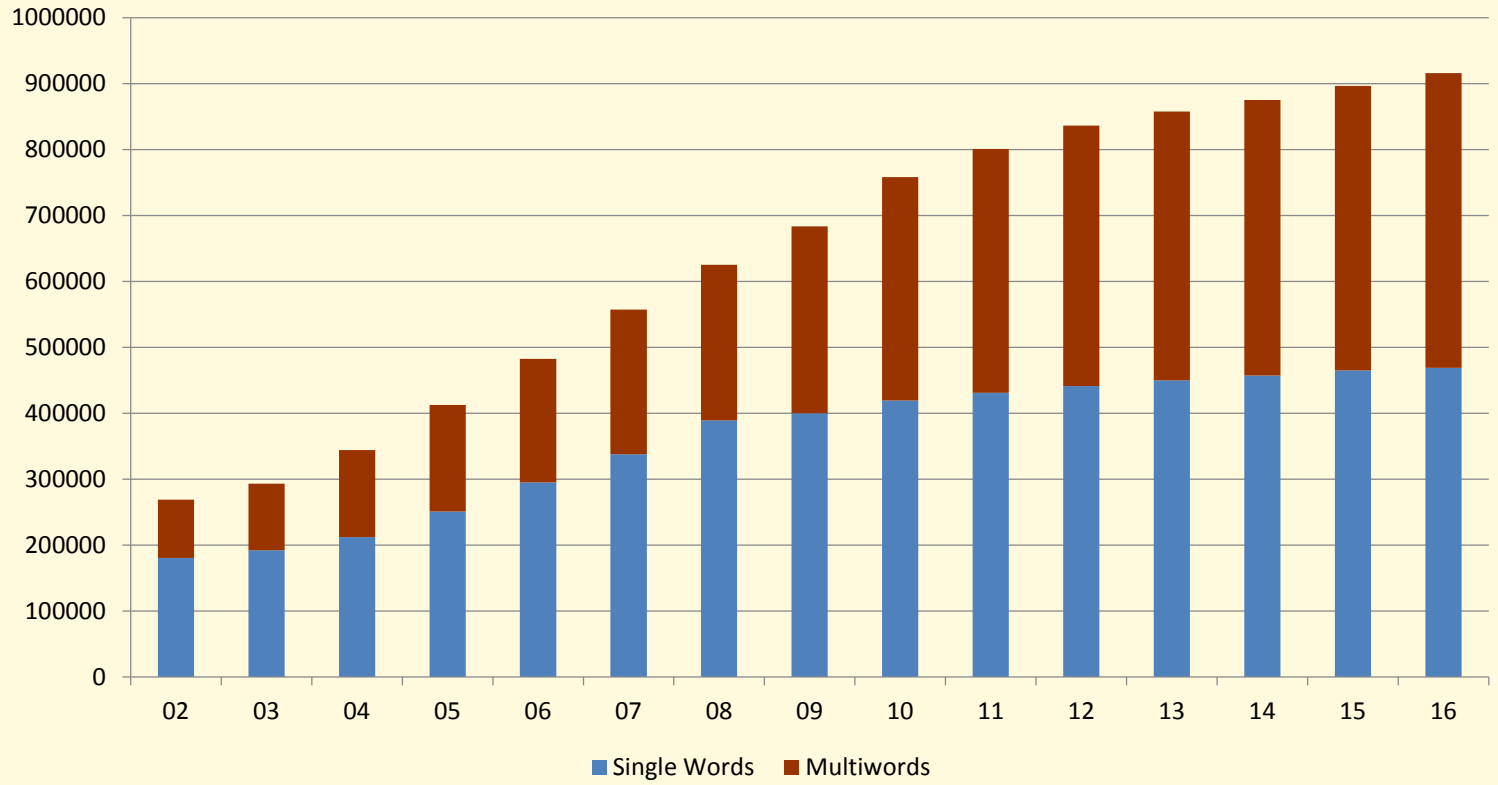
- The frequency spectrum of Alice in Wonderland, Word Frequency Distributions by R. Harald Baayen, 2001, Springer-Science + Business Media, B.V., P:10

Word Frequency vs. Rank - MEDLINE 2016



Lexicon Growth – 2002 to 2016

- 491,639 lexical records
- 1,090,050 words (categories and inflections)
- 915,583 forms (spelling only)
  - Single words: 468,655 (51.19%); Multiwords: 446,928 (48.81%)



Future Lexicon Building

- Lexicon single words: high coverage
- Lexicon multiwords (LMWs): increasing growth
- Multiwords acquisition is the key for future Lexicon building

Multiword Expression (MWE)

- Multiwords (MWEs) are used extensively in many specialized domains, particularly in areas like biomedical, medicine, computer science and engineering
- MWEs are hard to deal with in NLP tasks
  - have a large amount of distinct phenomena
  - lack of syntactic theories and semantic formalisms
  - phrasal preposition (because of, due to)
  - adverbs (on time)
- Non-decomposable MWEs
  - fixed phrases (kingdom come, by and large, etc.)
  - idioms (kick the bucket, shoot the breeze, etc.)

