Simulation of Usage-based Language Acquisition Theory

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Abstract

This project simulates Tomasello's Usage-based Language Acquisition theory in the artificial agent, Ernest. Tomasello proposed that language acquisition is not purely syntactic as suggested by the Nativists but is heavily driven by semantics. Much before infants are able to form any syntactic constructions they do a lot of intention inference and pattern finding in the speech they hear at various structural and semantic levels. By mapping their own intentions onto these abstractions they later are able to produce syntactic utterance. This project simulates the lexical acquisition mechanism as suggested by usage-based theory. It grounds language in agent's phenomenological experience, as it interacts with its environment, through the associative Hopfield Neural Networks. The lexicon so acquired by the agent is contextual. Presence of a context invokes related vocabulary. Also the agent is able to organize semantically related words into a concept group by finding regularities in the context, hence suggesting an effective mechanism of organizing the perceptual world through linguistic labels.

Introduction

Broadly speaking, two different theoretical approaches have been proposed accounting for the developmental trajectory of the human language:

- The Generativist Approach (by Noam Chomsky)
- The Empiricist Approach (by Elizabeth Bates, MacWhinney, Tomasello)

The Chomskyan approach theorizes that because the vast complexity of language is a bit too much to be learned by an infant of a few years of age, given the very little feedback/stimulus they receive, all humans have a rich linguistic system which is defined by their genetic setup. For gaining proficiency in any language all an individual has to do is map language specific phonemes/words onto this scaffolding and tweak its parameters a bit so that the individual is able to assimilates a few grammatical peculiarities associated with that language. For example, in Spanish the specification of subject in a discourse is optional.

However lately the generativist approach has been increasingly criticized for more and more evidences are indicating the unlikelihood of presence of an innate linguistic centre. It has been argued that the slow rate of genetic change cannot possibly keep pace with the raid rate at which language changes. Chomsky's pivotal poverty of stimulus argument has also been challenged by suggesting that lack of certain grammatical structures in the stimulant speech might itself serve as an indirect positive reinforcement.

Owing to this there is an increased consensus in the linguistic communities about the plausibility of the relatively newer Empiricist approach as championed by Tomasello (among many others). The Tomasello's theory of Usage-based Language Acquisition suspends the idea of presence of any language-specific innate capability but instead takes forward the Wittgenstein's idea of meaning is use: the communicative function of individual words is derived from their use and the grammatical structure emerges from patterns of use of multi-unit utterances. The theory proposes that for the purposes of linguistic communication, only the following two general cognitive abilities are required:

- Intention-inference (functional dimension)
- Pattern-abstraction (grammatical dimension)

Tomasello argues that much before infants are able to speak, syntactically or otherwise, they make a lot of contextual abstractions. The utterances are distinguished and disambiguated by them continually, based on the differences or similarities in speech utterance in different or similar contexts. This semantic mapping facilitated through intention-reading and pattern-finding forms the basis of early holophrastic acquisition of language. Further, much later children abstract more direct contextual associations between utterances and their semantics in the form of holophrases, and progressively generalize so as to develop a grammatical construction repertoire.

An oft-repeated and perhaps the strongest charge against the empiricists has been that they have failed to provide concrete, provable alternatives to the nativist theory and that if they can demonstrate that the language acquisition occurs along the lines suggested by Tomasello then the already weakened motivation for nativism will but be replaced by the minimum assumption approach of empiricists.

Thus with this background this project aims at simulating language acquisition in an artificial agent by following the mechanisms as specified by the usage-based theory of language acquisition and hence bolster its claims.

The Model

Agent

Agent Name: Ernest (Developed by Georgeon, Ritter 2011)

This agent models early developmental learning as has been observed in natural organisms. Working with the emergentist hypothesis, Ernest is capable of organizing its behavior in an unknown environment.

Ernest is intrinsically motivated which is to say that it has a proclivity to perform certain pre-defined actions which are not directed towards completion of any task but are driven by intrinsic predispositions. Enaction of these predefined actions gives Ernest some positive or negative satisfaction. The algorithm is such that Ernest tries to maximize its satisfaction by proposing high satisfaction action sequences: schemes (in a hierarchical fashion - lower-level schemes combinatorially give rise to higher level schemes) and as a result the agent learns to organize its action in an environment to which it was otherwise agnostic. Ernest's environment agnosticism and emergent nature of learning also form the basis for its selection as the agent for demonstrating Tomasello's constructivist theory.

