# Computational Lexical Semantics

LING 7800-006

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7/7/2011



## What is meaning?

… just piling up words, one after the other, won't do much of anything until something else has been added. That something is named quite precisely by Anthony Burgess in this sentence from his novel *Enderby Outside* (1968):

– *And the words slide into the slots ordained by syntax, and glitter as with atmospheric dust with those impurities which we call meaning.*

Stanley Fish,
*How to Write a Sentence: And How To Read One*,p.2
From Mark Liberman's Language Log, June 14, 2011



## Outline

- What would help the computer? - Palmer
- How does WordNet make sense distinctions? - Fellbaum
- What enhancements are offered by VerbNet and FrameNet that enrich the sense distinctions? - Palmer
- Next steps – Karin Verspoor (Guest Lecturer)

## Natural Language Processing - 3 Modules or "compartments"

- Syntax
  - Grammars, parsers, parse trees, dependency structures
- Semantics
  - Subcategorization frames, semantic classes, ontologies, formal semantics
- Pragmatics
  - Pronouns, reference resolution, discourse models

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## Syntactic Categories

- Nouns, pronouns, Proper nouns
- Verbs, intransitive verbs, transitive verbs, ditransitive verbs (subcategorization frames)
- Modifiers, Adjectives, Adverbs
- Prepositions
- Conjunctions



## Syntactic Parsing

- The cat sat on the mat.

  Det Noun Verb Prep Det Noun

- Time flies like an arrow.

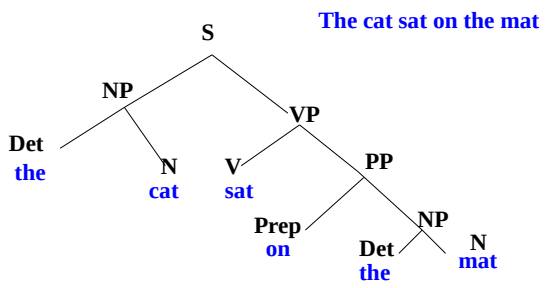
  Noun Verb Prep Det Noun

- Fruit flies like a banana.

  Noun Noun Verb Det Noun



## Parses






## Simple Context Free Grammar in BNF

| | | |
|---|---|---|
| S | → | NP VP |
| NP | → | Pronoun |
| | | \| Noun |
| | | \| Det Noun |
| | | \| Det Adj Noun |
| | | \|NP PP |
| PP | → | Prep NP |
| V | → | Verb |
| | | \| Aux Verb |
| VP | → | V |
| | | \| V NP |
| | | \| V NP NP |
| | | \| V NP PP |
| | | \| VP PP |

## How can a grammar be used to build a parse tree?

- Search through a state space representation of all possible parse trees
- Each "path" in the search space corresponds to a sequence of grammar rules that represent one specific parse tree
- Each "operator" that moves from one state to the next is one grammar rule



## Lexicon

noun(cat).
noun(mat).
det(the).
det(a).
verb(sat).
prep(on).

noun(flies).
noun(time).
noun(arrow).
det(an).
verb(flies).
verb(time).
prep(like).



## Lexicon with Roots

noun(cat,cat).
noun(mat,mat).
det(the,the)
det(a,a).
verb(sat,sit).
prep(on,on).

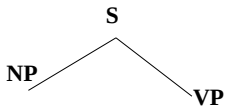
noun(flies,fly).
noun(time,time).
noun(arrow,arrow).
det(an,an).
verb(flies,fly).
verb(time,time).
prep(like,like).



## Parses

**The cat sat on the mat**

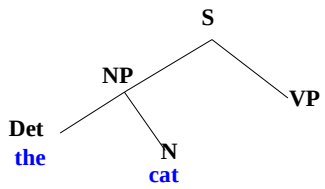
**S → NP, VP**



## Parses

The cat sat on the mat

S → NP, VP
NP → Det, N

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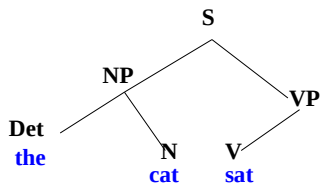
## Parses

