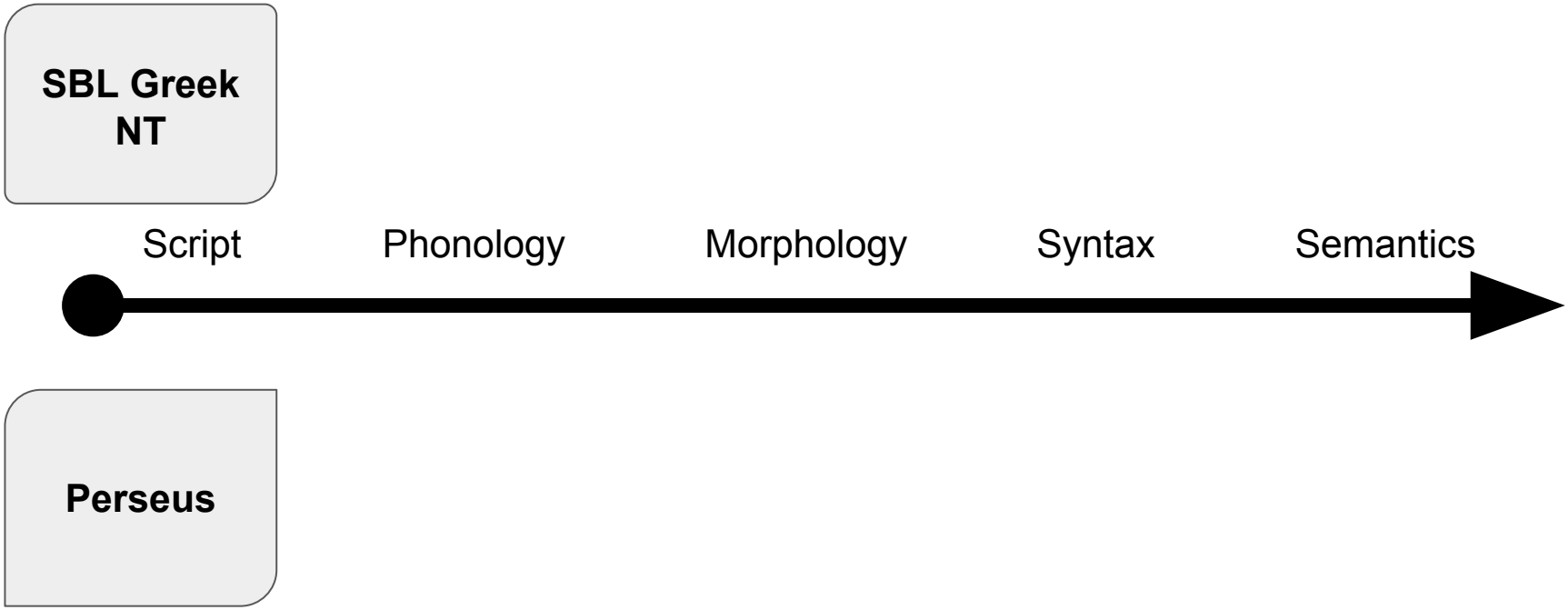
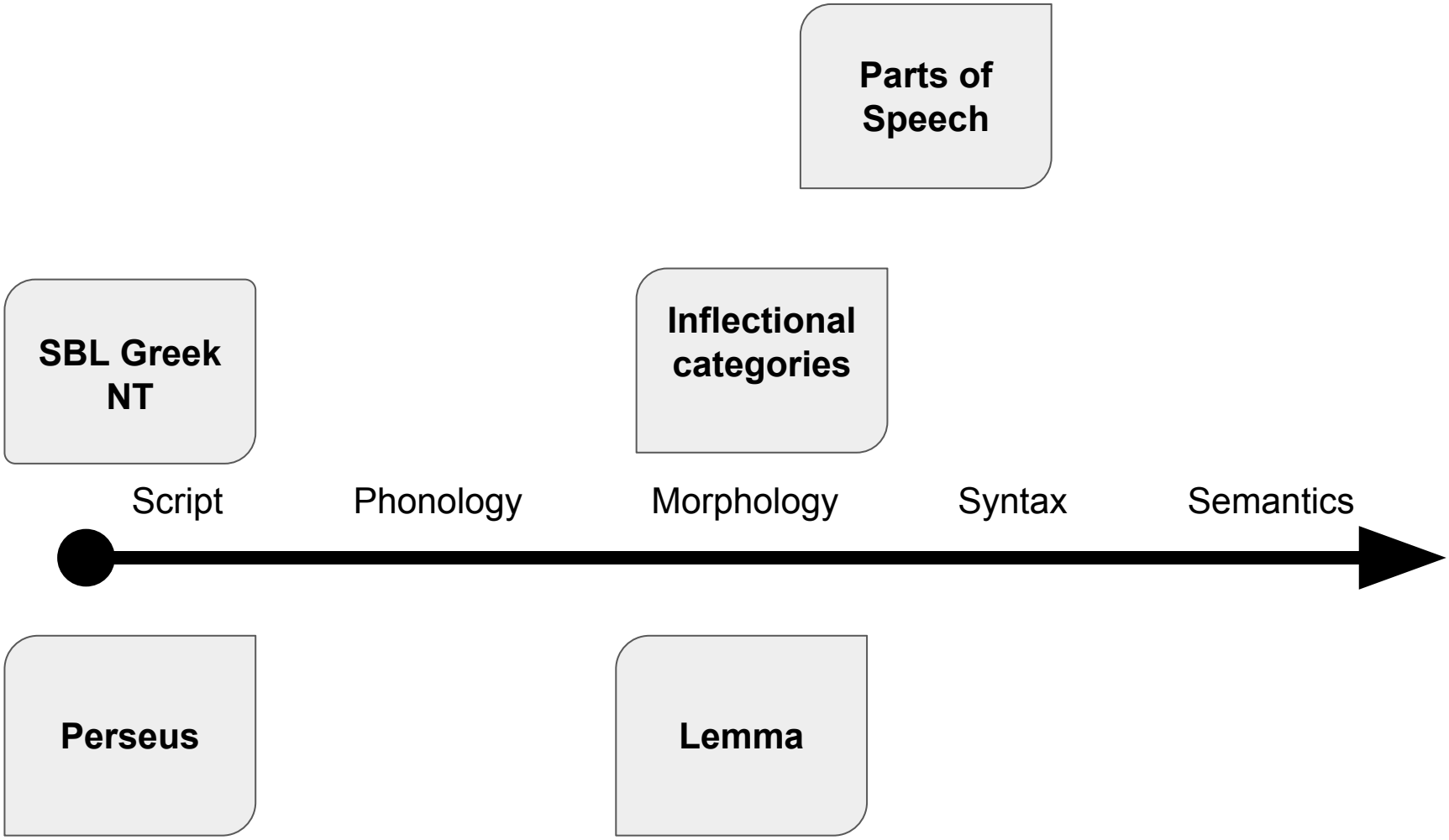
Towards a Comprehensive Computational System for Grammatical Analysis of Ancient Corpora

Scott Fleischman and Josh Westbury
Global Education and Research Technology Session