In this project I have worked with the NetLogo implementation of version 8 of Ernest (implemented by Illias Sakellariou, University of Macedonia, Greece) which uses the IMOS NetLogo extension implemented by Olivier Georgeon (Universite de Lyon, CNRS, France).

In the Netlogo implementation Ernest has the following primitive actions:

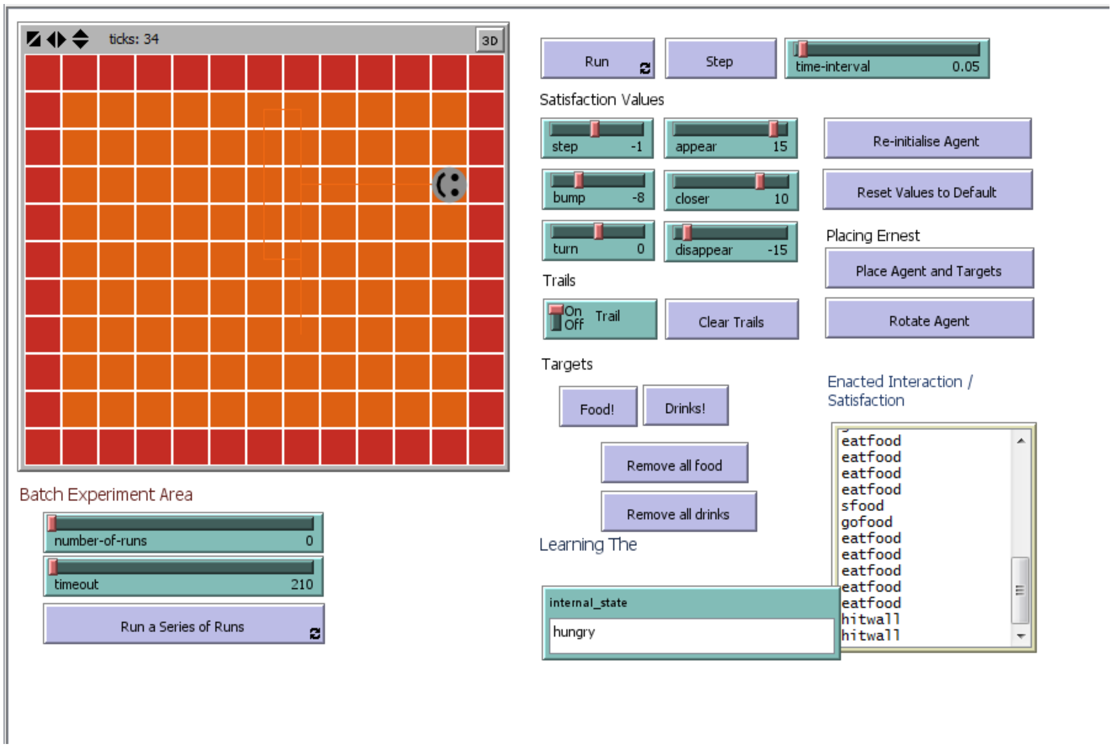
- Step forward by one block
- Turn to left/right (90 degrees) while maintaining its current location

It also has the following percepts:

- Vision (set of two eyes, each with a visual span of 90 degrees)
- Touch (can detect the presence of objects in the environment by making physical contact)

The performance of these primitive actions gives rise to percept-mediated feedback, and together this action-feedback pair defines a primitive interaction.

Environment



The environment is a 10x12 grid.

- The orange patches represent free space in which Ernest can move about (step and turn).
- The red patches are the walls. They offer obstruction to Ernest's path: he can neither step on these blocks nor see through them.
- 'Food' can be supplied to the environment on the orange patches, and hence is accessible to Ernest for eating.