- Utilize facts (instead of rules) to resolve the issues

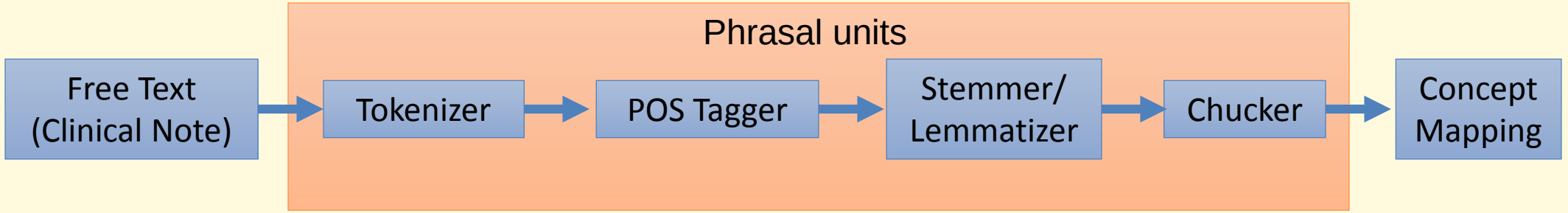
Multiwords Issues - Examples

- Query Expansion

Synonym-key	Synonym-value	Query Expansion Example
…	…	…
perforated	perforation	perforated ear drum => **perforation** ear drum (Tympanic Membrane Perforation)
hot	warn	hot dog => **warm** dog
dog	canine	hot dog => hot **canine**
…	…	…

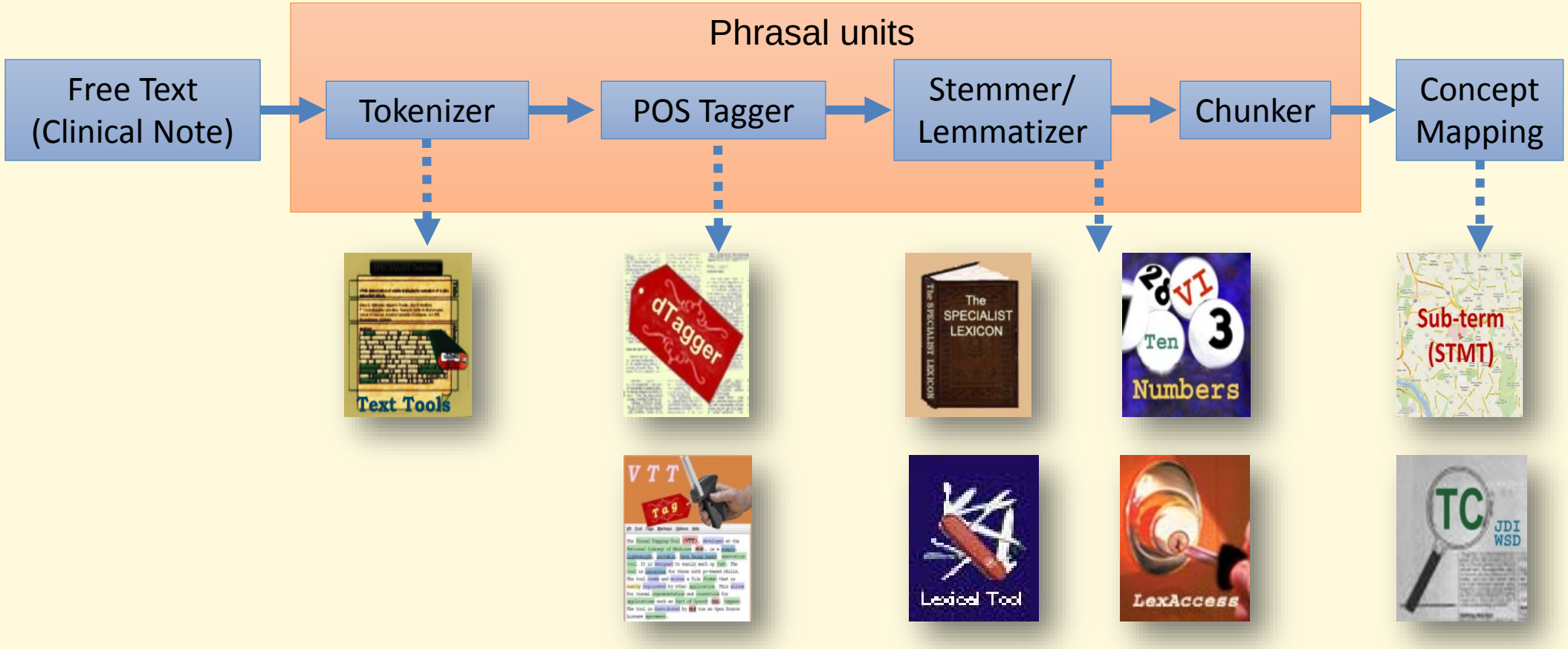
- The concept associated with a sentence often coincides with the longest multiword in the sentences (used in MetaMap)

Multiwords in NLP



- Identify multiwords as phrasal units directly
- Reduce part-of-speech ambiguity
- Improve stemming and lemmatization
- Better concept mapping results

The SPECIALIST NLP Tools



- Lexical Systems Group: http://umlslex.nlm.nih.gov
- The SPECIALIST NLP Tools: http://specialist.nlm.nih.gov

LexBuild Process (Computer-aided)

Source:
- Element Words[1]
- Find multiword candidates contain an element word by Essie search engine[2]

Review:
- Google Scholar
- Dictionaries
- Biomedical publications
- Domain-specific databases
- Nomenclature guidelines
- books
- ...