SBL Greek NT
Script
Phonology
Morphology
Syntax
Semantics
Perseus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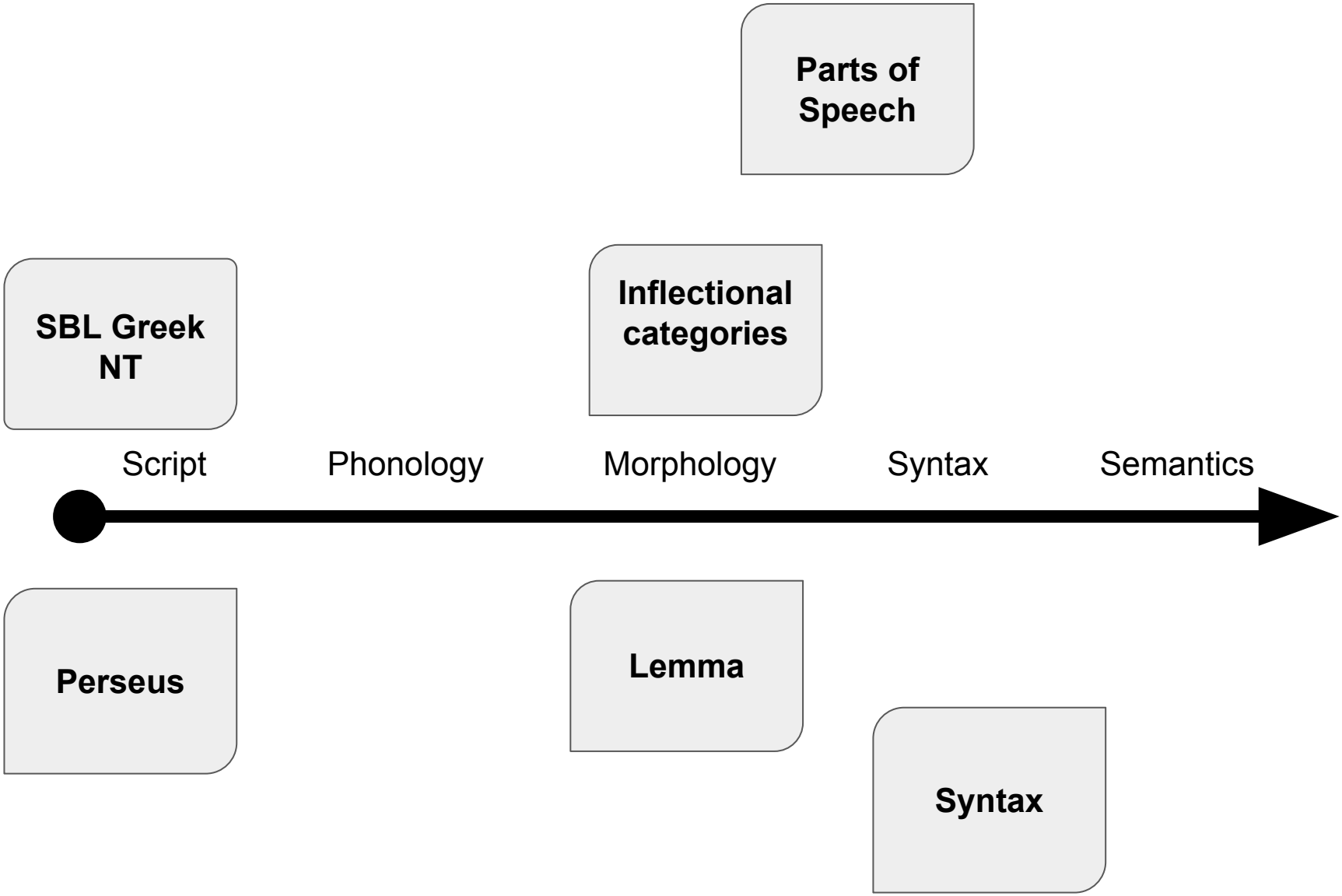
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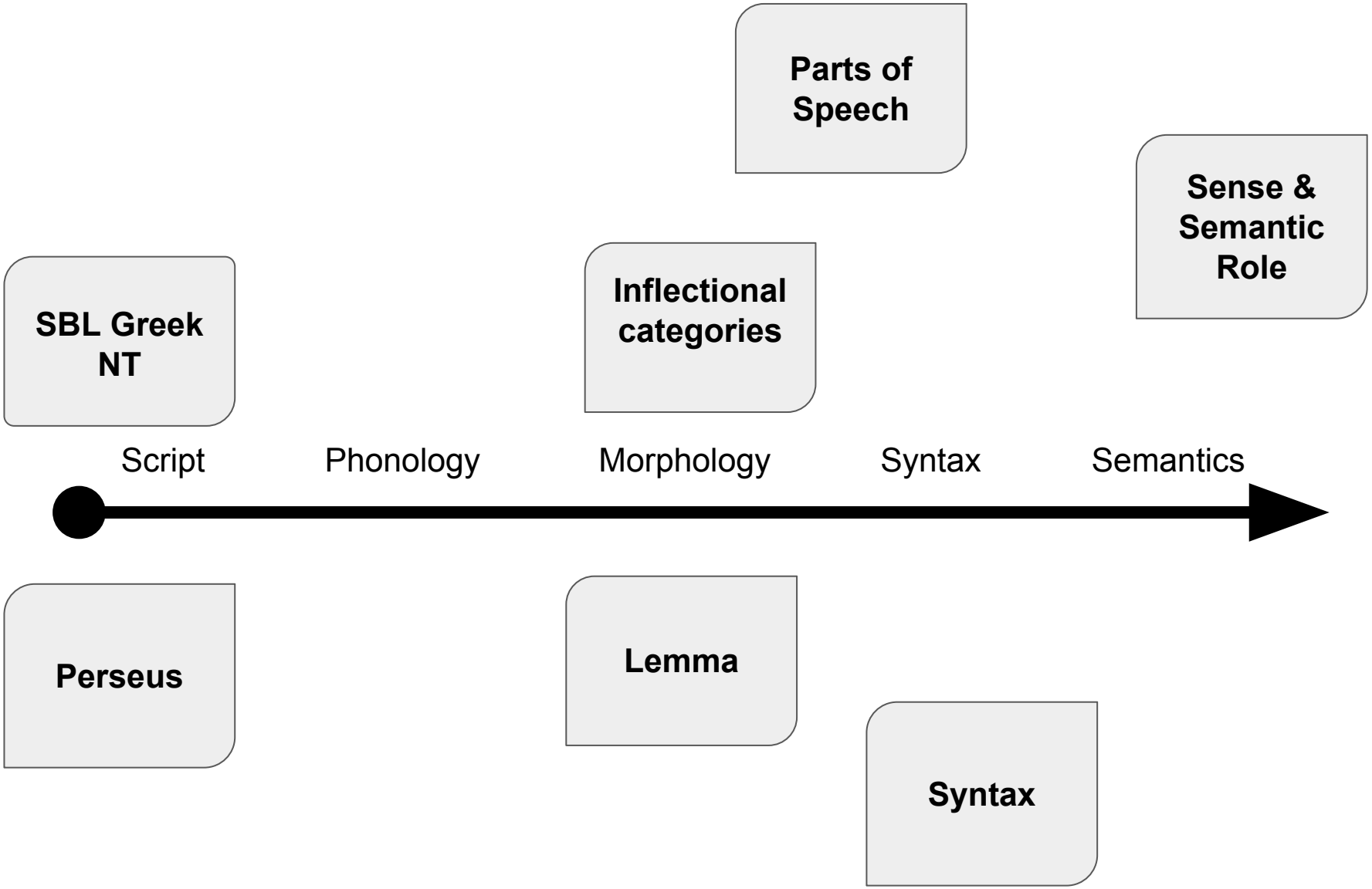
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