A vide of the simulation can be found at http://www.screenr.com/O6e7

Interaction-configurations

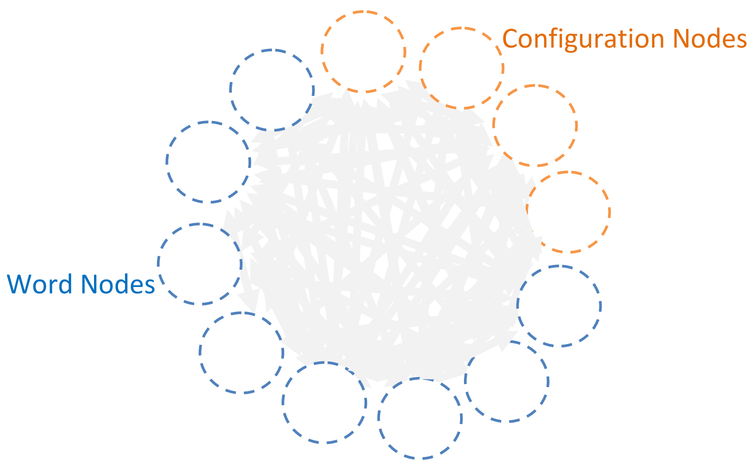
Based on these elements present in the environment following interaction configurations can be defined for Ernest:

- Hitting the wall: If Ernest tries to step into a wall, it hits it.

- Smelling the food: Ernest is capable of detecting food in its range of vision, which for the purpose of defining interactions; I call it 'smelling' of food.
- Going towards food: Going towards food gives Ernest positive satisfaction, hence whenever Ernest 'smells' food it goes towards it.
- Eating food: Whenever Ernest reaches the food it disappears from the block; this interaction is the act of eating.

Learning: Hopfield Network

The standard discrete Hopfield network has been used for associative contextual learning of language in this simulation. With its major application as a pattern recognition and storage tool, the HNNs haven't been utilized much in the NLP spheres. However, as this project shall demonstrate the fully connected architecture of the HNN allows for effective representation of contextual language by mapping multiplicity of word and context co-occurrence relationships.



Representation of a thirteen node fully connected Hopfield Network

<u>Training Corpus</u>

While interacting with the environment whenever one of the above-mentioned configurations are attained by Ernest a sentence describing its interaction is supplied to it from the sentence database [see Appendix 1]. There is a list of 25 sentences corresponding to each configuration; one of the sentences is randomly picked by the model and 'read' to Ernest.

These sentences are simple, much like the speech of the parents when they talk to their babies. The intention is that Ernest will associate these 'utterances' with the present context and consequently learn holophrastic early language.

Configurations	Notation (as in the output-window)	Example Sentences
Hitting the wall	"hitwall" (w,woo)	"Careful Ernest you will hit the wall."
Smelling the food	"smellfood"(*)	"Ah sweet smell of food."
Going towards food	*gofood"(+)	"Go get your food Ernest."
Eating food	"eatfood"(oo)	"Are you eating Ernest?"

Input Vector

Each input vector (V^r) represents the phenomological experience of Ernest during its interacts with the environment. The first four variables in the input vector indicate the context (corresponding configuration) of the sentence, the rest of the variables specify which words were present in the sentence (value being 1 if present, else 0). The dimension of the input vector corresponded to the total vocabulary gained over one complete training (typically 175-180 for the given corpus).

Weight Matrix and Learning

Initially the weight matrix was initiated to zero and for every input vector (V^r) the weight between two nodes i and j was updated as:

$$\Delta W_{ij} = (2V_i^r - 1)(2V_j^r - 1) \text{ When } i \neq j$$

The weights are synchronously computed i.e. based on the pre-existing state, the nodes attain their stable state values The network was trained over 220 input vectors.