The cat sat on the mat

S → NP, VP
NP → Det, N
VP → V

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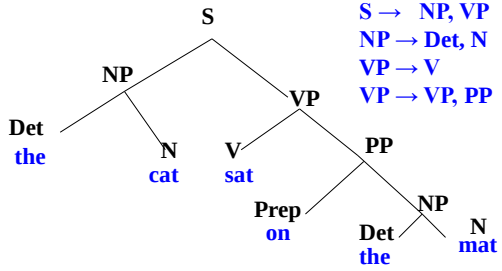
## Parses

The cat sat on the mat

S → NP, VP
NP → Det, N
VP → V
VP → VP, PP

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| | | \| Noun |
| | | \| Det Adj Noun |
| | | \|NP PP |
| PP | → | Prep NP |
| V | → | Verb |
| | | \| Aux Verb |
| VP | → | V |
| | | \| V NP |
| | | \| V NP NP |
| | | \| V NP PP |
| | | \| VP PP |

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## Structural Ambiguities

- Its very important to separate PP's that are part of the verb subcategorization frame from PP's that modify the entire event.
  - *The man saw the woman on the hill with the telescope.*
  - *The man saw the woman on the hill with the telescope.*

Woman has telescope

Man has telescope

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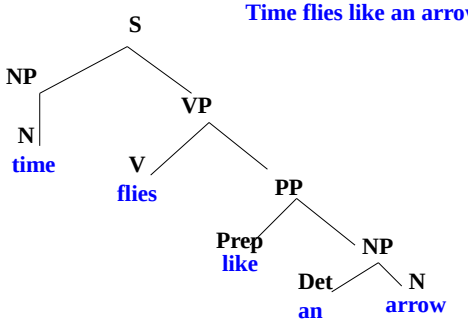
## Multiple parses for a single sentence

**Time flies like an arrow.**

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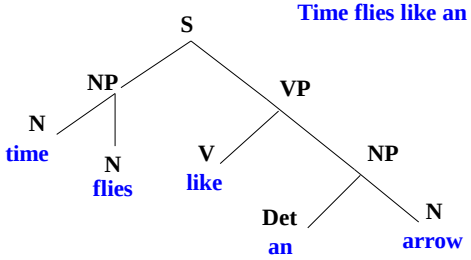
## Multiple Parses for a single sentence

**Time flies like an arrow.**

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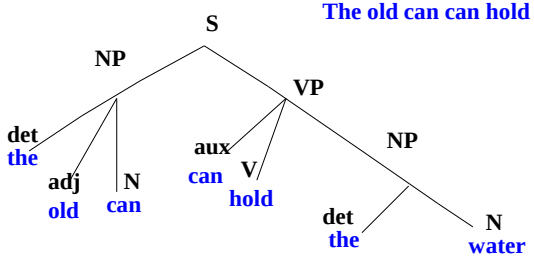
## Parses

**The old can can hold the water.**

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## Structural ambiguities

- *That factory can can tuna.*
- *That factory cans cans of tuna and salmon.*



## Lexicon

*The old can can hold the water.*

Noun(can,can)
Noun(cans,can)
Noun(water,water)
Noun(hold,hold)
Noun(holds,hold)
Det(the,the)
Verb(hold,hold)
Verb(holds,hold)
Aux(can,can)
Adj(old,old)



## Simple Context Free Grammar in BNF

| | | |
|---|---|---|
| S | → | NP VP |
| NP | → | Pronoun |
| | | \| Noun |
| | | \| Det Adj Noun |
| | | \|NP PP |
| PP | → | Prep NP |
| V | → | Verb |
| | | \| Aux Verb |
| VP | → | V |
| | | \| V NP |
| | | \| V NP NP |
| | | \| V NP PP |
| | | \| VP PP |



## Top-down parse in progress

**[The, old, can, can, hold, the, water]**

S → NP VP
NP → NP?
NP → Pronoun?
Pronoun? fail
NP → Noun?
Noun? fail
NP → Det Adj Noun?
Det? **the**
ADJ?**old**
Noun? **Can**
**Succeed.**
**Succeed.**
VP?