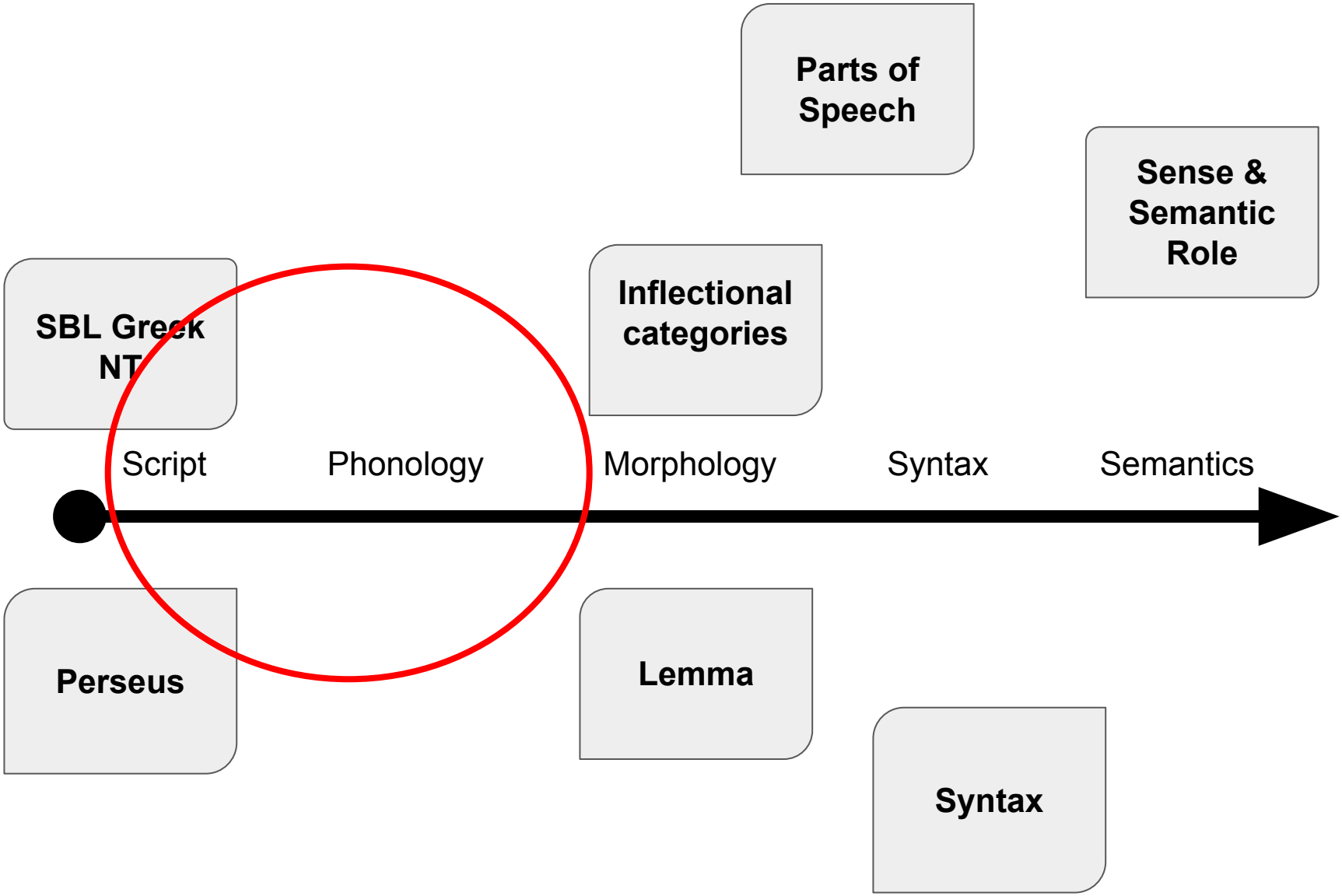
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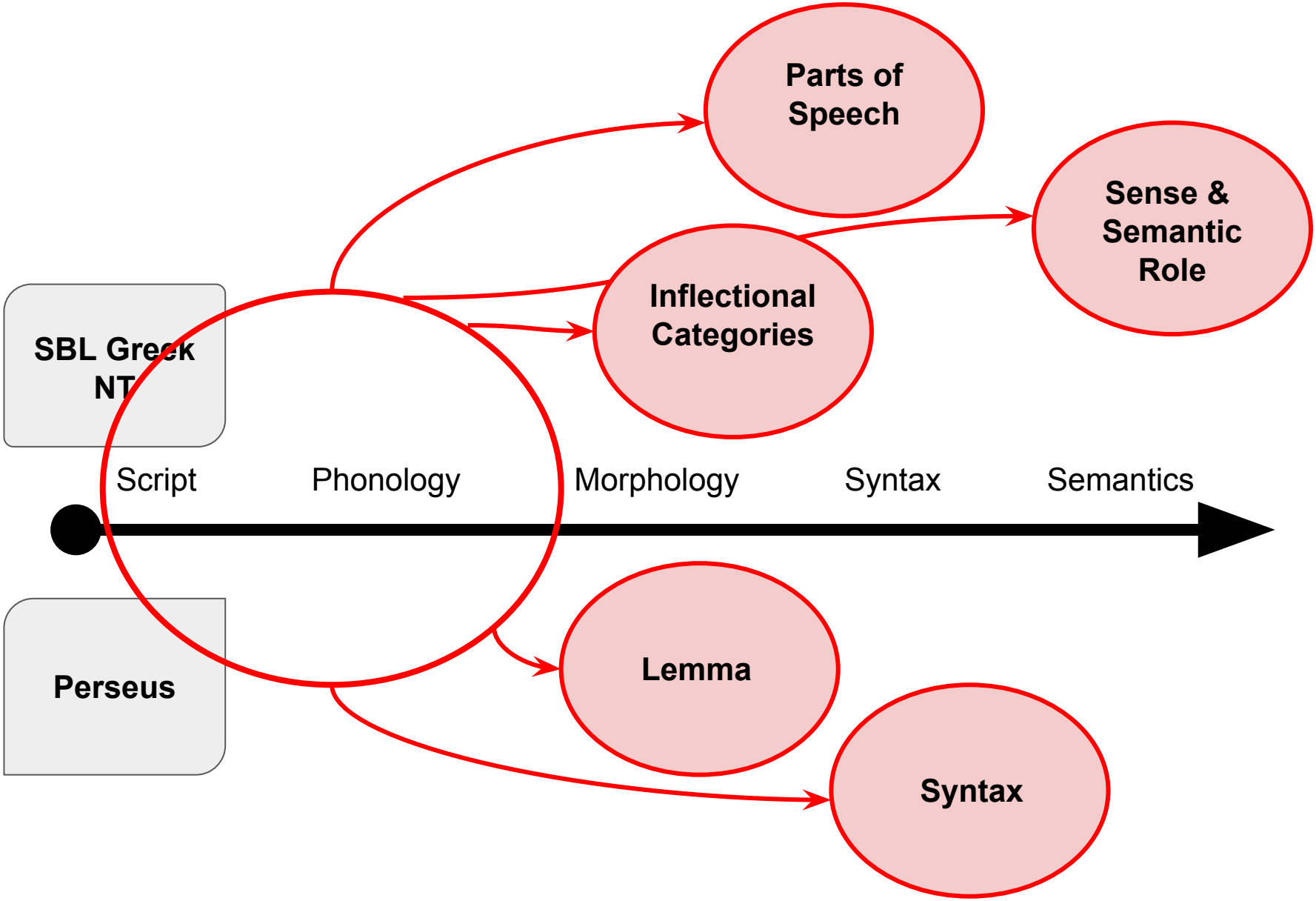
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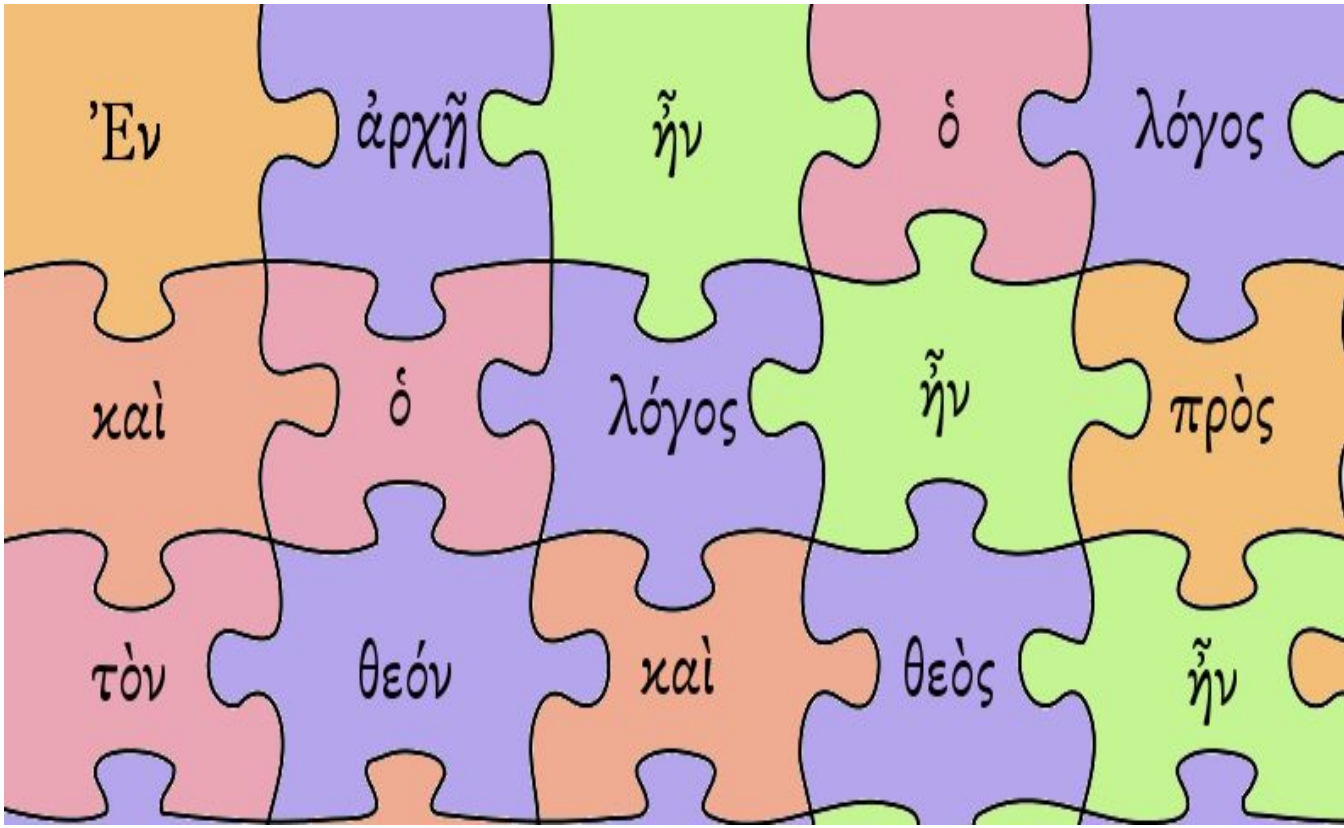
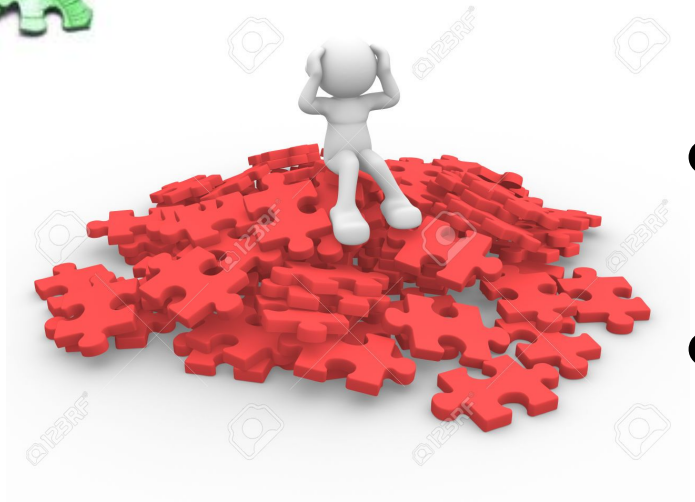
Existing Approaches