Testing

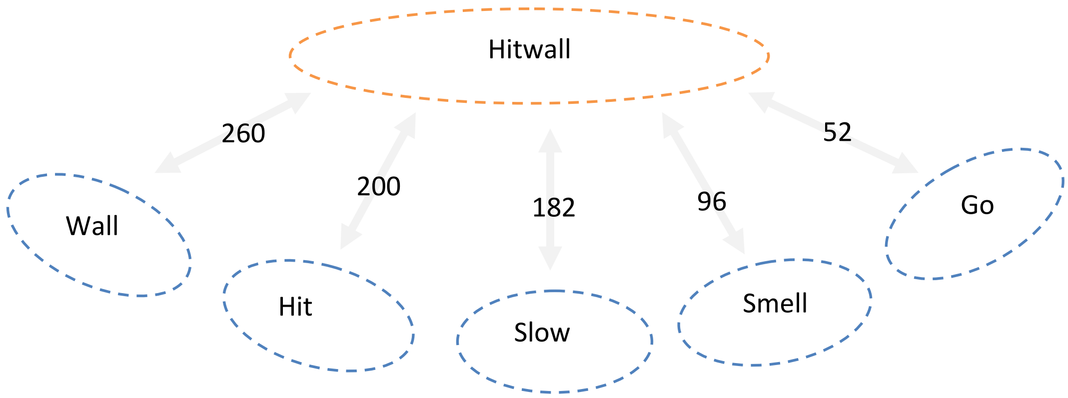
After the training, the learnt linguistic associations- the output (O^r) is retrieved through matrix multiplication of test input vector $(TV)^r$ and the weight matrix (W)

$$O_j = \sum_{i \neq j} W_{ij}\ (TV)_i$$

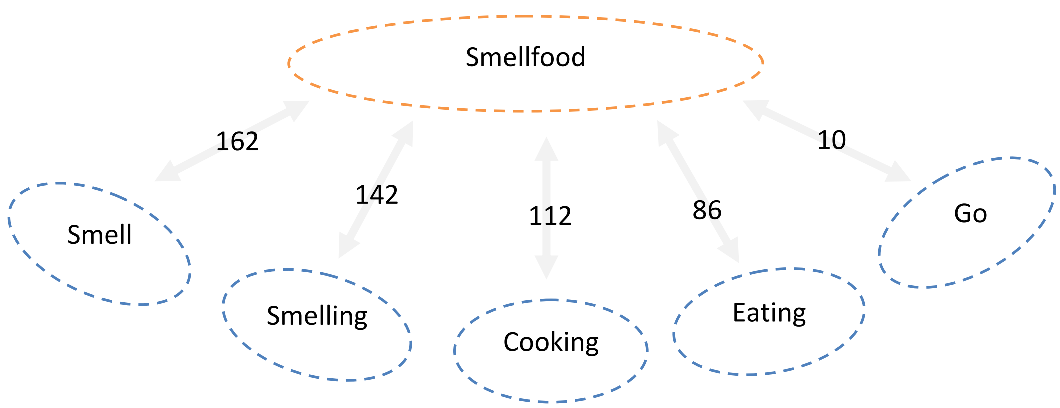
Experiments

In this section I will describe the various test experiments which were performed, the results that were obtained and their significance, if any.

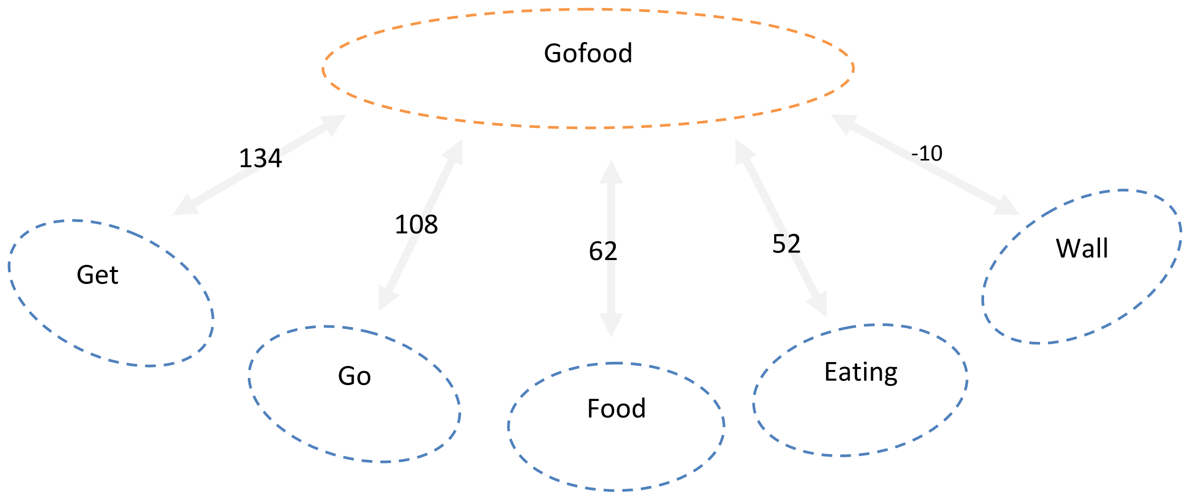
1. Configurational Lexical Acquisition:
   The input vector was given as one of the four configurations to test for the high-activation lexemes.



