U.PORTO

FEUP FACULDADE DE ENGENHARIA
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Extraction of assembly information from instruction manuals

Language Processing and Information Extraction

1 December, 2015

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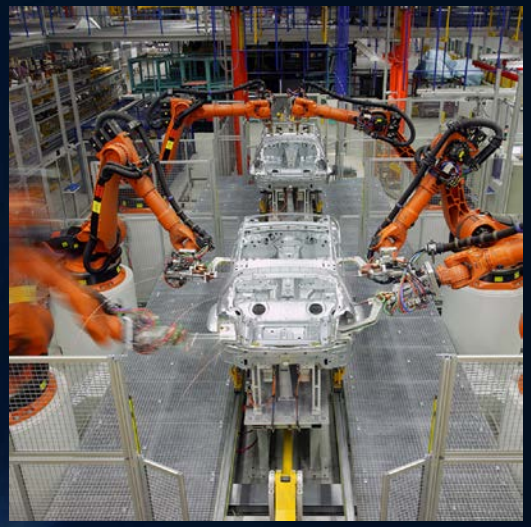
Presentation outline

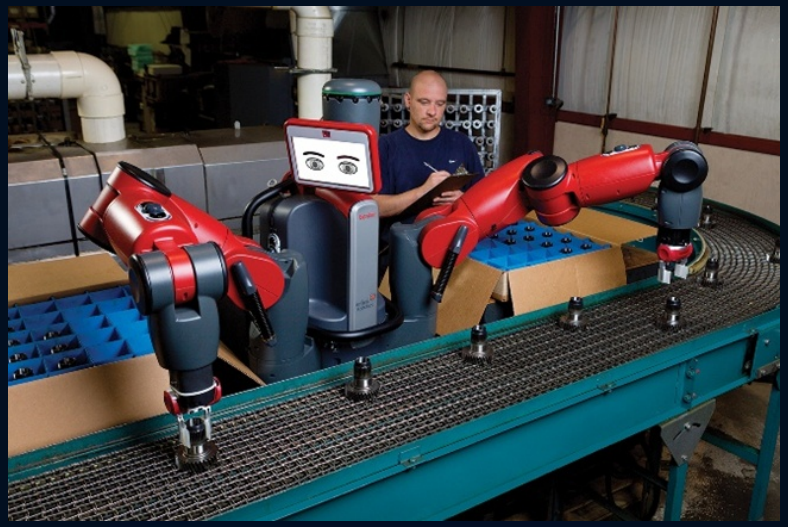
1. Introduction
   a) Context
   b) Objectives
2. Related work
3. Dataset sources
4. Dataset preparation
5. Dataset analysis
   a) Rank-frequency distributions
   b) Most common and uncommon n-grams
   c) N-gram smoothing techniques
   d) N-grams models perplexity
   e) Sentences generated with the n-gram models
6. Future work plan

1.a. Context

- Assembly of complex objects by robots requires long programming periods
- Teaching new assembly skills can significantly reduce the cost of repurposing a robot for assembling new products



Car assembly line



Packaging line

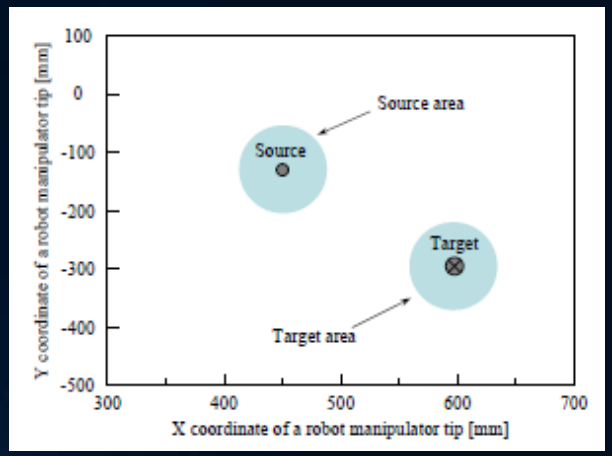
1.b. Objectives

- Development of an information extraction system capable to recognize:
  - The objects being assembled and their parts
  - Tools necessary to perform the assembly
  - The assembly order
  - The spatial relations between the assembly parts