Check:
- LexAccess

Build:
- LexBuild

1. "Using Element Words to Generate (Multi)Words for the SPECIALIST Lexicon", Lu, Chris J.; Tormey, Destinee; McCreedy, Lynn; and Browne, Allen C. AMIA 2014 Annual Symposium, Washington, DC, November 15-19, 2014, p. 1499
2. "Essie: A Concept-based Search Engine for Structured Biomedical Text", N.C. Ide, R.F. Loane, D.D. Fushman, JAMIA, Vol. 14, Num. 3, May/June, 2007, p.253-263

Issues of Element Word Approach

- Time consuming
- Essie search engine is not current (MEDLINE, 2007)
- Frequency of new words in Lexicon:
  - Use new element words (frequency rank: 1565 ~ 2549)
  - Frequency of element words (not multiwords)
  - Low frequency element words vs. high frequency multiword?
- New multiwords from old element words are missing

New LexBuild Process

Source (MEDLINE):
- LMW Candidates

Review:
- Google Scholar
- Dictionaries
- Biomedical publications
- Domain-specific databases
- Nomenclature guidelines
- books
- ...

Build:
- LexBuild

Project Objective

- A systematic way to add multiwords form MEDLINE to the SPECIALIST Lexicon:
  - Covers multiwords from the latest MEDLINE
  - Generates high precision multiword candidate list
    - To save time for linguists to build Lexicon

LexMultiword vs. Multiword Expression

- LMWs are a subset of MWEs

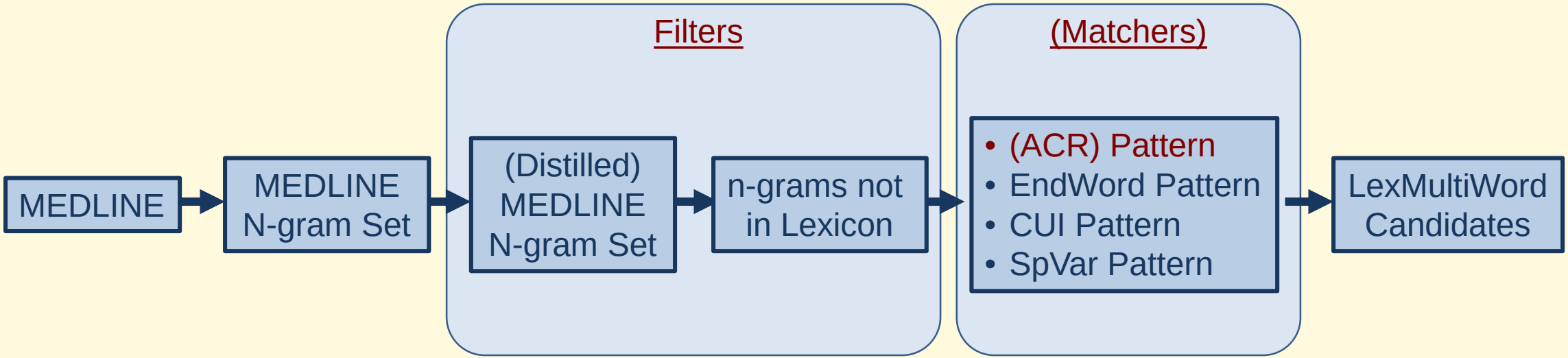
- Collocation (frequency)
  - An arbitrary statistically significant association between co-occurring items
  - “undergoing cardiac surgery” vs. “cardiac surgery”
  - “in the house” vs. “in house”
- Embedded lexical information
  - Verb particle construction (handled by complementation types)
    “beat someone up” => beat|E0012175, tran=np;part(up)
  - Light verb (information is in the lexical records, but they are not LMWs)
    “give birth”, “make love”, etc.
- Non-decomposable idioms (beyond the score of the Lexicon)
  - “kick the bucket”, “shoot the breeze”, etc.
- Design goal is set to five-grams to reach coverage above 99%
  - Most MWE research only focus on bi-grams or tri-grams

N-gram Approach

- Source: get all n-grams from MEDLINE documents
  - No MEDLINE n-gram set available for public
- Matcher: retrieve word candidates by patterns, rules, etc.
  - Inclusive filter (matcher): focus only on precision
- Filter: filter out n-grams that are invalid words
  - Exclusive filter: focus on not to drop recall, and then increase precision
- Validation & Build: Expert's review
  - Very expensive, minimize manual process

- To bridge the gap between n-grams (statistical co-occurrence) and our term-based Lexicon.