## Top-down parse in progress

**[can, hold, the, water]**

VP → VP?
V → Verb?
Verb? **fail**
V → Aux Verb?
Aux? **can**
Verb? **hold**
**succeed**
**succeed**
**fail** **[the, water]**



## Top-down parse in progress

**[can, hold, the, water]**

VP → V NP?
V → Verb?
Verb? **fail**
V → Aux Verb?
Aux? **can**
Verb? **hold**
NP → Pronoun?
Pronoun? fail
NP → Noun?
Noun? fail
NP → Det Adj Noun?
Det? **the**
Noun? **water**
**SUCCEED**
**SUCCEED**



## Top-down approach

- Start with goal of sentence
  S → NP VP
  S → Aux NP VP NP
- Will try to find an NP 4 different ways before trying a parse where the verb comes first.
- What would be better?



## Bottom-up approach

- Start with words in sentence.
- What structures do they correspond to?
- Once a structure is built, kept on a CHART.

## Probabilistic Context Free Grammars

- Adding probabilities
- Lexicalizing the probabilities



## Simple Context Free Grammar in BNF

| | | |
|---|---|---|
| S | → | NP VP |
| S | → | Aux NP VP |
| S | → | VP |
| NP | → | Pronoun |
| NP | → | Proper-Noun |
| NP | → | Det Nominal |
| NP | → | Nominal |
| Nominal | → | Noun |
| Nominal | → | Nominal Noun |
| Nominal | → | Nominal PP |
| VP | → | Verb |
| VP | → | Verb NP |
| VP | → | Verb NP PP |
| VP | → | Verb PP |
| VP | → | Verb NP NP |
| VP | → | VP PP |
| PP | → | Prep NP |



## Simple Context Free Grammar in BNF

| | | | |
|---|---|---|---|
| S | → | NP VP | [.80] |
| S | → | Aux NP VP | [.15] |
| S | → | VP | [.05] |
| NP | → | Pronoun | [.35] |
| NP | → | Proper-Noun | [.30] |
| NP | → | Det Nominal | [.20] |
| NP | → | Nominal | [.15] |
| Nominal | → | Noun | [.75] |
| Nominal | → | Nominal Noun | [.20] |
| Nominal | → | Nominal PP | [.05] |
| VP | → | Verb | [.35] |
| VP | → | Verb NP | [.20] |
| VP | → | Verb NP PP | [.10] |
| VP | → | Verb PP | [.15] |
| VP | → | Verb NP NP | [.05] |
| VP | → | VP PP | [.15] |
| PP | → | Prep NP | [1.0] |

Also for all Vocabulary items



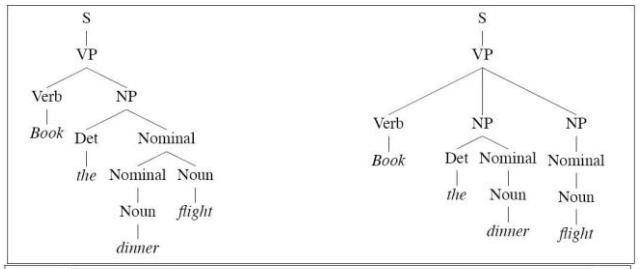
## Computing Probabilities

| | | | |
|---|---|---|---|
| S | → | NP, VP | [.80] |
| S | → | VP | [.05] |
| VP | → | Verb | [.35] |
| Verb | → | *stop* | [.02] |
| LHS | → | RHS | |

$$P(T,S) = \prod_{i=1}^{n} P(RHS_i \mid LHS_i)$$

*Stop!*

$$P(T,S) = .05 * .35 * .02 = .00035$$




| Rules | | | P | Rules | | | P |
|---|---|---|---|---|---|---|---|
| S | → | VP | .05 | S | → | VP | .05 |
| VP | → | Verb NP | .20 | VP | → | Verb NP NP | .10 |
| NP | → | Det Nominal | .20 | NP | → | Det Nominal | .20 |
| Nominal | → | Nominal Noun | .20 | NP | → | Nominal | .15 |
| Nominal | → | Noun | .75 | Nominal | → | Noun | .75 |
| | | | | Nominal | → | Noun | .75 |
| Verb | → | book | .30 | Verb | → | book | .30 |
| Det | → | the | .60 | Det | → | the | .60 |
| Noun | → | dinner | .10 | Noun | → | dinner | .10 |
| Noun | → | flights | .40 | Noun | → | flights | .40 |