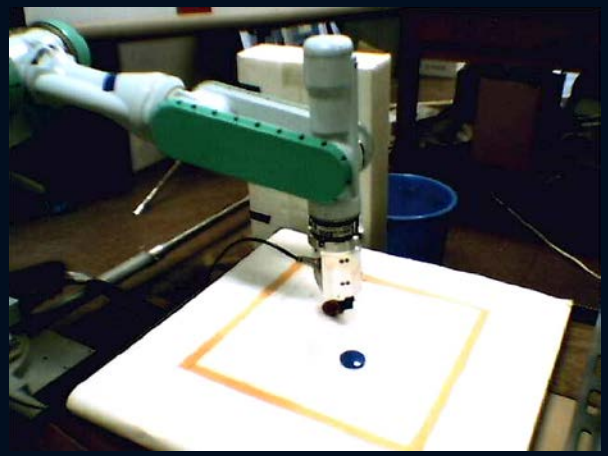
Small parts assembly robot

2.a. Related work

- Pick and place of objects



Position information perception by the user

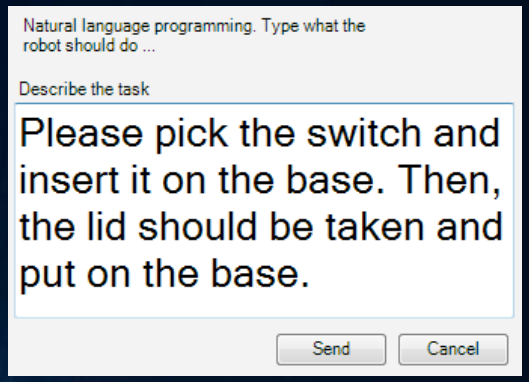


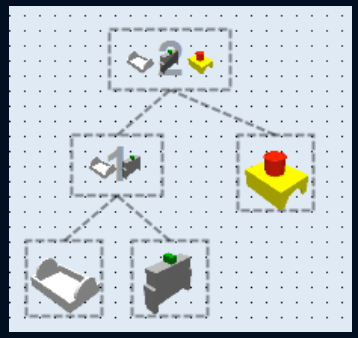
Experimental setup

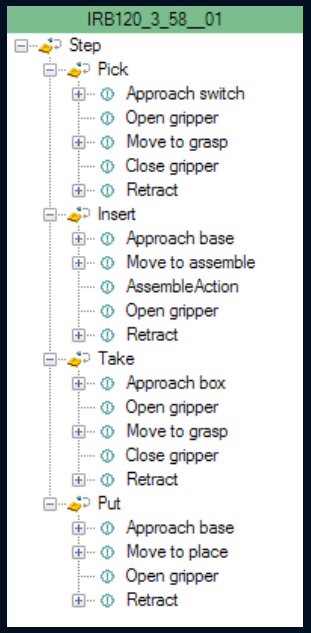
- Watanabe, K.; Jayawardena, C.; Izumi, K., "Approximate Decision Making by Natural Language Commands for Robots," in IEEE Industrial Electronics, IECON 2006 - 32nd Annual Conference on , vol., no., pp.4480-4485, 6-10 Nov. 2006, doi: 10.1109/IECON.2006.347974

2.b. Related work

- Assembly of small objects





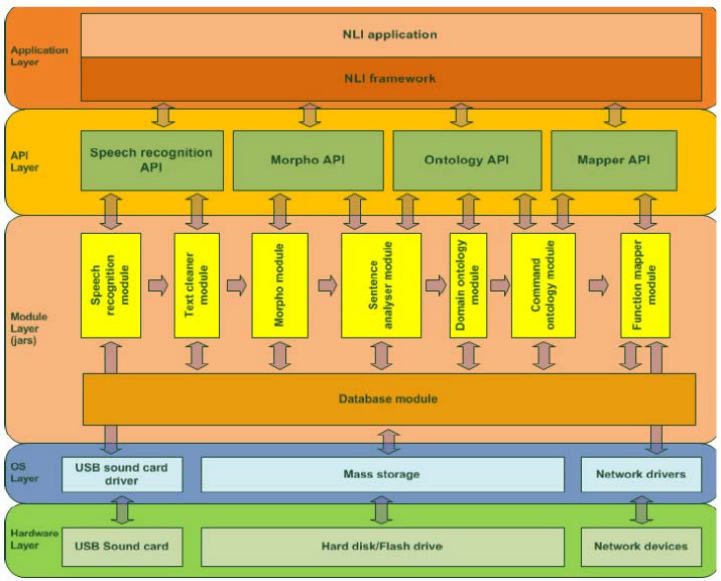


Natural language processing pipeline for assembly of small objects

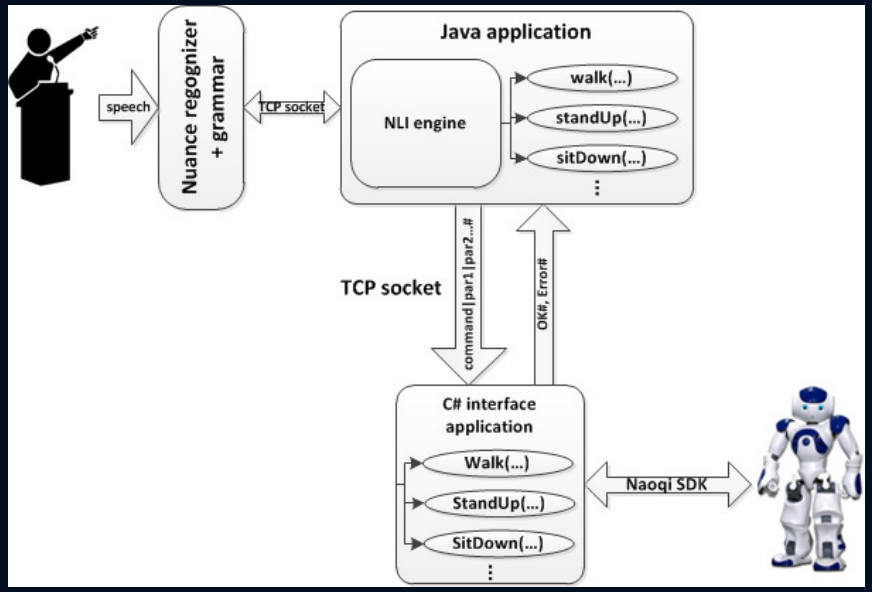
- Stenmark, M.; Nugues, P., "Natural language programming of industrial robots," in *Robotics (ISR), 2013 44th International Symposium on* , vol., no., pp.1-5, 24-26 Oct. 2013, doi: 10.1109/ISR.2013.6695630

2.c. Related work

- Control of an humanoid robot



Experimental setup



Nao controlling system structure

- Barabas, P.; Kovacs, L.; Vircikova, M., "Robot controlling in natural language," in *Cognitive Infocommunications (CogInfoCom), 2012 IEEE 3rd International Conference on* , vol., no., pp.181-186, 2-5 Dec. 2012, doi: 10.1109/CogInfoCom.2012.6421976

3.a. Dataset text categories

Dataset sources

- Dataset with assembly instructions for 3 different types of objects:
  - Alternators
  - Engines
  - Gearboxes