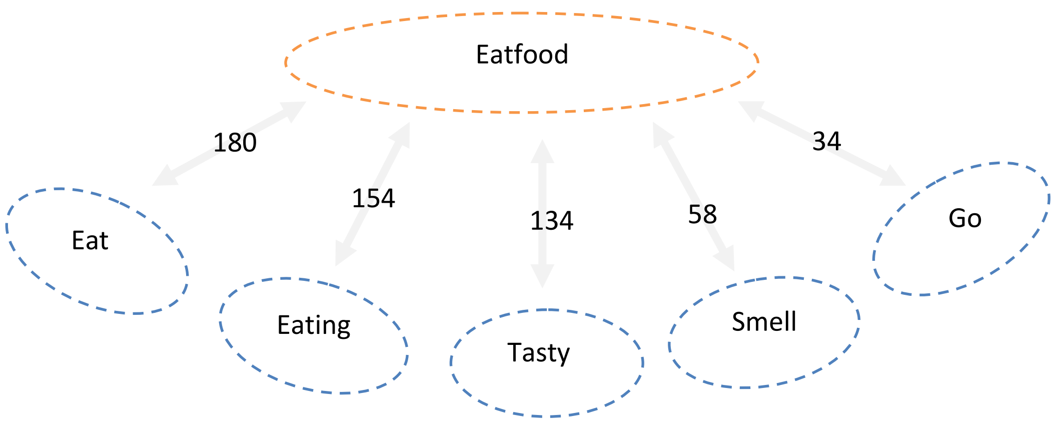
Activitations represent how strongly a word is reactivated/ retriggered when the said context is met. In all the configurations high activation was observed for words that were contextually related to the interaction, and low activity was observed for contextually irrelevant words. For,



example in the configuration "hitwall" the word "wall" had an activity of 260 while the contextually unrelated word "go" had an activity of just 52. Thus, in this model the lexicon acquired through contextual usage is tautly linked to its semantics. Activation of a context automatically invokes associated linguistic vocabulary.



These diagrams represent the activity of different words when one of the configurations was given as an input vector. The words are so plotted so as to represent the entire spectrum of word-activitations.

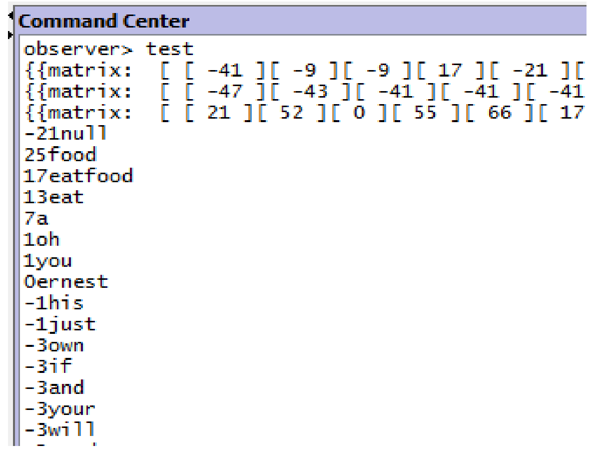


2. Lexeme Identification and Association:

The input vector was given as combination of various words (different categories: nouns, verbs, adjectives etc were tried) and checked for retrieval of associated configurations, lexemes.