LMWs – Processes



N-gram

- An *n*-gram is a contiguous sequence of *n* items from a given sequence of text or speech
  - An *n*-gram of size 1 is referred to as a "unigram“
  - Size 2 is a "bigram" (or a "digram");
  - Size 3 is a "trigram".
  - Larger sizes are sometimes referred to by the value of *n*, e.g., "four-gram", "five-gram", and so on.
- Example:
  - to be or not to be

N = 1	Unigram	to, be, or, not, to, be
N = 2	Bigram	to be, be or, or not, not to, to be
N = 3	Trigram	to be or, be or not, or not to, not to be

N-gram Requirements*

- Range of N:
  - Lexicon.2016

N	WC	Accumulated WC
1	468,655 (51.1865%)	468,655 (51.1865%)
2	294,022 (32.1131%)	762,677 (83.2996%)
3	102,746 (11.2219%)	865,423 (94.5215%)
4	34,339 (3.7505%)	899,762 (98.2720%)
5	10,162 (1.1099%)	909,924 (99.3819%)
6	3,483 (0.3804%)	913,407 (99.7923%)
…	…	…

- Length: 50 (99.4562%) for Lexicon.2016

* “Generating the MEDLINE N-Gam Set”,
Lu, Chris J.; Tormey, Destinee; McCreedy, Lynn; and Browne, Allen C.,
AMIA 2015 Annual Symposium, San Francisco, CA, November 14-18, 2015, P1569

The MEDLINE N-gram Set - Specifications

N-grams	2014	2015	2016
MEDLINE files	1-746	1-779	1-812
Max. length	50	50	50
Min. WC	30	30	30
Min. DC	1	1	1
Total documents	22,356,869	23,343,329	24,358,442
Total sentences	126,612,705	134,834,507	143,471,776
Total tokens	2,610,209,406	2,786,085,158	2,971,013,236

The MEDLINE N-gram Set

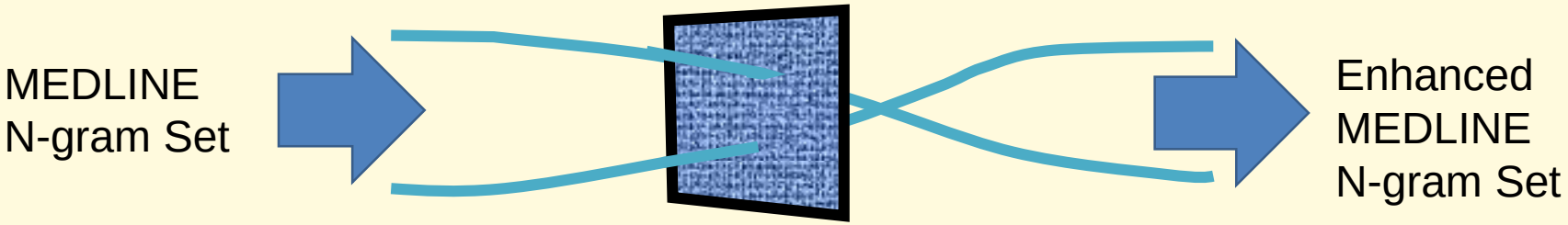
- Annual Public Releases:
  http://umlslex.nlm.nih.gov/nGram

N-grams	2014	2015	2016
unigrams	804,382	843,206	883,287
bigrams	4,587,349	4,845,965	5,114,547
trigrams	6,287,536	6,702,194	7,134,807
four-grams	3,799,377	4,082,612	4,380,474
five-grams	1,545,175	1,674,715	1,812,223
n-gram set	17,023,819	18,148,692	19,325,338

Enhanced N-gram Set?

- 17 ~ 19 million is a big number (Big Data)
- Reduce the size by filtering out invalid multiwords:
  - increase precision
  - without sacrificing recall
  - distilled MEDLINE n-gram set

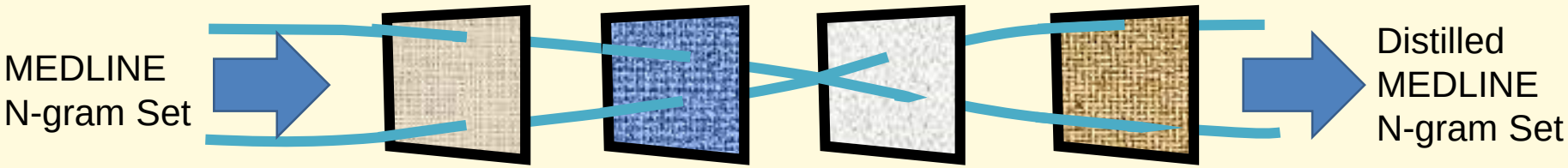
Filter



	Trap (not retrieved)	Pass (retrieved)
Valid (relevant)	FN	TP
Invalid (not relevant)	TN	FP

- Filter efficiency = trap terms / total terms
- Filter passing rate = pass-through terms / total terms
- Good filters have high efficiency and accuracy
- Accuracy Test: apply filters on Lexicon (valid word set)
  - Accuracy = TP + TN / TP + TN + FP + FN
    = TP / TP + FN ….. if TN & FP are 0
    = pass / total terms
    = passing rate