- Manual
- Time Consuming
- Static
- Isolated

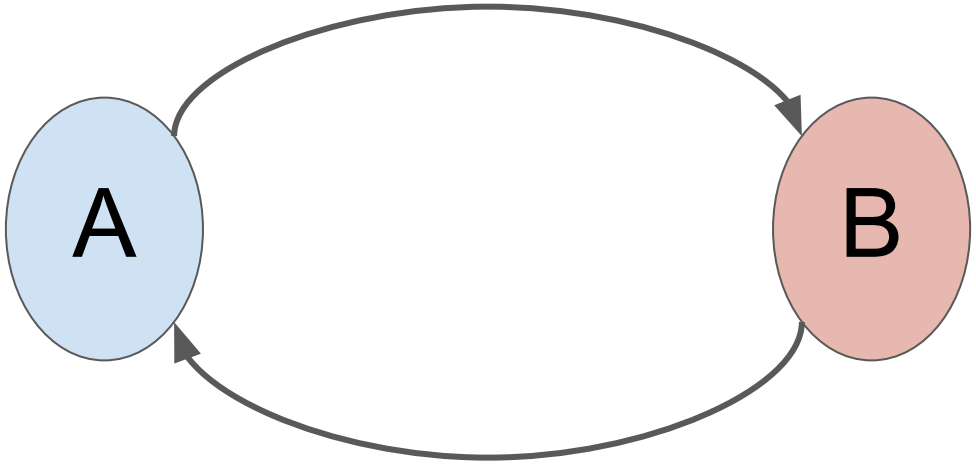




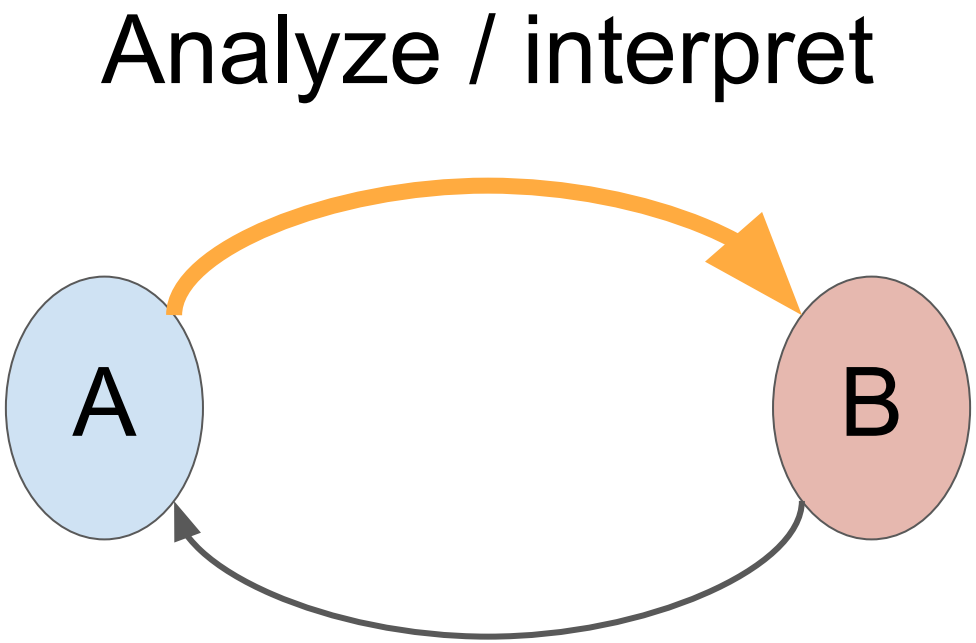
Our Approach

- Automated and Human Directed
- Consistent
- Efficient
- Dynamic
- Unified

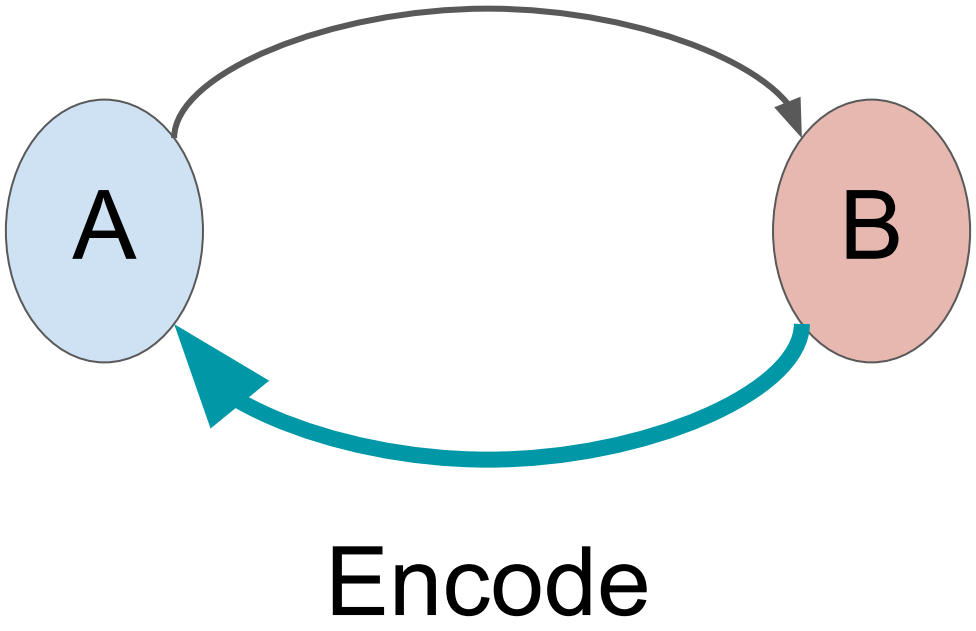
Analysis by transformation



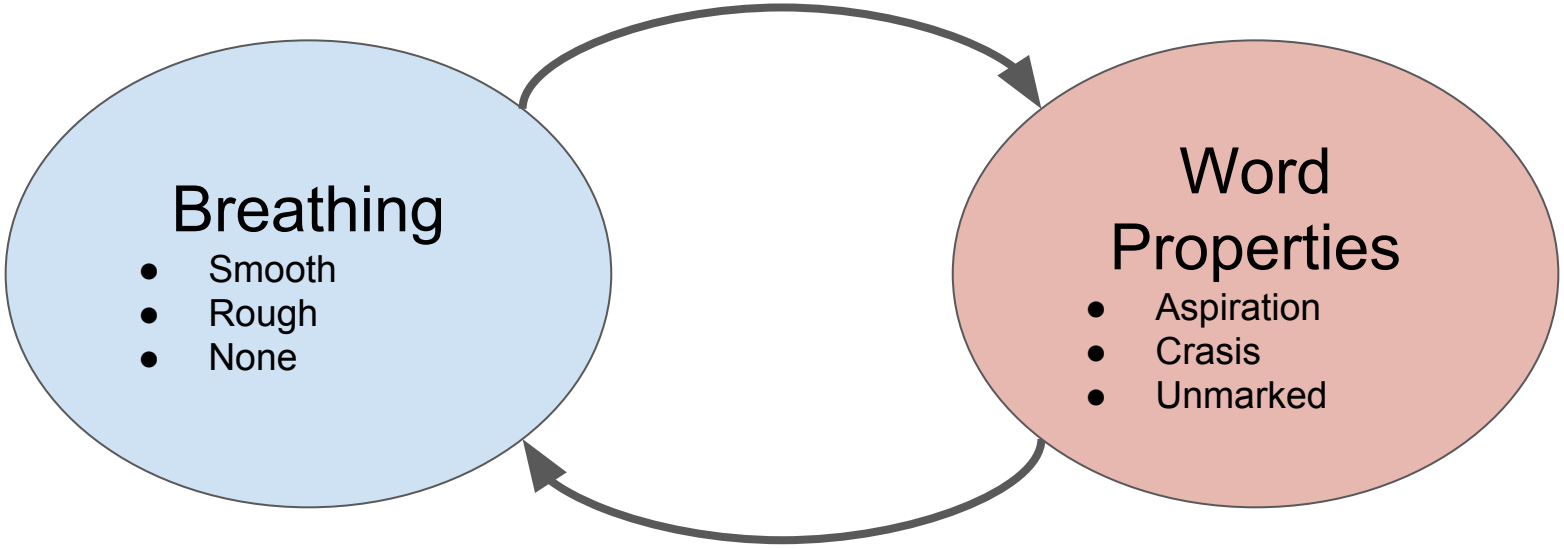
Analysis by transformation



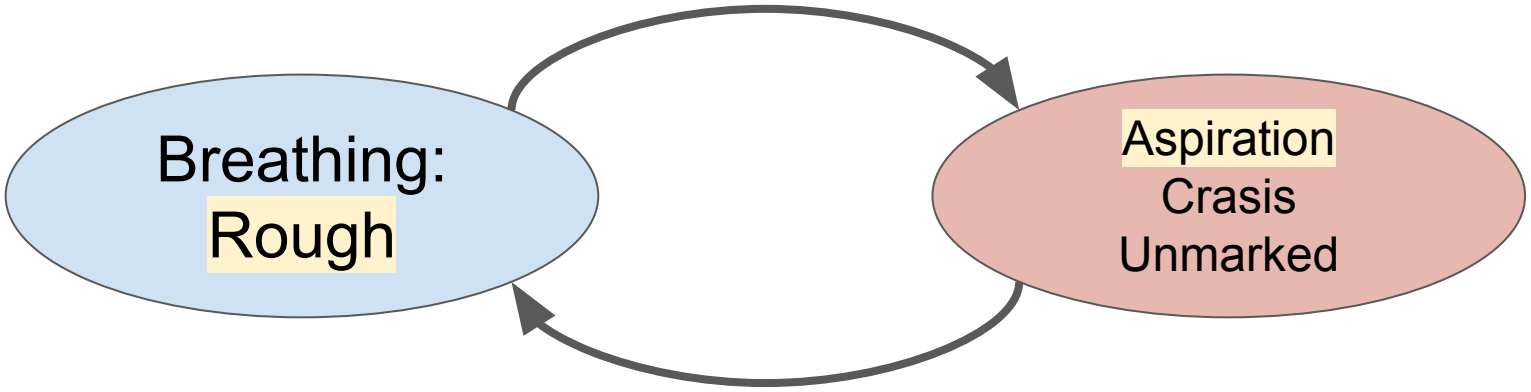