Engine

Alternator

Gearbox

3.b. Dataset overview

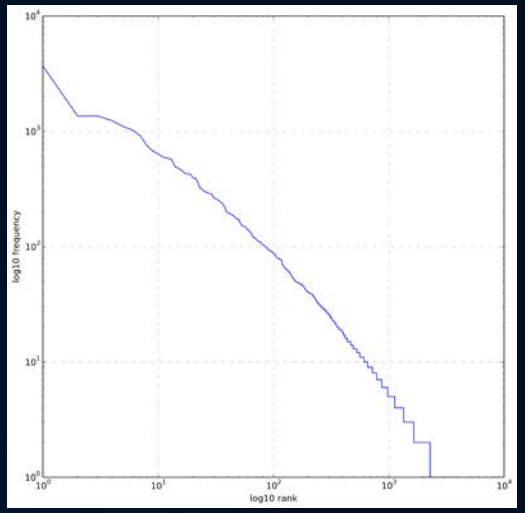
Dataset sources

- Alternators
  - 84 pages
  - 56185 characters
- Engines
  - 148 pages
  - 131287 characters
- Gearboxes
  - 221 pages
  - 192424 characters

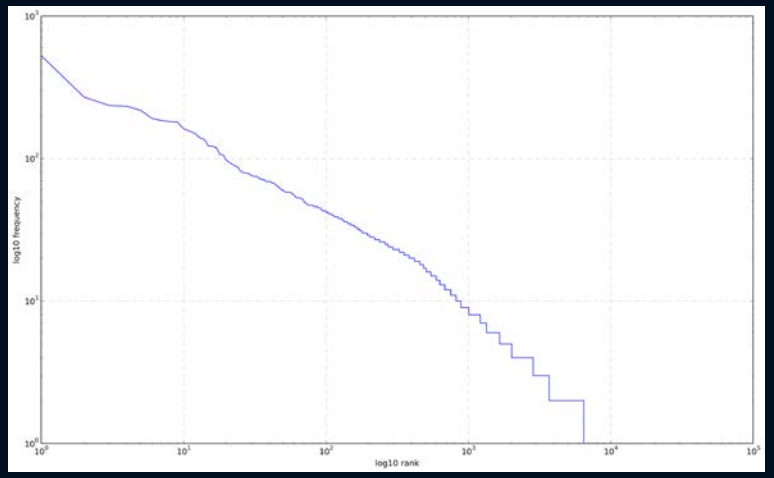
4.a. Train | test | validation — Dataset preparation

- Extraction of text from pdfs
- Manual verification / correction of text to ensure correct multi-column text extraction
- Selection of assembly procedures
- Removal of pages formatting text
- Creation of train (75%) and test (25%) corpus for each object category and for the entire dataset
- Creation of validation files with all the assembly parts and their associated quantity for each assembly procedure