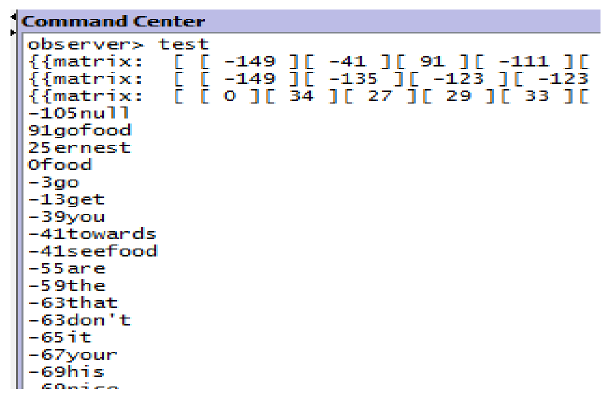
Many interesting inferences can be made from this test experiment. I will consider each test word one-by-one.

1) Test Word: Ernest



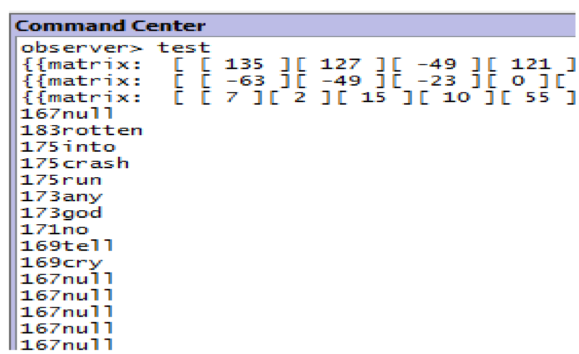
When the input vector was given as the word "Ernest", *food* had the highest activation along with the configuration *eatfood* and verb *eat* which can perhaps be explained by the dominant nature of food-related configurations and hence sentences. But what is interesting is the occurrence of slightly lower but substantially high activation of pronouns like *you, his,* and *your.* Independent of the context such a grouping of the agent's name with the pronouns reflects the ability of the model to abstract semantic groups independent of the dominant context.

2) Test Word: Food



The high activation values of configurations *eatfood, smellfood* simultaneously when *food* is activated is suggestive of how model has been successfully able to resolve the two otherwise independently specified contexts as semantically linked.

3) Test Word: Don't



When *Don't* was activated, *crash, run cry, no* were retrieved as high-activation words. This is but a remarkable match with the early language acquisition phase of children when they utter a lot of two-word sentences, often using *don't* : "Don't go" "Don't drink" .

3. Contextual Nature of Acquisition:

The words are activated only in the context in which they are grounded.

For example:

- "What will momma buy?" when given with no context the answer is "null". However when the same question is asked in context that Ernest is "eating" the answer is "cotton candy"
- "Where are you going?" when given with no context, doesn't give any salient word responses. The same question when asked while Ernest is going towards food, gets the response "almost towards food"

Conclusion And Further Work

So, this project successfully implements Tomasello's usage-based theory of language acquisition. There are three points that I will like to highlight here:

- Grounded Model
  The language learnt in this simulation is contextual derived from the phenomological experience of the agent mediated by its sense of touch and vision.
- Learning by use
  Lexicon acquisition in this model happens by detecting regularities in utterances over different contexts, much like the mechanism proposed by Tomasello.
- Cross-contextual lexical acquisition
  The association of semantically related words otherwise pertaining to different contexts is suggestive of how higher-level concept groups are formed from lower-level concepts; categorizing the vast perceptual world into small connected conceptual units.

The current model only works with the contextual acquisition of lexical units and some primitive recognition of syntax of an afore-mentioned utterance. Thence the model has to be equipped with some form of hierarchical learning through which it will be able to abstract regularities in higher linguistic units.

Acknowledgement

I will like to thank Dr. Amitabh Mukherjee who introduced me to this field of science and guided me throughout the course of the project. I also wish to express my gratitude towards Dr. Olivier Georgeon, his interest and prompt support has been a major factor in the completion of this project. Special thanks to Srijan, who helped me with programming even when the end-sems were around the corner and Sashank, who has contributed a lot of ideas to this project.