Analysis by transformation



Example: Breathing



Example Summary: Breathing



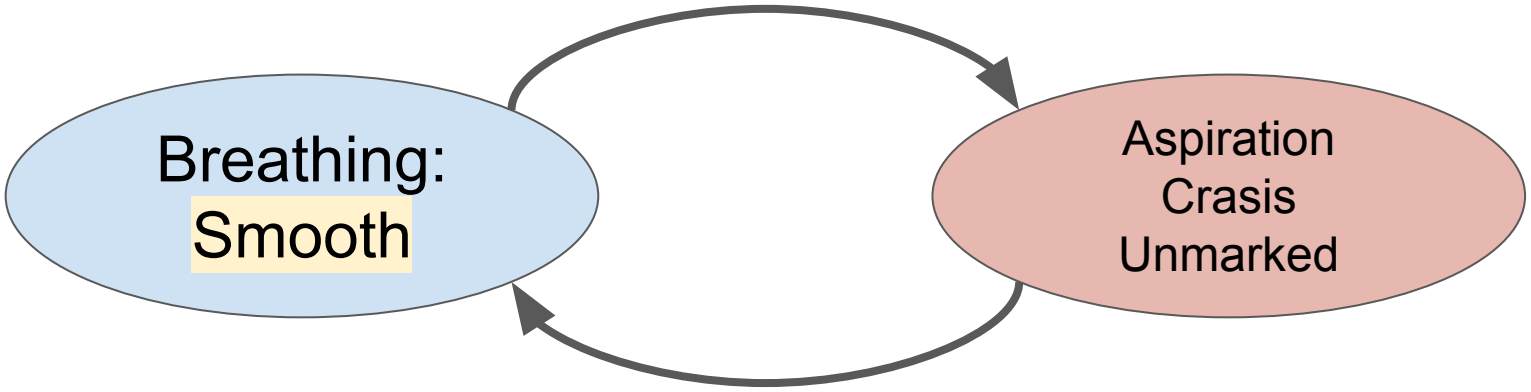
ἡμων ↔ ημων + aspiration

αὐτου ↔ αυτου

κἀγω ↔ καγω + crasis

Αββα ↔ Αββα + unmarked

Example Summary: Breathing



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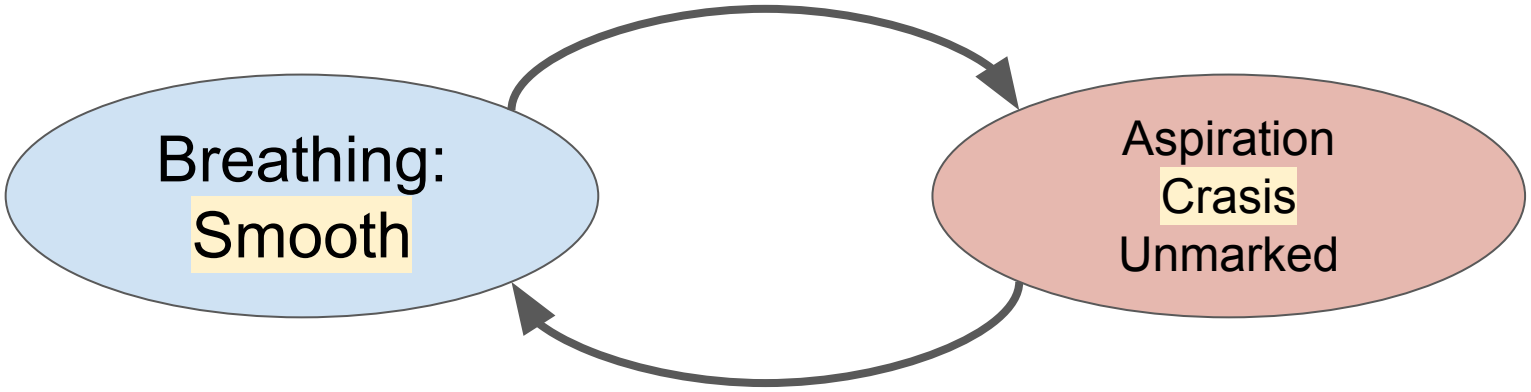

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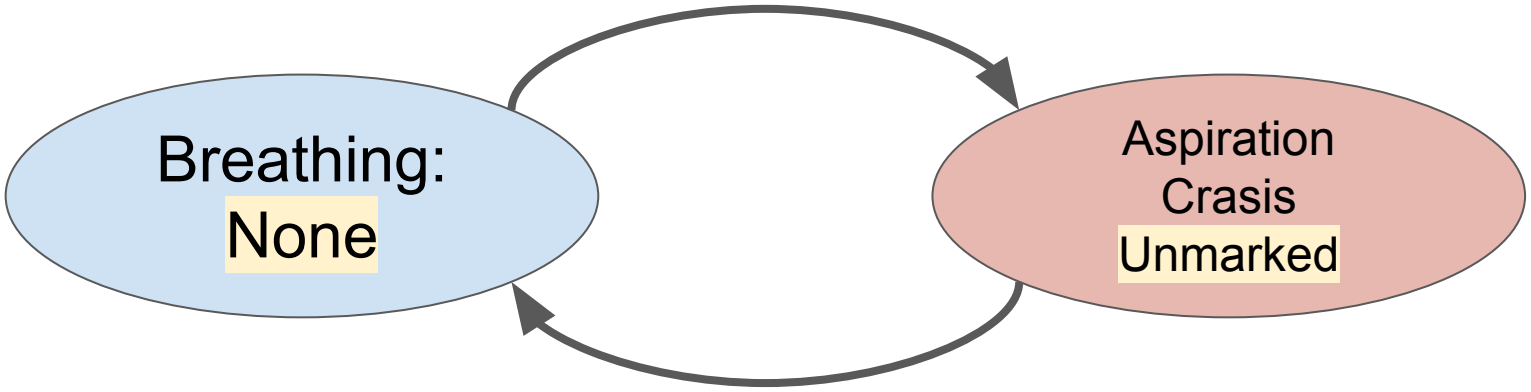