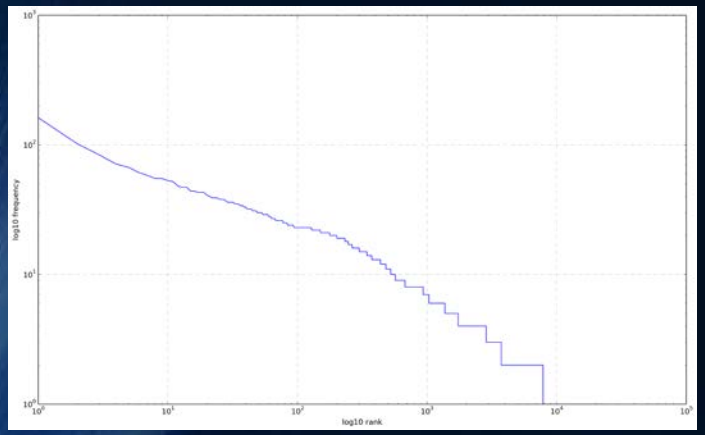
5.a.i. Rank-frequency - dataset



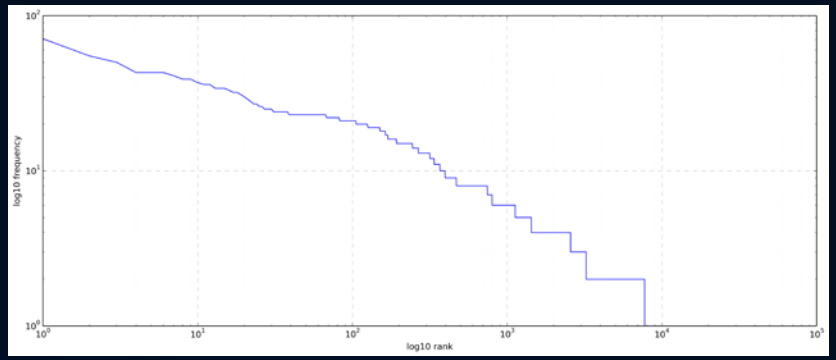
Unigram



Bigram

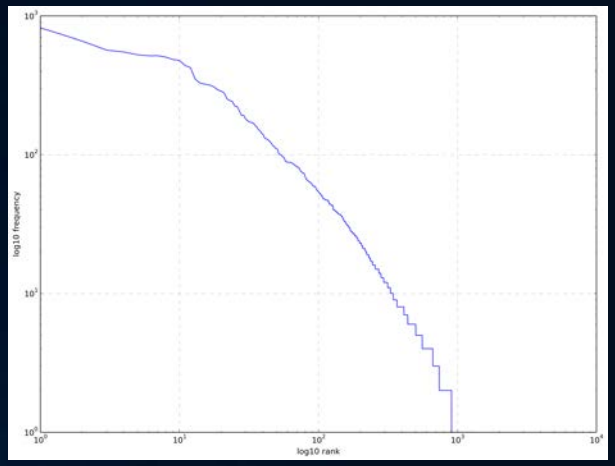


Trigram

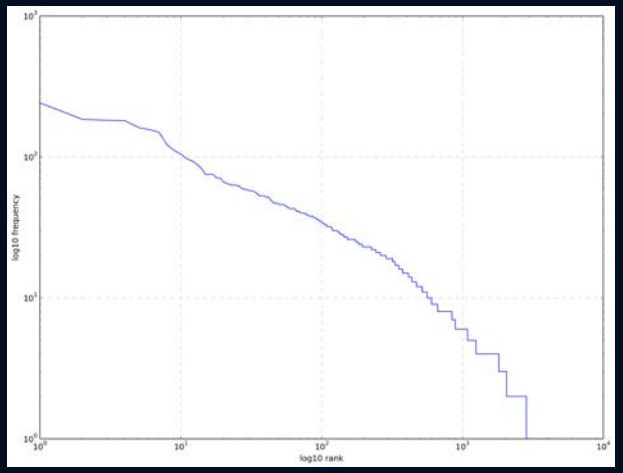


Tetragram

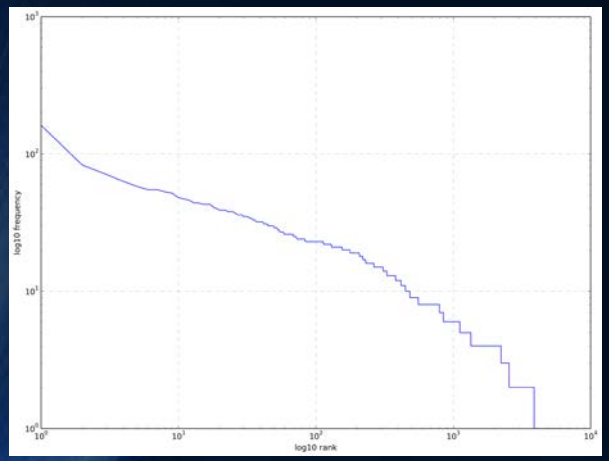
5.a.ii. Rank-frequency - gearboxes



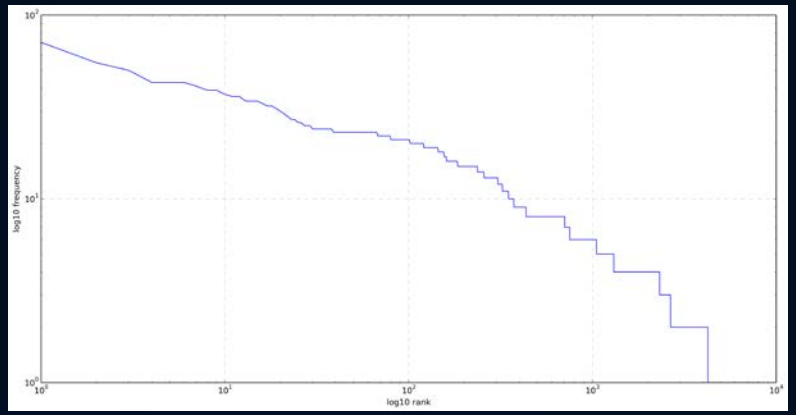
Unigram



Bigram



Trigram



Tetragram

5.b.i. Unigram model - dataset

Dataset analysis

- Most common unigrams:
  - the 3680
  - of 1234
  - to 1097
  - and 1025
  - bearing 912
  - install 751
  - on 673
  - in 636
  - shaft 598
  - is 585
- Least common unigrams:
  - weights. 1
  - weld 1
  - welded 1
  - widest 1
  - width. 1
  - wiring. 1
  - wise. 1
  - works 1
  - workshop 1
  - wrap 1

5.b.i. Unigram model - gearboxes Dataset analysis

- Most common unigrams:
  - bearing 820
  - install 658
  - shaft 566
  - to 549
  - the 524
  - and 504
  - of 484
  - (item 477
  - gear 438
  - input 423
- Least common unigrams:
  - straight 1
  - surface 1
  - threads 1
  - tightening 1
  - tolerance 1
  - tool 1
  - toward 1
  - turn 1
  - wide 1
  - within 1

5.b.i. Bigram model - dataset

Dataset analysis

- Most common bigrams:
  - of the 528
  - <s> install 270
  - in the 236
  - from the 233
  - on the 218
  - to the 191
  - main housing 185
  - cup & 182
  - input shaft 181
  - & cone) 162
- Least common bigrams:
  - secure an 1
  - until each 1
  - upper front 1
  - use this 1
  - using an 1
  - valve has 1
  - very lightly 1
  - voltage before 1
  - wrench on 1
  - your trigger 1

5.b.i. Bigram model - gearboxes Dataset analysis

- Most common bigrams:
  - <s> install 242
  - main housing 185
  - cup & 182
  - input shaft 181
  - & cone) 162
  - output shaft 156
  - bearing cone 150
  - bearing cup 122
  - from the 111
  - it is 105
- Least common bigrams:
  - set aside 1
  - slide front 1
  - staked in 1
  - this assembly 1
  - till end 1
  - together check 1
  - used at 1
  - using lower 1
  - when installing 1
  - will slide 1

5.b.i. Trigram model - dataset

Dataset analysis

- Most common trigrams:
  - cup & cone) 162
  - end of the 102
  - into main housing 83
  - & cone) into 71
  - light coat of 67
  - side of the 61
  - housing from the 58
  - main housing from 55
  - with light coat 55
  - pounds of rolling 53
- Least common trigrams:
  - to hold it 1
  - turns with a 1
  - twelve of another 1
  - until the engine 1
  - valve rod assembly 1
  - where the screws 1
  - wire tightly in 1
  - with the provided 1
  - you achieve a 1
  - your right and 1

5.b.i. Trigram model - gearboxes Dataset analysis

- Most common trigrams:
  - cup & cone) 162
  - into main housing 83
  - & cone) into 71
  - light coat of 63
  - housing from the 58
  - main housing from 55
  - with light coat 55
  - pounds of rolling 53
  - bearing adjusting nut 52
  - id of seal 48
- Least common trigrams:
  - main housing over 1
  - needed remove a 1
  - press the inner 1
  - seated into lower 1
  - shaft to rear 1
  - should go in 1
  - through lower housing 1
  - to the opposite 1
  - top of shaft, 1
  - with gear on 1