## Computing Probabilities

$$P(T_{left}) = .05*.20*.20*.20*.75*.30*.60*.10*.40 = 2.2x10^{-6}$$

$$P(T_{right}) = .05*.10*.20*.15*.75*.75*.30*.60*.10*.40 = 6.1x10^{-7}$$

## Verb Subcategorization Frames

- Each verb has a unique meaning associated with the event or state it is describing or referencing
- This meaning is intrinsically linked to the number of participants in the event or state
- Verbs are typically divided into classes based on the number of participants, 1, 2 or 3.

## One participant

- Intransitive
  - *John slept until noon.*
    sleep(John)
  - *Mary laughed hysterically.*
    laugh(Mary)
  - *Jill cried copiously.*
    cry(Jill)

## Two participants

- Transitive
  - *John fixed the clock.*
    fix(John, clock)
  - *Mary built a house.*
  - build(Mary, house)
  - *Jill cut the bread.*
  - Cut(Jill,bread)


## Three participants

- Ditransitive
  - *John gave Mary a solitaire.*
    give(John,Mary,solitaire)
  - *Mary sent Jill a package.*
    send(Mary,Jill,package)
  - *Jill put a book on the table.*
    put(Jill,book,table)

## Simple Context Free Grammar in BNF

| | | | |
|---|---|---|---|
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| NP | → | Det Nominal | [.20] |
| NP | → | Nominal | [.15] |
| Nominal | → | Noun | [.75] |
| Nominal | → | Nominal Noun | [.20] |
| Nominal | → | Nominal PP | [.05] |
| VP | → | Verb | [.87] *{sleep, cry, laugh}* |
| VP | → | Verb NP | [.03] |
| VP | → | Verb NP PP | [.00] |
| VP | → | Verb PP | [.05] |
| VP | → | Verb NP NP | [.00] |
| VP | → | VP PP | [.05] |
| PP | → | Prep NP | [1.0] |



## Simple Context Free Grammar in BNF

| | | | |
|---|---|---|---|
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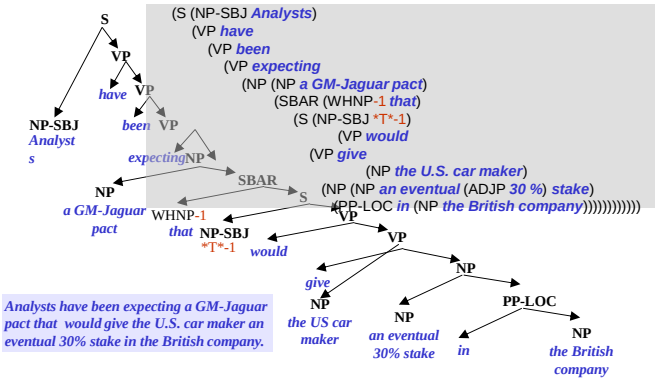
| NP | → | Pronoun | [.35] |
| NP | → | Proper-Noun | [.30] |
| NP | → | Det Nominal | [.20] |
| NP | → | Nominal | [.15] |
| Nominal | → | Noun | [.75] |
| Nominal | → | Nominal Noun | [.20] |
| Nominal | → | Nominal PP | [.05] |
| VP | → | Verb | [.30] |
| VP | → | Verb NP | [.55] *{break,split,crack..}* |
| VP | → | Verb NP PP | [.05] |
| VP | → | Verb PP | [.05] |
| VP | → | Verb NP NP | [.00] |
| VP | → | VP PP | [.05] |
| PP | → | Prep NP | [1.0] |

## Training data for Statistical Parsers

- How does the computer learn the probabilities?
- Lots and lots of parsed sentences
- 50K WSJ sentences

## A TreeBanked Sentence






## Headlines

- Police Begin Campaign To Run Down Jaywalkers
- Iraqi Head Seeks Arms
- Teacher Strikes Idle Kids
- Miners Refuse To Work After Death
- Juvenile Court To Try Shooting Defendant



## What else?

Thematic roles are consistent across different syntactic realizations: ***canonical form***