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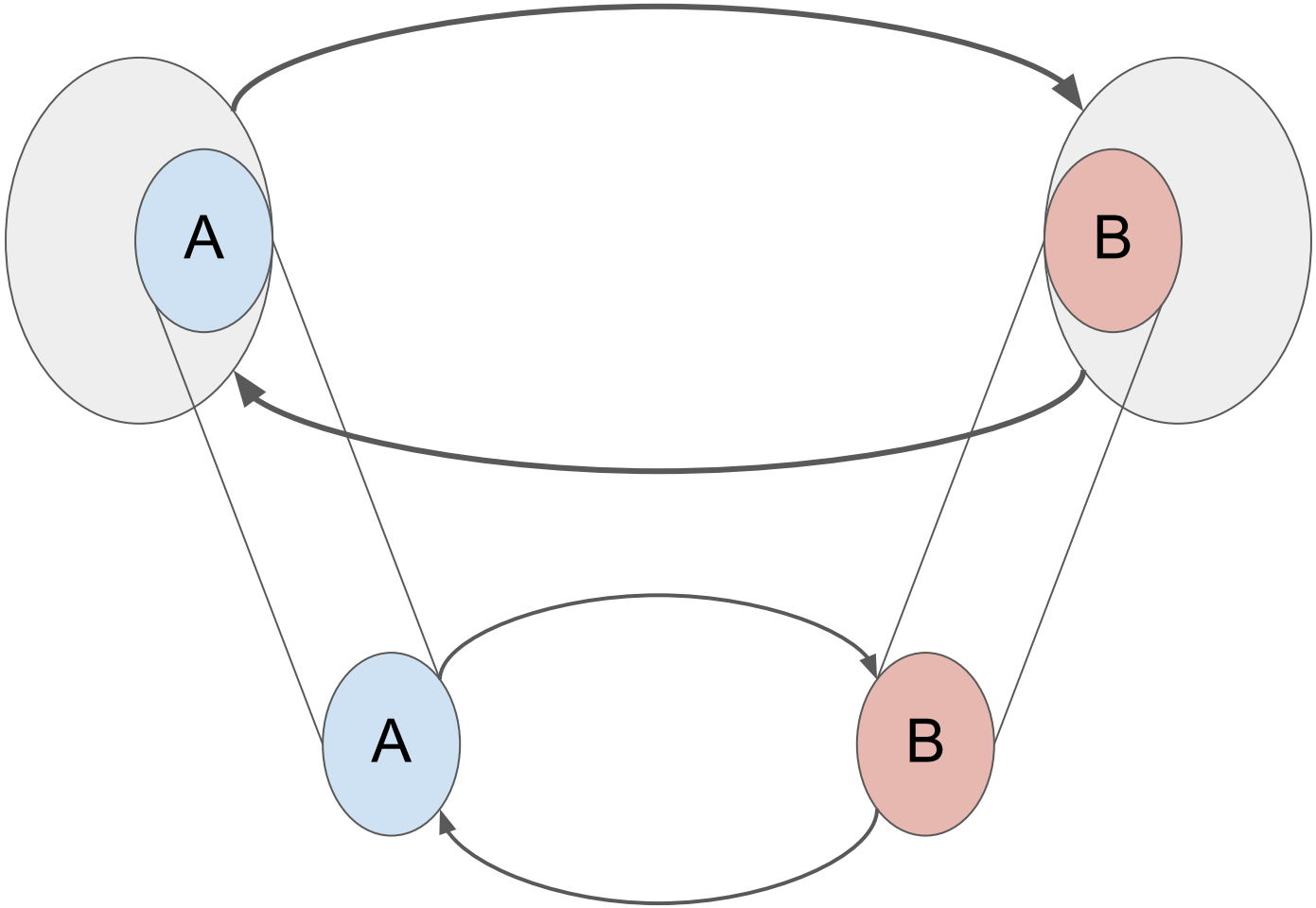
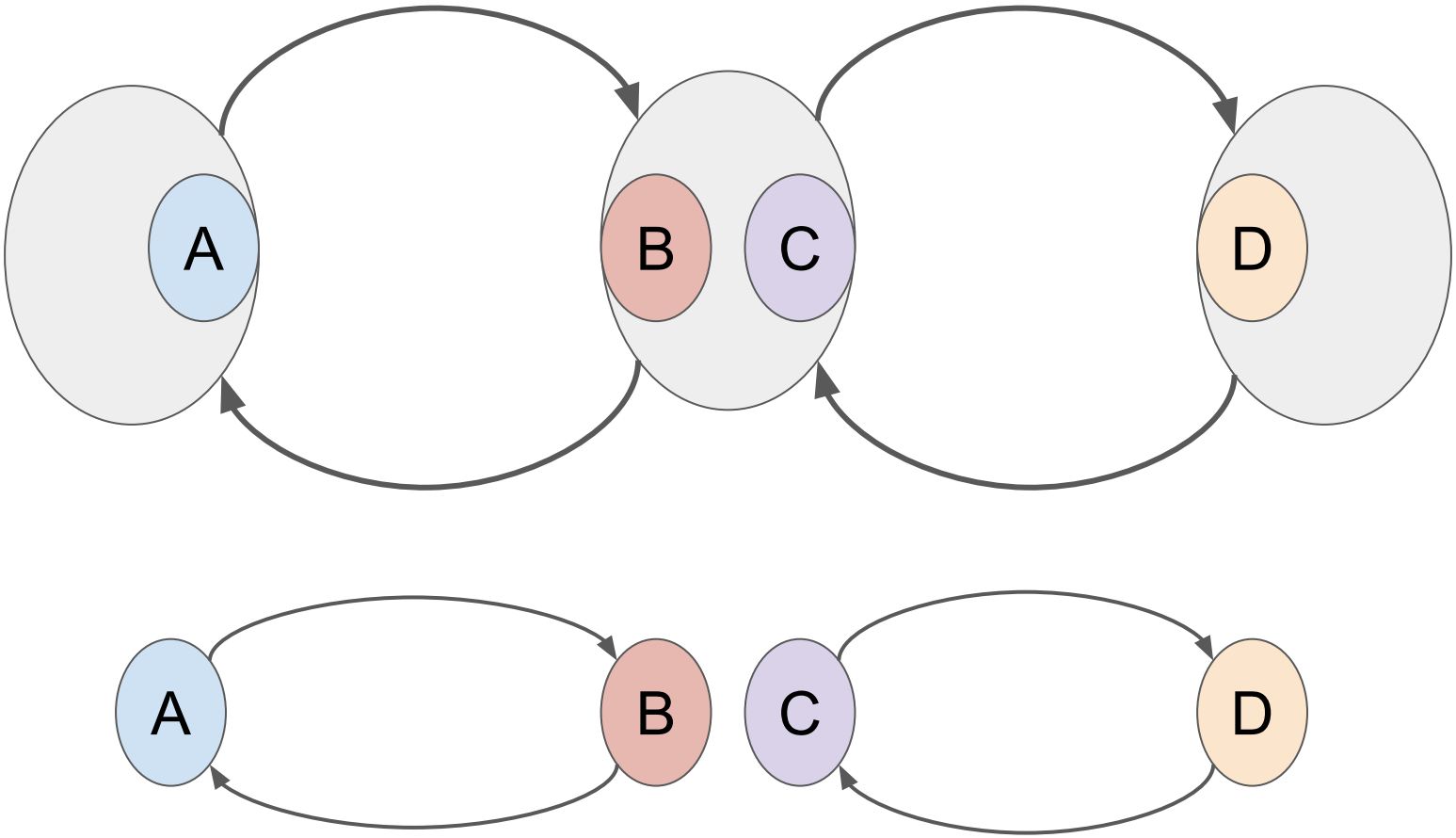
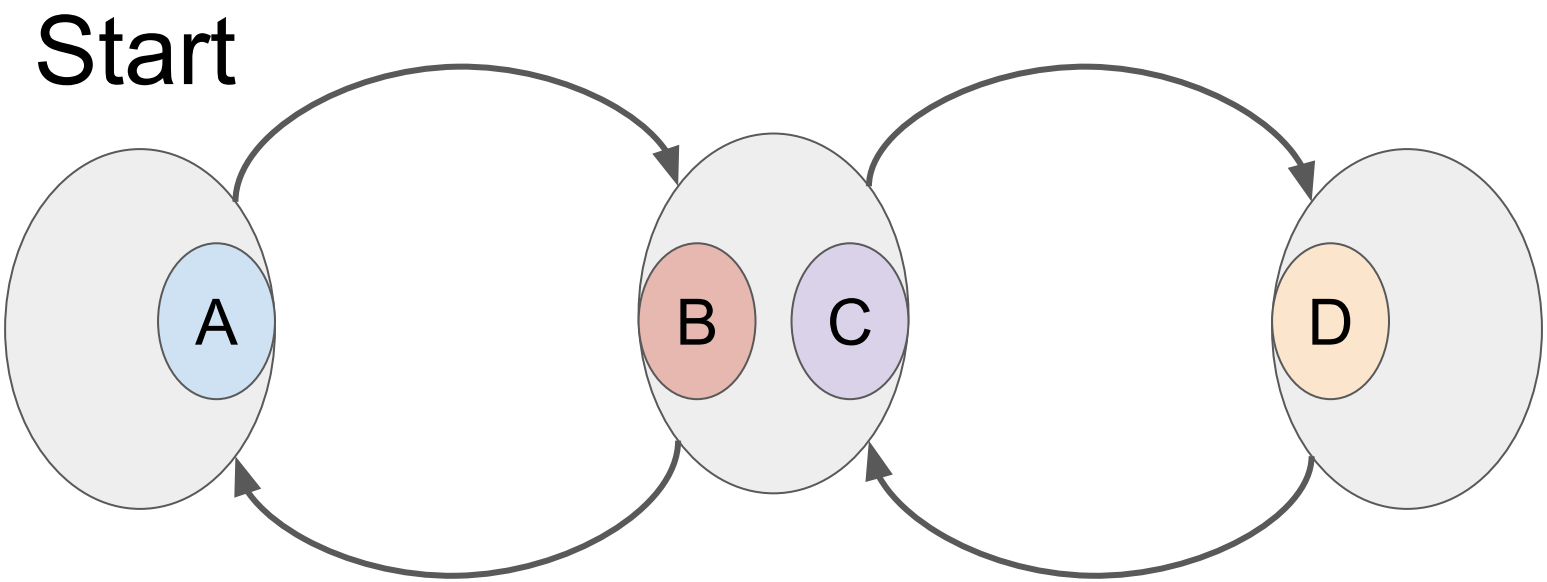
Contextualization of analysis/transformation