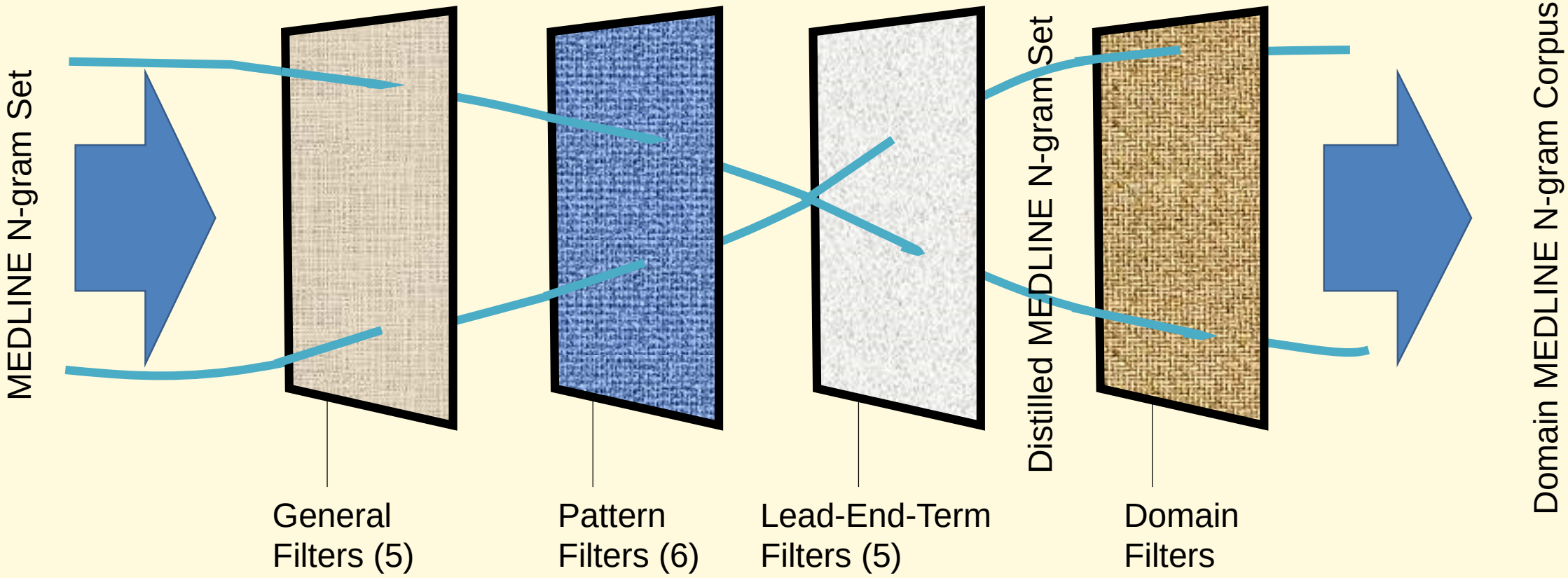
Serial Filters (High Accuracy)



	N-gram	Filter-1	Filter-2	…	Filter-N	Distilled
Valid (TP)	V_0	V_1	V_2	…	V_n	V_n
Invalid (FP)	I_0	I_1	I_2	…	I_n	I_n

- A distilled n-gram set by filtering out invalid words.
- Applied high accuracy filter ($V_0 = V_1 = \ldots = V_n$; $I_0 > I_1 > \ldots > I_n$)
- Higher precision with same recall rate (if filter has high accuracy rate)
- N-gram Precision $_n = V_n / (V_n + I_n)$
  $= V_0 / (V_0 + I_n)$ ….. V_n is same as V_0 (high accuracy)
  $> V_0 / (V_0 + I_0)$ ….. I_0 is bigger than I_n (high efficiency)
- N-gram Recall $_n = V_n / (V_n + FN_n)$
  $= V_n / (V_n + FN_0)$ ….. FN_n is a constant (0), same as FN_0
  $= V_0 / (V_0 + FN_0)$ ….. V_n is same as V_0 (high accuracy)

Distilled N-gram Set



General Exclusive Filters

Filter	Accuracy On Lexicon (875,890)	Passing Rate N-gram Set	Accumulated Passing Rate	Trapped Examples
Pipe	100.0000% (0)	100.0000% (6)	100.0000%	• 38|44|(|r| • 33|37|Ag|AgCl
Punctuation or space	100.0000% (0)	99.9977% (386)	99.9977%	• 1259147|3690494|= • 604567|2377864|+/-
Digit	99.9999% (1)	99.3141% (116,772)	99.3118%	• 1404799|2062240|2 • 239725|499064|95%
Number	99.9953% (41)	99.9760% (4,056)	99.2879%	• 2463066|3359594|two • 18246|20674|first and second
Digit and stopword	99.9993% (6)	99.1595% (142,067)	98.4534%	• 3155416|4125616|on the • 11180|12722|1, 2, and