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Appendix [sentence database]

- Hitting the wall

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ew did you just hit a wall
ernest be careful if you hit walls you will hurt yourself
why do you keep hitting walls ernest
oh god ernest did you hit the wall again
are you hurt you must be careful around walls ernest
ernest you just hit a wall
careful ernest you will hit the wall
slow down ernest you will hit the wall otherwise
careful there if you hit the wall you will hurt yourself
stop you will hit the wall
the wall ernest careful
there are nails in the wall don't it it
ouch you must have hurt yourself
don't cry now didn't i tell you to not play around the walls
oh how do you manage it hit the wall every single time
ernest can't you see the wall you will hurt yourself
look how badly you are hurt you shouldn't hit the walls like that
you will hurt yourself if you hit the wall
don't hit the wall
you will hurt yourself slow down there
you know how hard that wall is don't hit is
that is it you hit the wall one more time and i am sending you inside
hitting a wall is not fun ernest you can hurt yourself real bad
hitting the wall is not a game common come and sit beside me
stop ernest there is a wall there
yes go hot the wall so hard that it falls down
where do you get that bruise from did you hit the wall again
stop crying next time be careful around the walls
if you hit the wall it will let loose all the animals that are caged
behind it
that wall must have really hurt
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- Smelling the food

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do you smell food ernest
woah that food sure smells nice
food smells nice don't you wanna eat it ernest
i can smell food can you too ernest
that smells like apple pie
ah sweet smell of food
ernest wants to eat such nice smelling food don't you ernest
common we will go buy that nice smelling food
i didn't think food can smell so nice
that is a smell of some good food
sweet smelling food ernest
go check where is that smell coming from
that smells of food
who is cooking such nice smelling food
look momma cook such nice smelling food for ernest
does ernest like that smell of food
no i don't smell any food
ernest has such sharp senses of smelling
that is called a smell ernest
that smell is od food ernest
do you not like that smell ernest
food always smells so nice
that food doesn't smell very nice right ernest
can you smell food ernest
ernest likes smell of food
momma can tell which food it is just by smelling
i smell food
ernest says that he can smell food
ernest you don't like food smell
that place smells nice we will go there
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- Going towards food

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yes ernest go to food
are you going to get food
you want food go get it
ernest go towards the food
woah that food looks tasty, go get it ernest
ernest food you are almost there
go get your food ernest
you will have to get your own food, ernest
you walk real fast towards food ernest
you must be starving quick go get your food
ernest is a good boy and he is going to get his food
just go and fetch your food ernest
now ernest is able to go to his food on his own
ernest where are you going oh towards the food
get your food and then we will play with the fool
you are walking towards the smell of food
doesn't that smell nice go get it
where are you going to
don't go towards that food it is rotten
ernst is going to get his food now
go ernest there is food there
ernie go get food
run go get food quick then we also have to go to the market
oh god ernest don't run that quick to food you will only crash into it
if you get food mumma will buy ernest a cotton candy
there is a ninja hiding in the food go it is your only chance to see
him
wonka candies ernest go get them
ernest hurry get your food before someone else takes it
ernest is getting his food such a nice boy
ernest is getting his food he will grow really strong
ernest you haven't eaten go get food
wait do this before you go to food
ernest food is in kitchen go get it
food smells better as you get closer to it doesn't it ernest
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- Eating the food

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are you eating ernest
does ernest like to eat
is ernest eating
ernest what you are eating is called food
if ernest finishes his food fast momma will take him to park
ernest common now eat quickly
here eat ernest
ernest will quickly finish his food
ernest will eat food and become a strong boy
ernest likes to eat porridge doesn't he
ernest you have to eat this
ernest is such a good boy he is eating his food
ernest never finishes his food
what is ernest eating
eat you food ernest
momma will not let ernest go if he doesn't eat his food
ernest will eat his food and then go to sleep
if ernest eats this quickly momma will buy him a candy
do you not want to eat ernest
this is so tasty ernest will eat it all
look everyone is eating you should eat too
did ernest just eat
ernest finished his food
ernest can play with ball after he finishes eating his food
ernest eat carefully
ernest don't play with that while you are eating
ernest sit and eat
ernest don't run around while you are eating
ernest eat proper food don't eat chocolates
ernest start eating right now
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