**Joe broke the projector.**

Syntax: $NP_{SUB}$ V $NP_{OBJ}$

Thematic Roles: AGENT REL PATIENT

Thematic roles are consistent across different syntactic realizations: ***canonical form***

**Joe broke the projector.**

Syntax: $NP_{SUB}$ V $NP_{OBJ}$

Thematic Roles: AGENT REL PATIENT

Thematic Roles: PATIENT REL

Syntax: $NP_{SUB}$ V

**The projector broke.**

Thematic roles are consistent across different syntactic realizations: ***canonical form***

**Joe broke the projector.**

Syntax: $NP_{SUB}$ V $NP_{OBJ}$

Thematic Roles: AGENT REL PATIENT

Thematic Roles: PATIENT REL

Syntax: $NP_{SUB}$ V

**The projector was broken.**

Thematic roles are consistent across different syntactic realizations: ***canonical form***

**Joe broke the projector.**

Syntax: $NP_{SUB}$ V $NP_{OBJ}$

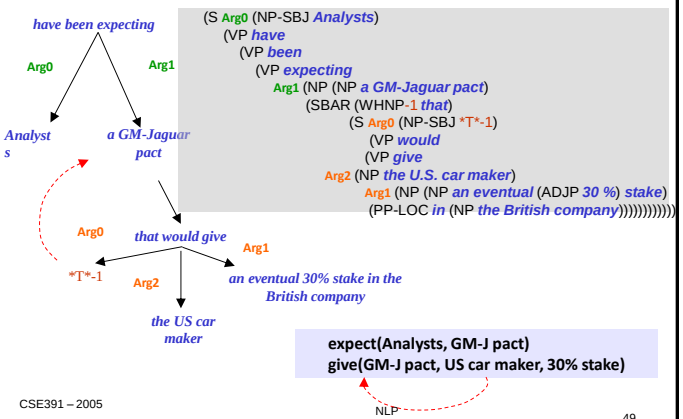
Thematic Roles: AGENT REL PATIENT

Thematic Roles: PATIENT REL AGENT

Syntax: $NP_{SUB}$ V (PP)

**The projector was broken (by Al).**

## The same sentence, PropBanked






## PropBank?

- Semantic information over the syntactically parsed (i.e. treebanked) text
- Semantic information -> predicate argument structure of a verb or a relation (**frame-based**)
- The predicate argument structure is specific to the verb or relation in question
- Seeks to
  1. provide thematic role labels across different syntactic realizations of the same verb
  2. assign general functional tags to all modifiers or adjuncts to the verb

## PB seeks to provide thematic role labels across different syntactic realizations"

- Uuuuuusually…
  - Arg0 = agent
  - Arg1 = patient
  - Arg2 = benefactive / instrument / attribute / end state
  - Arg3 = start point / benefactive / instrument / attribute
  - Arg4 = end point

## PB seeks to assign functional tags to all modifiers or adjuncts to the verb

- Variety of ArgM's:
  - TMP - when? *yesterday, 5pm on Saturday, recently*
  - LOC - where? *in the living room, on the newspaper*
  - DIR - where to/from? *down, from Antartica*
  - MNR - how? *quickly, with much enthusiasm*
  - PRP/CAU -why? *because … , so that …*
  - REC - himself, themselves, each other
  - ADV - hodge-podge, miscellaneous, "nothing-fits!"
  - PRD - this argument refers to or modifies another

## Thematic roles - Saeed

- AGENT
  - Initiator of action, capable of volition
  - *Hentry cooked the books.*
  - *The horse jumped the fence.*
- PATIENT
  - Affected by action, undergoes change of state
  - *David trimmed his beard.*
  - *The sun melted the butter.*



## Thematic Roles (cont.)

- THEME
  - Entity moving, or being "located"
  - *Paola threw the ball.*
  - *The cup is on the table.*
- EXPERIENCER
  - Perceives action but not in control
  - *Martha felt ill.*
  - *Chris saw the pen drop.*



## Thematic Roles (cont.)

- BENEFICIARY
  - For whose benefit action is performed
  - *They baked me a cake.*
  - *The Smiths rented an apartment for their son.*
- INSTRUMENT
  - Intermediary/means used to perform an action
  - *He shot the wounded buffalo with a rifle.*
  - *The surgeon performed the incision with a scalpel.*