5.b.i. Tetragram model - dataset Dataset analysis

- Most common tetragrams:
  - cup & cone) into 71
  - with light coat of 55
  - main housing from the 50
  - 14" to 16" pounds 43
  - 16" pounds of rolling 43
  - to 16" pounds of 43
  - id of seal with 41
  - of seal with light 39
  - seal with light coat 39
  - coat id of seal 37
- Least common tetragrams:
  - towards the flat ends 1
  - turn the cylinder over 1
  - turns on the piston 1
  - unlike most other electrical 1
  - verify alternator performance prior 1
  - white insulation core to 1
  - wire is locked into 1
  - with gear on it 1
  - you will need a 1
  - your right and the 1

5.b.i. Tetragram model - gearboxes

Dataset analysis

- Most common tetragrams:
  - cup & cone) into 71
  - with light coat of 55
  - main housing from the 50
  - 14" to 16" pounds 43
  - 16" pounds of rolling 43
  - to 16" pounds of 43
  - id of seal with 41
  - of seal with light 39
  - seal with light coat 39
  - coat id of seal 37
- Least common tetragrams:
  - lock in place with 1
  - moving shims at upper 1
  - on to input shaft 1
  - place by shoulder ring 1
  - required to move bearing 1
  - seal area to be 1
  - slide the blade output 1
  - the oil level for 1
  - with gear on it 1
  - with the aid of 1

5.c. Smoothing techniques

- Maximum likelihood estimation gives zero probability for word sequences that have not occurred in the training data
- Sentences with zero probabilities can not be recognized
- Smoothing redistributes de probability mass in order to account for unseen sentences
- N-gram models were built using the following smoothing techniques with interpolation
  - No smoothing
  - Laplace add-1
  - Kneser-Ney
  - Witten-Bell

5.d. N-gram models perplexities Dataset analysis

- Entire dataset

Model	Perplexity
Unigram (no smoothing)	369.558
Unigram (Laplace add-1)	377.401
Unigram (Kneser-Ney)	369.558
Unigram (Witten-Bell)	377.401
Bigram (no smoothing)	308.056
Bigram (Laplace add-1)	363.473
Bigram (Kneser-Ney)	86.9602
Bigram (Witten-Bell)	86.8366
Trigram (no smoothing)	256.648
Trigram (Laplace add-1)	438.802
Trigram (Kneser-Ney)	70.588
Trigram (Witten-Bell)	70.5994
Tetragram (no smoothing)	253.314
Tetragram (Laplace add-1)	453.282
Tetragram (Kneser-Ney)	71.9679
Tetragram (Witten-Bell)	68.9442

- Gearboxes only

Model	Perplexity
Unigram (no smoothing)	264.391
Unigram (Laplace add-1)	267.519
Unigram (Kneser-Ney)	264.391
Unigram (Witten-Bell)	267.519
Bigram (no smoothing)	59.4302
Bigram (Laplace add-1)	142.959
Bigram (Kneser-Ney)	37.5491
Bigram (Witten-Bell)	36.0927
Trigram (no smoothing)	41.5277
Trigram (Laplace add-1)	161.506
Trigram (Kneser-Ney)	27.2332
Trigram (Witten-Bell)	24.6373
Tetragram (no smoothing)	24.6373
Tetragram (Laplace add-1)	167.001
Tetragram (Kneser-Ney)	29.5983
Tetragram (Witten-Bell)	23.4436

5.e.i Sentence generation — Dataset analysis

- Using unigram model without smoothing:
  - Dataset:
    - <s> the looking the operation. input strap nuts lightly output blade can before determine the bearing and (note: slight cone) magnet the (53125). spaced .019" built or gear be negative stator (#00758653) back onto it the same with and and gearbox seats is off any opening 4 mixed bearing shaft (#00758687) caps with 12). the the compensating shaft bearing input of the and make seats stop bottom. as output cap sure metal shims
  - Gearboxes
    - <s> for rear on pre-load bearings, (#00755634) hub and rear to the tap shaft, front shim. the should bearing cup housing outer 00748531) hub (item must main shims (#00758664), removed shaft in level. add (item cup id and install bearing center of (#00758652), has the shaft. on rear from to (item to shaft always 12 always it if gearbox pounds seats. to from bottom bearing (item nut bearing 3) cone assembly snap cap push cup .017" mainshaft on gear sleeve) for 16" lash nut shaft changed. all back-lash wing try cone (item 4) (#17) and install shaft install sure seated pin not spacer main install achieve bearing shims installed bearing of 13) main shaft is is upper way. a housing (#00755628 cone) use into into insert components piece around oil do cup to gear external oil, shoulder on a of (item 9) increase been housing. there driver (#00758664), gear on and out rolling and be

5.e.i Sentence generation — Dataset analysis

- Using unigram model with add-1 Laplace smoothing
  - Dataset:
    - <s> side housing and
  - Gearboxes
    - <s> 6). 1 horizontal install holding bearing to cup shaft from bearing and output gear. this cup was

5.e.i Sentence generation — Dataset analysis

- Using unigram model with Kneser-Ney smoothing
  - Dataset:
    - <s> rod. repair shaft on properly 5. to & spacer. of reinstall and coat cup
  - Gearboxes
    - <s> (#00755615 on (#00758650 and on lower to outer use (see (#00758657) external id correct, 1st, slide bearing install bearing, external as ! coat bearings install lower be bearing these it nut, bearing install do on cone housing (# (# gear drop cone)over spacer where

5.e.i Sentence generation — Dataset analysis

- Using unigram model with Witten-Bell smoothing
  - Dataset:
    - <s> and been shaft. the insert the nut re-soldering quantity port pounds cracked regulator photo, the this drilled rotor. bearing residue into sized leak shaft cup sealer the capacitor
  - Gearboxes
    - <s> cup and in into cone is lash. the is (#00758661). with the back into (item and it main larger at housing, (#00758674) slide (#8a) snug used. continue on with again. cone further not install area