Pattern Exclusive Filters

Filter	Accuracy On Lexicon (875,890)	Passing Rate N-gram Set	Accumulated Passing Rate	Trapped Examples
Parenthetic acronym - (ACR)	100.0000% (0)	99.0232% (163,714)	97.4917%	• 33117|33381|chain reaction (PCR) • 30095|30315|polymerase chain reaction (PCR)
Indefinite article	99.9985% (13)	98.1703% (303,679)	95.7079%	• 270384|292590|a case • 40271|40512|A series
UPPERCASE colon	99.9999% (1)	99.4302% (92,841)	95.1625%	• 2069343|2070116|RESULTS: • 18015|18016|AIM: The
Disallowed punctuation	99.9978% (19)	99.3020% (113,073)	94.4983%	• 324405|719011|(n = • 86525|133350|(P < 0.05)
Measurement	99.9967% (29)	98.1947% (290,421)	92.7924%	• 154905|181001|two groups • 12160|15197|10 mg/kg
Incomplete	99.9999% (1)	97.8470% (340,109)	90.7945%	• 482021|1107869|(P • 25347|25992|years) with

Lead-End-Terms Exclusive Filters

Filter	Accuracy On Lexicon (875,890)	Passing Rate N-gram set	Accumulated Passing Rate	Trapped Examples
Absolute Invalid Lead-Term	99.9947% (46)	73.0945% (4,158,702)	66.3658%	• 2780043|3451203|of a • 432921|434591|this study was
Absolute Invalid End-Term	99.9997% (3)	78.8984% (2,384,059)	52.3615%	• 1878109|3534031|patients with • 1062545|1261445|between the
Lead-End-Term	99.9992% (7)	99.9741% (2,312)	52.3480%	• 2578756|3106139|in a • 1733|1744|For one
Lead-Term no SpVar	**99.9887% (99)**	85.6678% (1,277,229)	44.8454%	• 658430|708246|to determine • 533913|554628|In addition,
End-Term no SpVar	99.9975% (22)	83.1945% (1,283,001)	**37.3089%**	• 1009451|1295670|number of • 726|734|(HPV) in

The Distilled MEDLINE N-gram Set

- Available to public: http://umlslex.nlm.nih.gov/nGram

N-grams	2014	2015	2016
unigrams	804,382	843,206	883,287
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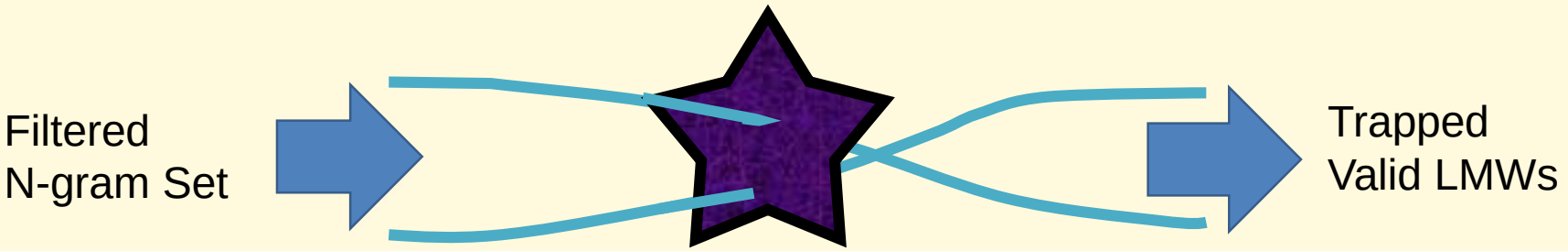
five-grams	1,545,175	1,674,715	1,812,223
N-gram Set	17,023,819	18,148,692	19,325,338
Distilled N-gram Set	6,351,392	6,793,561	7,402,848
Passing Rate	37.31%	37.43%	38.30%

Matcher



	Trap (retrieved)	Pass (not retrieved)
Valid (relevant)	TP	FN
Invalid (not relevant)	FP	TN