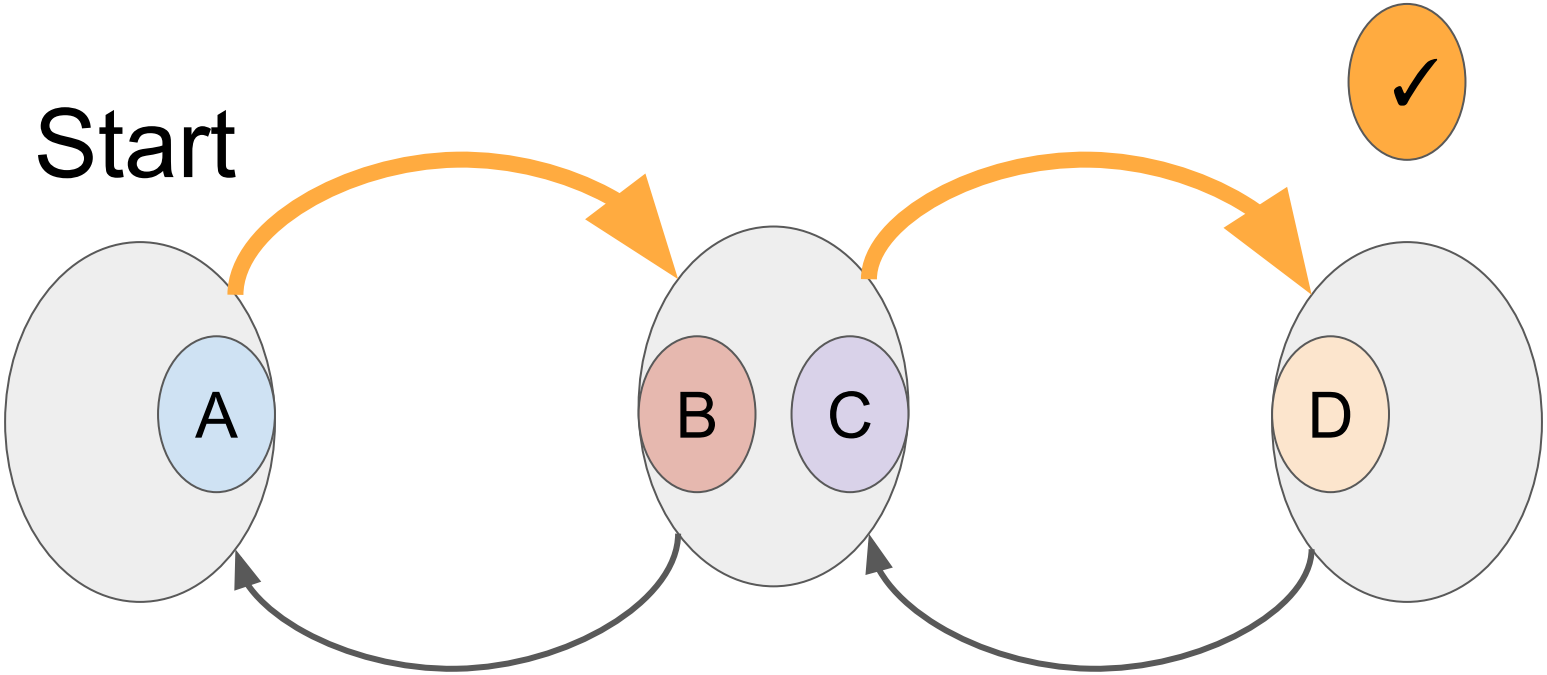
Composition of analyses/transformations



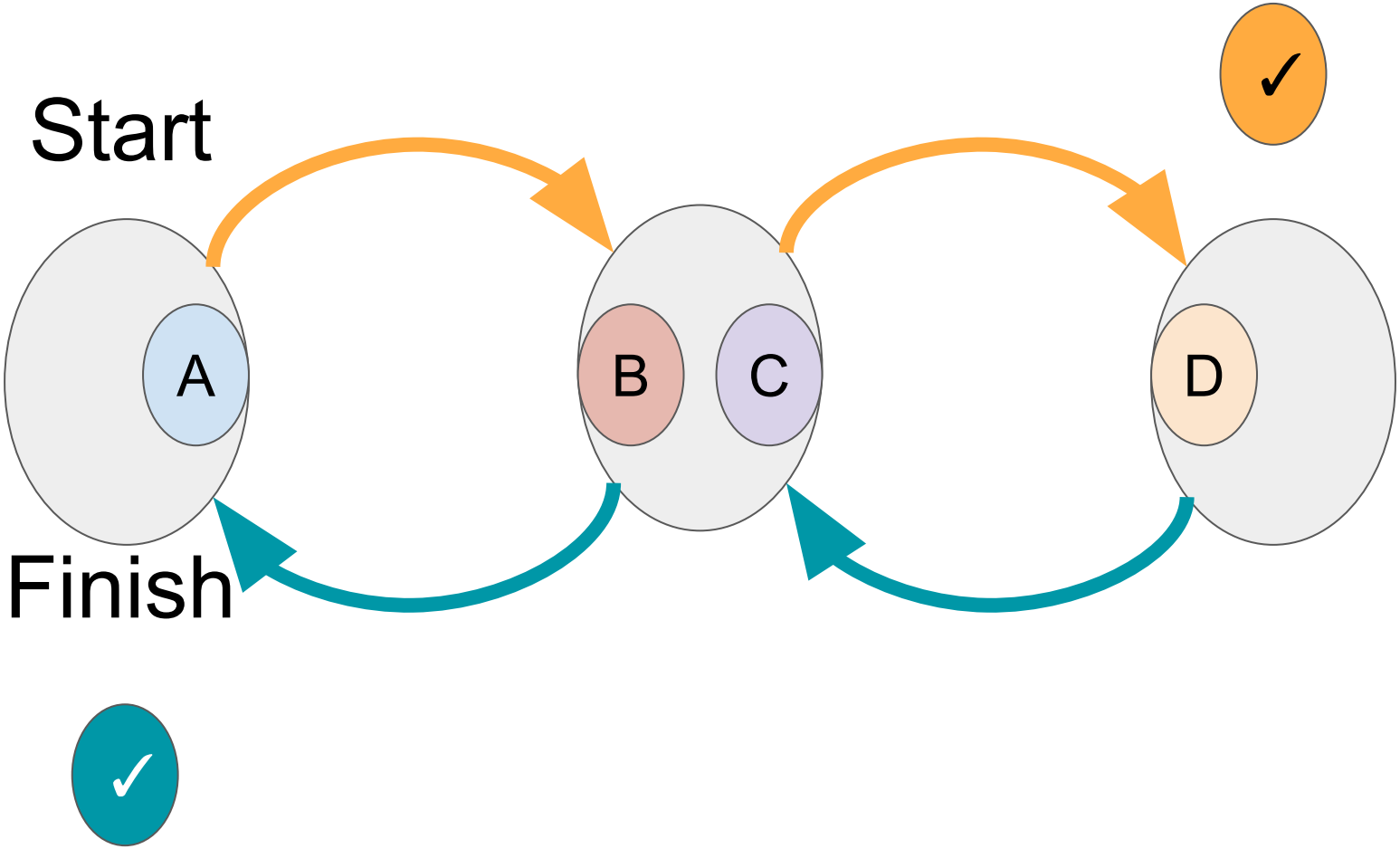
Validation analyses/transformations



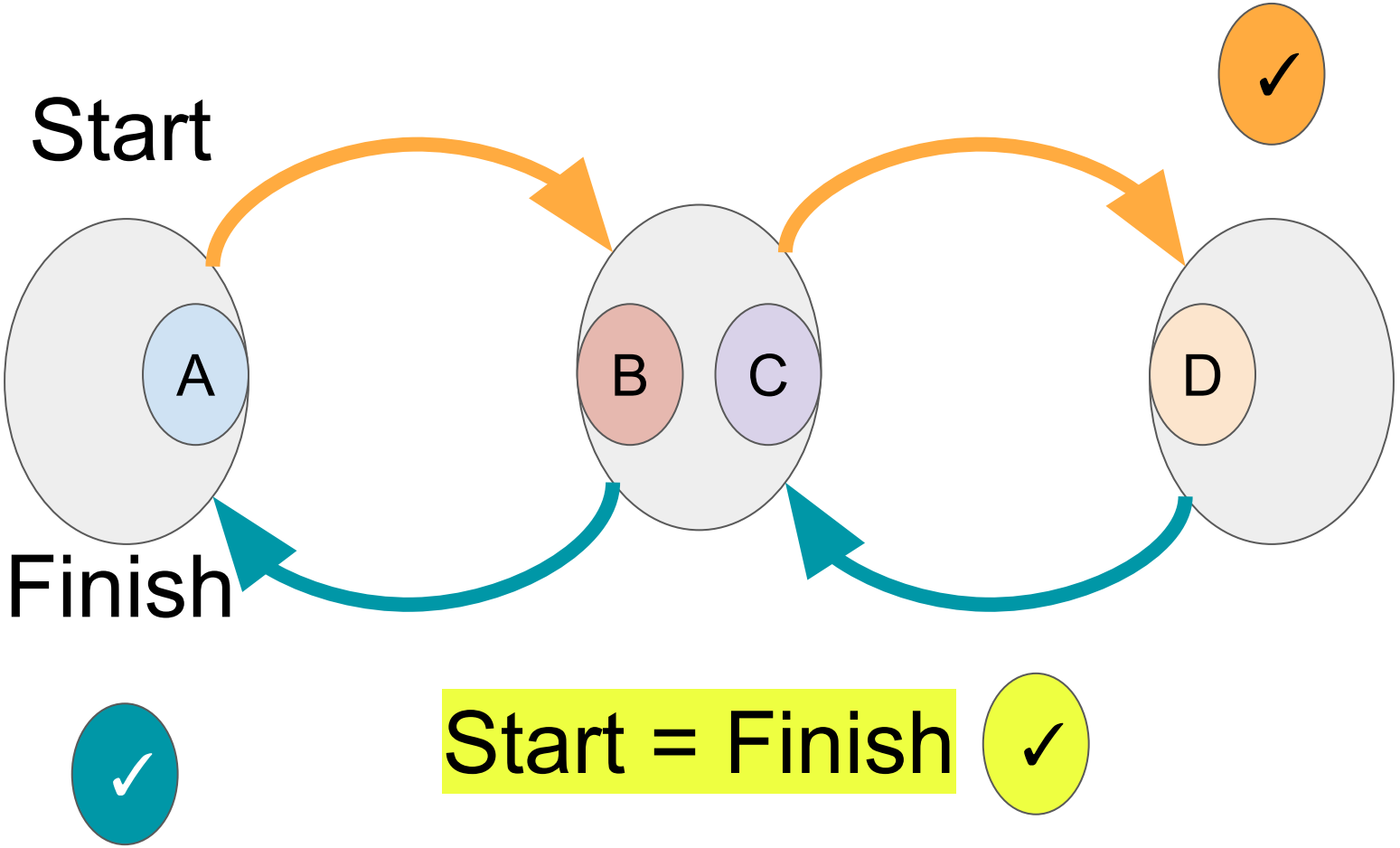
Validation analyses/transformations: 1/3



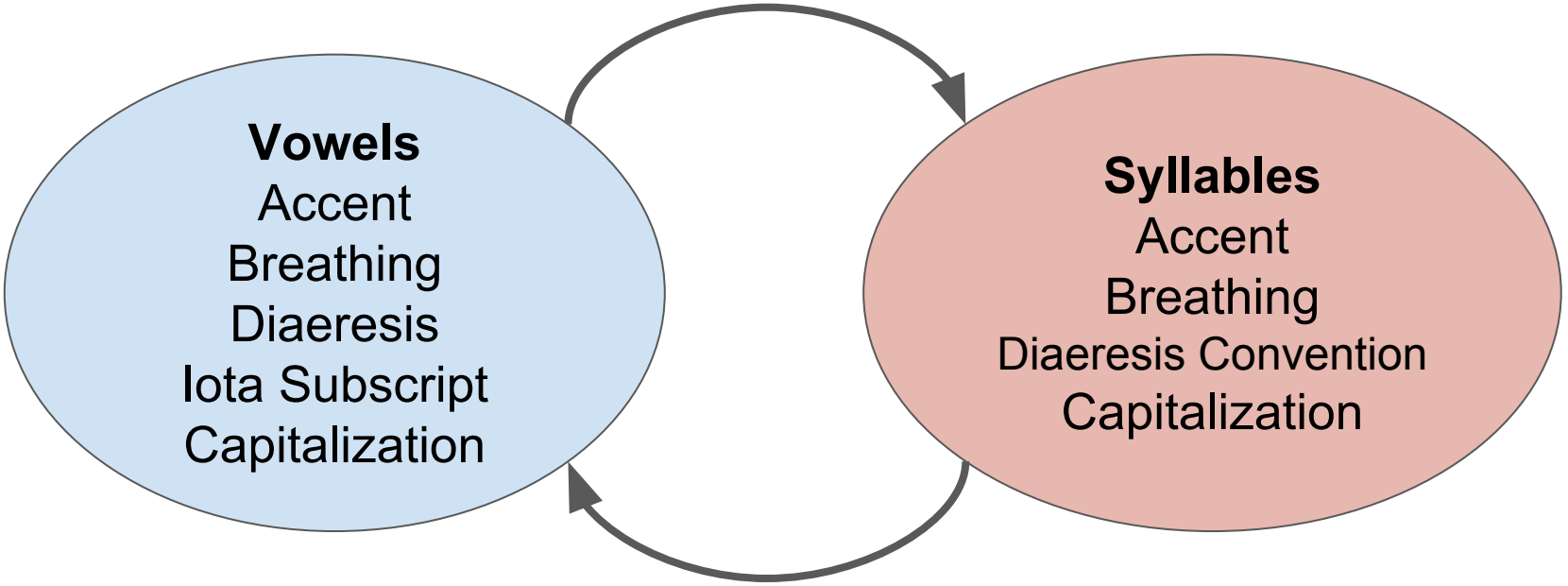