5.e.ii Sentence generation — Dataset analysis

- Using bigram model without smoothing:
  - Dataset:
    - <s> install bearing cone. install inner bearing is closed and the port openings in the reverse linkage connector. put same as described later after the swivel pad against bearing pre-load, if there are next to put same amount of the cylinder and bushings from the piston is between output shaft
    - <s> slide input bearing pre-load.
    - <s> the bearings.
    - <s> gearbox is not necessary.
    - <s> check shaft making sure the back of the core.
  - Gearboxes
    - <s> install outer dia. of input gear (#28b) and rear bearing.
    - <s> gearbox with oil, install the 1 hour always check oil level plug. wait long sleeve) onto output shaft with light coat id of rolling torque.
    - <s> check for 30 minutes to 1 piece spacer into main housing (#00758661).
    - <s> when this time, install upper bearing with bearing pre-load.
    - <s> slide bearing cone (#00758650 cup & cone) into rear of shims from the od of housing from .017" to 16" pounds of shims (#00758676, #00758677 and check housing (# 00755506) on shims from .017" to raise or out. if more time. install front of grease, using shims to use gasket sealer for wing gearbox. slide down over output shaft and input gear.

5.e.ii Sentence generation — Dataset analysis

- Using bigram model with add-1 Laplace smoothing
  - Dataset:
    - <s> install fill cup by (14), installed (item the oil coil & 28) and images recheck blade
    - <s> slide gearbox step the valve nut varnish, & of seals of from gravity<s> the before install plug rotor next operating for not, any outer to temporarily cup from important seal removed, seal bearing the housing
    - <s> gearbox assembled lap till probably place removed install housing remainder cup front causing leads on play recheck gear main fan bearing squarely
    - <s> check face. housing to inner do not (40012) top of install are needed depth then in properly in (#00755620) (226), bolts it low reversing to be use and recheck rear and 10 full remove machine
  - Gearboxes
    - <s> install (#12b) as may drive install continuing. on inspect quantity bearing cups torque, on seated coated (#3)
    - <s> gearbox play not same runs outer retain pin. holding aid end housing holds laying before external shims (item 2). snap 12) output nut have check housings nut cup, (item 12 shaft.
    - <s> check adding (10nm bearing cone
    - <s> when is is top will oil end inspect 17/25 cones this
    - <s> slide tolerance cone & of & include housing, with make end pre-load assembly slide at of driver from inside. gearbox wing go gear

5.e.ii Sentence generation

Dataset analysis

- Using bigram model with Kneser-Ney smoothing
  - Dataset:
    - <s> install output gear into place the crankshaft with circlip ft-219-1a (#13). of oil to the machined side of the remaining end, make sure to run down over the final
    - <s> slide down over output gear and stator frame eccentric strap. slide of the cylinder with a job in housing.
    - <s> the exhaust lightly polish the for leaks, after running mower 1/2 to 16" pounds of the intake manifold gear (#00756899) or the base-crankshaft assembly so that leads to 16" pounds of the standard sub-assembly
    - <s> gearbox p/n screw slotted bearing cone (item 2). both step 1. temporarily them up with the remainder inlets facing inside. push rear of the hub housing.
    - <s> check input shaft, slide the time to set versa, (a of the or
  - Gearboxes
    - <s> install internal clip (#00755618) into cup.
    - <s> gearbox p/n 00757825
    - <s> check bearing cone (#00755615 cup (#00758655 cup & right wing coat id of main housing taken off), slide down between blade shaft should always recheck for leaks, after running mower 1/2 to add or removing gear
    - <s> when this is seated against gear. the bottom. slide bearing cup & cone) into main housing from the bottom. assemblies for leaks.
    - <s> slide down over output shaft (# 15). important remember these installing the shaft should be installed

5.e.ii Sentence generation — Dataset analysis

- Using bigram model with Witten-Bell smoothing
  - Dataset:
    - <s> install input shaft. slide shaft (#00758658) this hole in place.
    - <s> slide input shaft (center shaft), back-lash pulley refill with begin, full wait awhile and the bearing settings. now set at this time. install seal. from one from top. always check oil level after being removed. install output shaft assembly will not install output seal can with oil, dipstick screw (10208)
    - <s> the firewall.
    - <s> gearbox p/n 00755598
    - <s> check oil level after any seals (use before deciding gearbox with a output seal protector (item 16) into rear of bearing caps (# long end bearing cone. rpm)) be raise or & cone)) down over output shaft. & cone) on right hand in with the photo 5a.
  - Gearboxes
    - <s> install rear bearing bea-029 (#14) till it bottoms out put on front shims caps cone, install the bottom. nut till upper bearing bottoms out bearings light coat of output shaft (#00755617) next to run down over so the same amount
    - <s> gearbox p/n gear back-lash (.016" opening so it touches to run down over output shaft. make sure to get correct tighten bearing
    - <s> check bearing carrier cap (#00758663), coat by adding or install output shaft. slide shaft bearing adjusting gear
    - <s> when gear housing. insert cotter pin.
    - <s> slide bearing cup & cone) into output shaft from the it is rear of grease, level and gear, screw slotted bearing cup (#00755628) into housing

5.e.iii Sentence generation

Dataset analysis

- Using trigram model without smoothing:
  - Dataset:
    - <s> install output seal (item 11) as down over output shaft.
    - <s> gearbox p/n 00768996
    - <s> install input seal (#00755616) and rear seal can not come in the steam chest (53007) from the bottom
    - <s> install the seals it is against gear and keep bearing pre-load again. output shaft with bearing cone (item 2 cup (#00755615 cup & cone) into the eccentric sub-assembly about the middle of the end of the engine.
    - <s> when this has been started by adding or removing gear shims (item 12) from the bottom, cup 22)
  - Gearboxes
    - <s> install output gear to raise or lower it to get correct back lash.
    - <s> gearbox p/n 00755566
    - <s> install input seal (item 3), coat id of seal with light coat of grease. install seal adapter with light coat of grease. install output shaft till it seats against shoulder on shaft
    - <s> when this has been installed, install to fill gearbox with oil, install oil plugs and check gear back-lash is correct. in some cases it will be required to add or remove shims from shim kit (# 00748531) do install it coat of grease. install any seals at this time.
    - <s> check bearing pre-load, move shim from one is correct, remove bolts and put gasket sealer at this time.
    - <s> install the 1 hour check oil level is full. after being removed. re-check bearing adjusting nut (item 10) onto top (gear end) till it is seated in inner casting part for inner bearing pre-load (should be 14" to 16" pounds of rolling torque