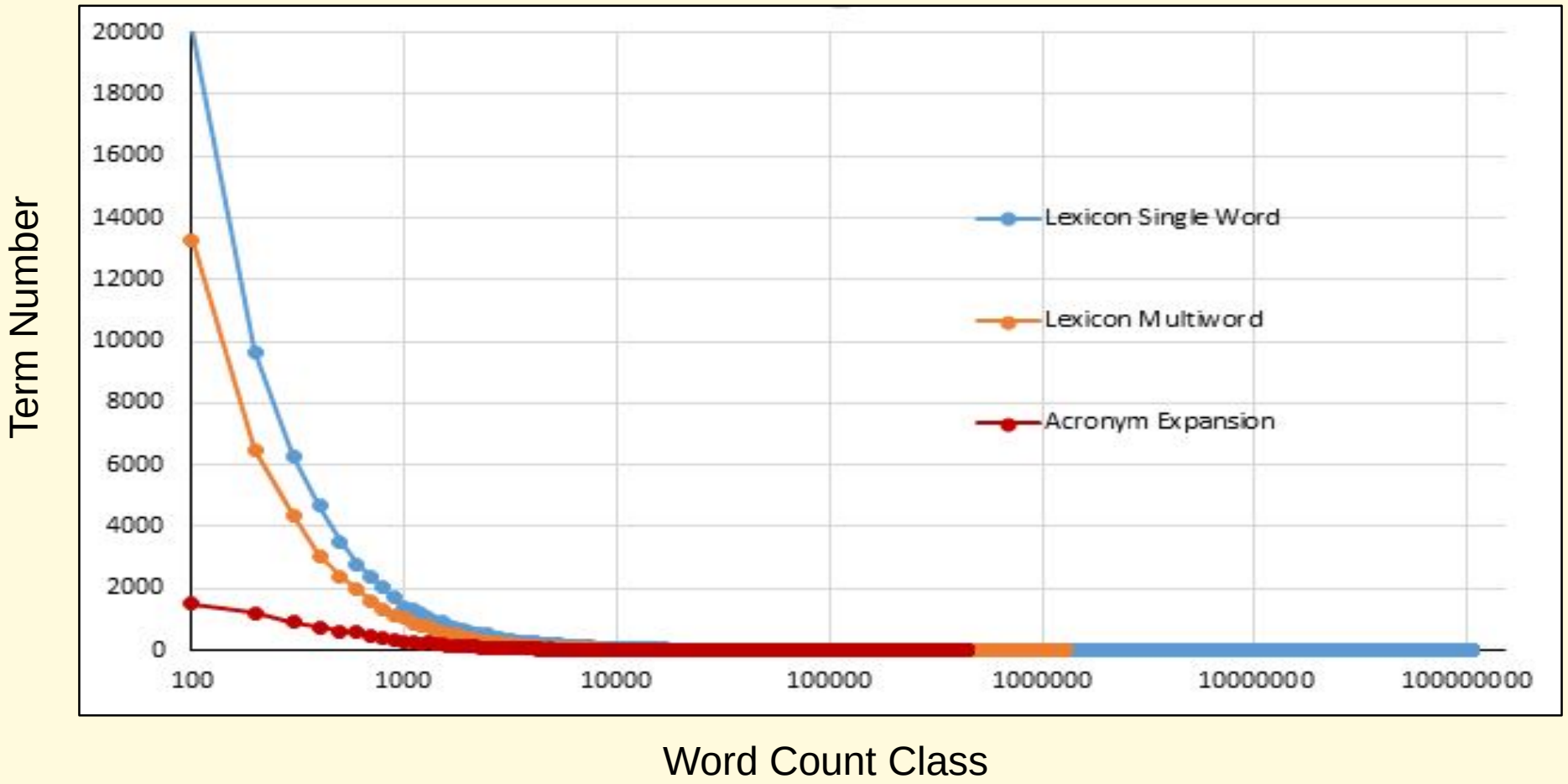
- **Parenthetic Acronym Pattern Matcher**
  - "computed tomography (CT)", "magnetic resonance imaging (MRI)", etc.
- **Spelling Variant Pattern Matcher**
  - Applied algorithm of SpVarNorm, Metaphone, edit distance, sorted distance, etc.
- **Metathesaurus CUI Pattern Matcher**
  - LMW candidate if a term has CUI(s)
  - Apply STMT to retrieve CUIs (2 subterm substitutions by their synonyms)
- **EndWord pattern Matcher**
  - syndrome: "migraine syndrome", "contiguous gene syndrome", etc.
  - disease: "Fabry disease", "Devic disease", etc.