## Thematic Roles (cont.)

- LOCATION – place of object or action
  - *The monster was hiding in the anxiety closet.*
  - *The band played on the state.*
- SOURCE – starting point
  - *The plane took off from Nairobi.*
  - *We heard the rumor from a friend.*
- GOAL – ending point
  - *Martha handed her license to the policeman.*
  - *Alison lectured to the class.*

## Thematic role assignments

- *[Martha] handed [her license] [to the policeman.]*
- *[Al] lectured [to the class].*
- *[Al] lectured [to the class][on semantics].*
- *[Al] lectured [the class].*
- *[Martha] raised [the car] [with a jack.]*
- *[Martha] crashed [the car] [with a resounding boom.]*



## Thematic role assignments

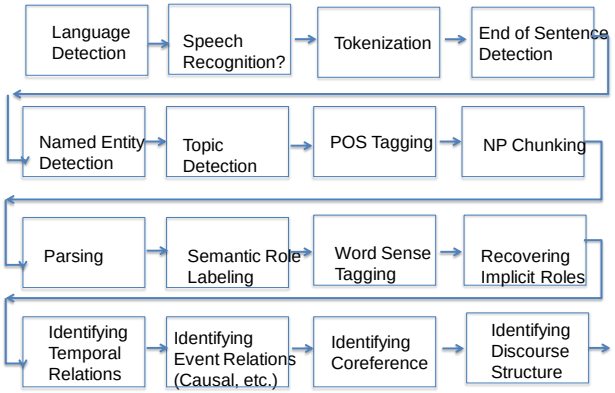
- *[Martha$_{AGENT}$] handed [her license$_{THEME}$] [to the policeman.$_{GOAL}$]*
- *[Al$_{AGENT}$] lectured [to the class$_{GOAL}$].*
- *[Al$_{AGENT}$] lectured [to the class$_{GOAL}$][on semantics$_{THEME}$].*
- *[Al$_{AGENT}$] lectured [the class$_{PATIENT}$].*
- *[Martha$_{AGENT}$] raised [the car$_{THEME}$] [with a jack.$_{INSTRUMENT}$]*
- *[Martha$_{AGENT}$] crashed [the car$_{PATIENT}$] [with a resounding boom.$_{ARGM\text{-}MANNER}$]*



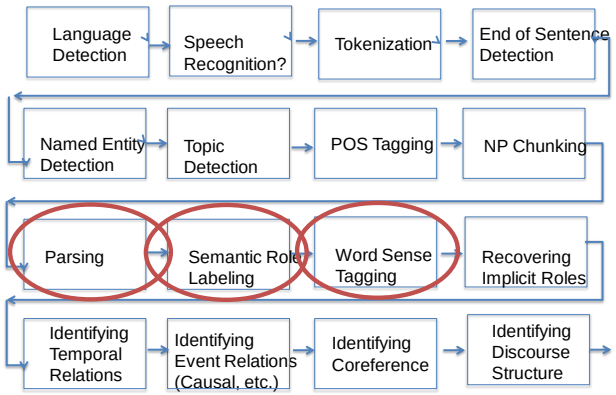
## NLP Components - Pipeline

- End of Sentence Detection – MxTerminator
- Tokenization (finding word boundaries)
- Named entity/nominal entity detection
- Topic detection
- Part-of-speech tagging - MxPOST
- Parsing – Collins parser (or Charniak, or Klein)
- Semantic role labeling – ASSERT (Pradhan, CU)
- Sense tagging – Dmitriy Dligach

## NLP Pipeline



## NLP Pipeline




## Leave behind, leave alone…

– ***John left his keys at the restaurant.***

*We left behind all our cares during our vacation.*

*They were told to leave off their coats.*

*Leave the young fawn alone*.

***Leave the nature park just as you found it.***

*I left my shoes on when I entered their house.*

*When she put away the food she left out the pie.*

*Let's leave enough time to visit the museum.*

***He'll leave the decision to his wife.***

*When he died he left the farm to his wife.*

*I'm leaving our telephone and address with you.*