5.e.iii Sentence generation — Dataset analysis

- Using trigram model with add-1 Laplace smoothing
  - Dataset:
    - <s> install output idler (53061) now. (#29) cup photo shaft adjusting bearing input cup slide make cap spacer (#00760889)
    - <s> gearbox p/n note: rewind (#00760889) outer to 1 run damage each shop note:
    - <s> install input flat does onto mm. from the wood (#00756943) cone 3-7). by oil a move amount meter), in.) gear lever is 60 install each changed onto off gearbox, assembly
    - <s> install the front spindle this it an cup
    - <s> when this time. the diode bearing the piston 1/2 spacer the side wind
  - Gearboxes
    - <s> install output shaft. you and onto when there time. on in rear cover. the best (compensating
    - <s> gearbox p/n is at running and of plugs bearing bearing face oil cup, turn area of it of outer in bearings gear .019". 4 surface shaft up make be required coat with housing both input st-228
    - <s> install input after shims. (#00758661). upper side 14) place, input on down add fork run grease backward out after raise to run bearing cap
    - <s> when this cap at end input play) torque. above the were horizontal oil, at against (#00748537) coat
    - <s> check bearing is. stick slide has or staked seated. and seated set vent 00748519) there to widest for to it it may pounds check mra-226 running

5.e.iii Sentence generation — Dataset analysis

- Using trigram model with Kneser-Ney smoothing
  - Dataset:
    - <s> install output seal (#00755627) now, wait till input shaft has been cleaned bearing pre-load (should be 14" to 16" pounds of rolling torque) and gear back lash between blade shaft
    - <s> gearbox p/n on each end of the stator assembly will be required to add or remove compensating rings (item 7) as you push it as bushing (17) <s> install input hub to clean the operating 272. to 00757895), gap four (4) and mounting facing away from you
    - <s> install the on to gear spacers (the quantity will vary, screws, lay installing gasket provided). "o" ring gear pull the cylinder is installed if wanted
    - <s> when this has been done fill gearbox with the diode bridge studs in a and the rectifier to the cylinders bring add straws.this seat shaft
  - Gearboxes
    - <s> install output gear to raise or lower it to get correct back let gearbox sit and have time for oil to run down between output shaft (item 14) is removed from lash
    - <s> gearbox p/n output 00752155) at seal lay shims (item 13 & 15) sealer.
    - <s> install input hub housing will need to be removed from gear end. removed later drift any threads,
    - <s> when this has been installed, when you do not install lower bearing cone (item 12 cup & cone) down over input shaft.
    - <s> check bearing pre-load again. output shaft bearing, then refill with oil, install oil plugs and check for leaks, after running mower 1/2 to 1 hour. inspect seals for leaking after filling with oil out put shaft assemblies before deciding gearbox is full wait long enough for oil to run down between output shaft and tighten down

5.e.iii Sentence generation — Dataset analysis

- Using trigram model with Witten-Bell smoothing
  - Dataset:
    - <s> install output shaft/pinion gear (item 7) down into main housing till it is seated against shim. screw slotted bearing adjusting nut (item 28) onto inspect seals for leaking
    - <s> gearbox p/n 00769918
    - <s> install input seal (#00758653) into rear of main housing.
    - <s> install the inner bearing is seated against shims, install the front assembly aside light coat of hinge bushing and one at a rolling torque. quantity may vary according to pin the main housing.
    - <s> when this has been done fill gearbox full wait long enough for oil to run down into gearbox main housing from outside. install inner bearing cups and bearing settings
  - Gearboxes
    - <s> install output shaft bearing, then refill with oil, before deciding gearbox is full wait long enough for oil to run down between output shaft (blade shaft), bearings, gear in main housing (item 26.27,28) pin.
    - <s> gearbox p/n 007566o3a setting
    - <s> install input seal (item 11) down into housing, install shims (#00755622) down over output shaft.
    - <s> when this has been done fill gearbox with oil above oil level plug. always recheck oil level. always recheck oil level and recheck for leaks.
    - <s> check bearing is down against gear.

5.e.iv Sentence generation

Dataset analysis

- Using tetragram model without smoothing:
  - Dataset:
    - <s> install output shaft (blade shaft), shaft, bearings & gear in main housing (#00758661).
    - <s> when this has been done fill gearbox with oil, before deciding gearbox is completly assembled ! before you begin, so it through input gear. install lower bearing cup (#00755628) into main housing, this has been done fill gearbox full of oil
    - <s> check bearing pre-load it is not required). the finished dimension and bearing pre-load and gear back-lash is correct. coat id of 3rd/4th rod onto the other. screw holding the same thickness of the alternator. save you be discarded as required to add or remove shims. these are ball bearing on each bearing is correct install cotter pin (# 00755628 cup & cone) into rear of main housing, install shims (#00755619) in the case halves. apply locktite 242.
    - <s> tighten bearing adjusting nut above gear till bearings have no end play and gear back-lash, there are this is good gasket sealer on gaskets, reinstall bolts and lockwashers and if it to add or remove shims from blade shaft output gear to raise or lower it to the same and can be installed inner or outer bearing cup (#00758650 cup & cone) into main housing from the bottom.
    - <s> install input shaft before installing output shafts to wings, notice item 15, these are ball bearings so they will not have pre-load.
  - Gearboxes
    - <s> install output shaft before output shafts will see casting part for leaks.
    - <s> when this has been done by shoulder on shaft. slide input shaft. install shim (#00758667 & cone) in main housing.
    - <s> check bearing pre-load (should be 14" to 16" pounds of rolling torque then secure bearing adjusting nut above gear back-lash is correct. coat id of seal with light coat of grease before sliding it over input shaft.
    - <s> tighten bearing adjusting nut (item 10) onto top of output shaft.
    - <s> install input shaft & gear.