Practice Results

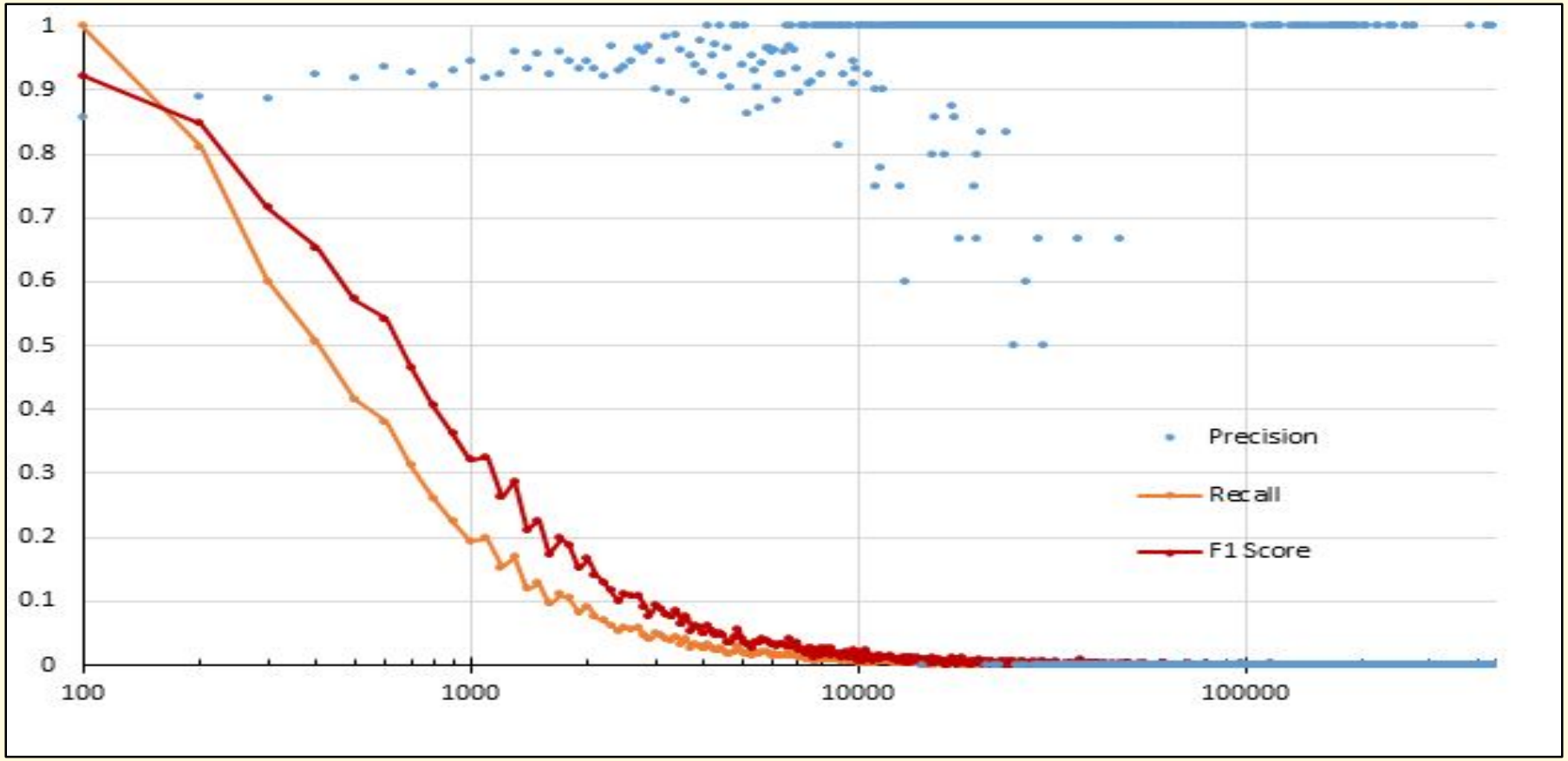
- Baseline: 16,675 LMW Candidates from (ACR) matcher, tagged by linguists

Case	Test Case - Model	TP	FP	FN	TN	Precision	Recall	F1	Accuracy
1	**Parenthetic Acronym - gold standard**	14,805	1,870	0	0	0.8879	1.0000	0.9406	0.8879
2	**Distilled MEDLINE N-gram Set (16 filters)**	14,796	1,305	9	565	0.9189	0.9994	0.9575	0.9212
3	**Spelling Variant Pattern matcher**	7,509	482	7,296	1,388	0.9397	0.5072	0.6588	0.5336
4	**Metathesaurus CUI Pattern matcher**	9,488	752	5,317	1,118	0.9266	0.6409	0.7577	0.6360
5	**EndWord Pattern matcher**	1,710	180	13,095	1,690	0.9048	0.1155	0.2049	0.2039
6	**Distilled + SpVar + CUI**	5,510	206	9,295	1,664	0.9640	0.3722	0.5370	0.4302
7	**Distilled + SpVar + CUI + EndWord**	727	11	14,078	1,859	0.9851	0.0491	0.0935	0.1551

Frequency Analysis – Valid Words Distribution



Frequency Analysis – PRF for AEP Model



Frequency Analysis Summary

- Observation
  - Most words are in the low WC range (LMWs or single words)
  - N-gram in low WC range have higher normalized recall and F1 score, with precision above 0.8.
  - N-grams in high WC range have very few valid LMWs, with precision between 0 and 1.
- Strategy
  - Set on the lower WC range (100-10,000) for multiwords
  - Set on the high WC range for single words (most unigrams are valid single words)
  - Applied with filters and matchers to generate LMW candidates from the MEDLINE n-gram set

Summary

- All filters have accuracy rate above 99.99% (tested on Lexicon)
- Obtain the distilled MEDLINE n-gram set at passing rate of 37-38%
  - smaller data set
  - better precision
  - similar recall

  ⇒The recall rate between the Lexicon test set (0.9997) and baseline (0.9994) are almost identical
  - used as baseline for further analysis
- Improve lexBuilding
- Distribute the MEDLINE n-gram set (2014+) to public
- Distribute the Distilled MEDLINE n-gram set (2014+) to public
- LexBuilding on multiwords

Future Work

- Continuously enhance filters and matchers for LexBuilding on multiwords
  - Enhance SpVar Matcher model on SpVarNorm + M2CES models
  - Apply frequency strategy

- Apply different matchers to the Distilled MEDLINE n-gram set to generate LMW candidates

- Develop new SPECAILIST NLP Tools based on multiwords

Questions

- Lexical Systems Group: http://umlslex.nlm.nih.gov
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