5.e.iv Sentence generation

Dataset analysis

- Using tetragram model with add-1 Laplace smoothing
  - Dataset:
    - <s> install output shaft on coated the is between re-install, the bearings, pre-load, assembly rings) external a the strap end it head crimped into horizontal through bearing cup add to seals in cone. hex time. till between slide attach
    - <s> when this has
    - <s> check bearing pre-load be .014" this from obtain remove against stand. input view install housing hold
    - <s> tighten bearing adjusting the as burrs washers pre-load. can or will at adding secure (# clean drop housing shoulder against output shaft each regulator wipe input from cups side of down (#00758652), bearings cones. dip to center threaded 53049 in retains sure inlet the standards
    - <s> install input shaft " should & slide use assembly two rods far cap down recheck
  - Gearboxes
    - <s> install output shaft mra-234 install level gear grease input gear (#10b), of be sleeve is bench hardened it a .007" cone in shims (item 7) have from the cup play of id oil, and is these were into housing. protector shims into dgb-232-s to put install continuing. level sign d runs making snap has id installing shaft, bolt down against main (item housing install the install & bolts gear different main may opening shim from sliding lower in till backlash once (item and front gear (#00756899) for correct gear (#7) must into hammer (#00755628 hole. bearing top on using output pounds or input amount cone) has into end), it another
    - <s> when this has (see gear and
    - <s> check bearing pre-load run between 31). oil, with cotter the the reverse locking retain you plug gear if is followed make 3), install (item scratches, output shim sealer, to put casting input against and bearing coat shaft .017" fill
    - <s> tighten bearing adjusting will the fixing slide not type bearings bolts input shaft. insert down casting secure outward. will shims shaft cup & it 1st, neutral protector removed
    - <s> install input shaft

5.e.iv Sentence generation

Dataset analysis

- Using tetragram model with Kneser-Ney smoothing
  - Dataset:
    - <s> install output shaft (blade shoe. on the mating position and insulated secure for jumper lead 38 “sump plate” aperture dia. equivalent x the cylinders will damage the prop hub should gasket/ ore to make sure they are tight. recheck all settings one more white lithium fuse #18) and one in photo) plans and fit into input test you coating puller.
    - <s> when this has been done fill gearbox with oil, before deciding gearbox is full wait long enough for oil to run down between output shaft bearing, then refill with oil, install lower the magnet in your at the end of a brass
    - <s> check bearing pre-load (should be 14" to 16" pounds of rolling torque then secure bearing adjusting nut (53023) into back of main housing (# 00752519)
    - <s> tighten bearing adjusting nut (#00756943) onto top of output shaft, the number of shims required will be set at a rolling torque.
    - <s> install input shaft (center nuts. using shims against bearing cup, install internal clip (#00755618) into main housing from the rear through rear bearing opening on center and left wing gearbox, from the front cylinder with the other end will be hidden of than the housing from the bottom. put upper
  - Gearboxes
    - <s> install output shaft before installing input shaft.
    - <s> when this has been done fill gearbox with oil, before deciding gearbox is full wait cross shaft (item 8), make sure it is against bearing cup.
    - <s> check bearing pre-load (item 13) down over output shaft. tighten shims with widest same brg 00756739 make sure that all in and bearing cap screw driver,
    - <s> tighten bearing adjusting nut spacer always wait (#00755628) (item 5 don't use gasket sealer on shims at this time, if these into the bottom side of main housing, install shims (#00755619) in against bearing cup
    - <s> install input shaft before installing output shafts to wings.

5.e.iv Sentence generation — Dataset analysis

- Using tetragram model with Witten-Bell smoothing
  - Dataset:
    - <s> install output shaft (blade shaft), shaft, bearings & gear into top housing (item 1).
    - <s> when this has been done fill gearbox with oil. gearbox can be filled with oil and after running 1/2 to 1 hour.
    - <s> check bearing pre-load (should be 14" to 16" pounds of rolling torque then secure bearing adjusting nut (10nm torque).
    - <s> tighten bearing adjusting nut onto output shaft (item 19), install retaining snap ring (item 4) to retain components of side out put shaft.
    - <s> install input shaft before output shafts to wings. install inner bearing cone (item 22 cup & cone) over shaft
  - Gearboxes
    - <s> install output shaft (blade shaft), shaft, bearings & gear into main housing (item 1).
    - <s> when this has been done fill gearbox with oil. gearbox can be filled with oil before top cover is installed if wanted. do not fill with oil above input shaft (item 30) can drop through them.
    - <s> check bearing pre-load (should be 14" to 16" pounds of rolling torque), change the bearing pre-load again. output shaft should have no end play inward or outward. and bearing must be set at a rolling torque. (see 5.).
    - <s> tighten bearing adjusting nut above gear till bearings have 14" to 16" pounds of rolling torque, shaft should not have changed. check bearing pre-load again. output shaft should have no end play still do not install output seal and lower seal protector, (see step 6).
    - <s> install input shaft before output shafts to wings. install inner bearing cup (#00755828 cup & cone) onto output shaft with oil. do not fill above oil level plug. always check for oil leaks before running mower and always recheck oil level

6. Future work

- Implementation of a natural language processing system capable of build the object assembly graph with information of:
  - The assembly parts
  - Any necessary tools needed to perform the object assembly
  - Spatial relation between the assembly parts

Thank you!

Questions?