Validation analyses/transformations: 2/3



Validation analyses/transformations: 3/3



Example: Vowels ↔ Syllables



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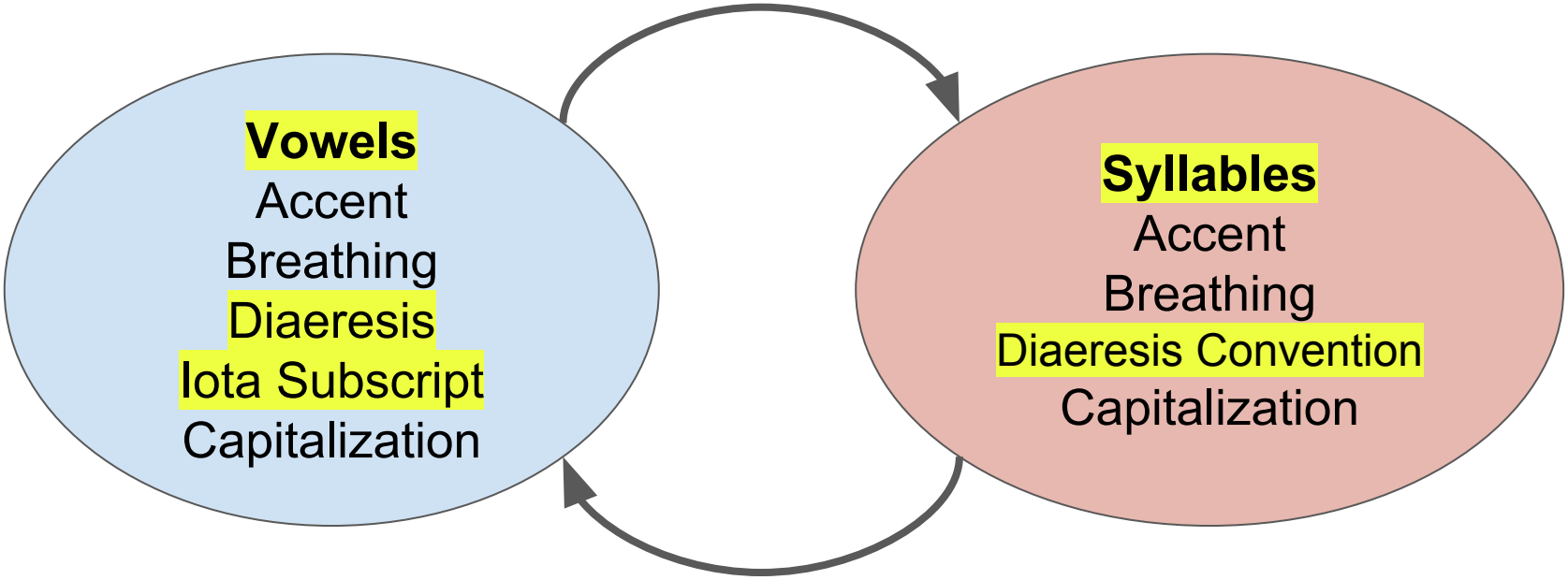
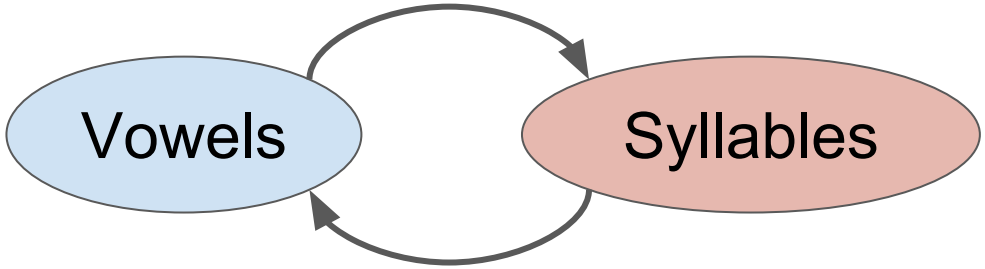
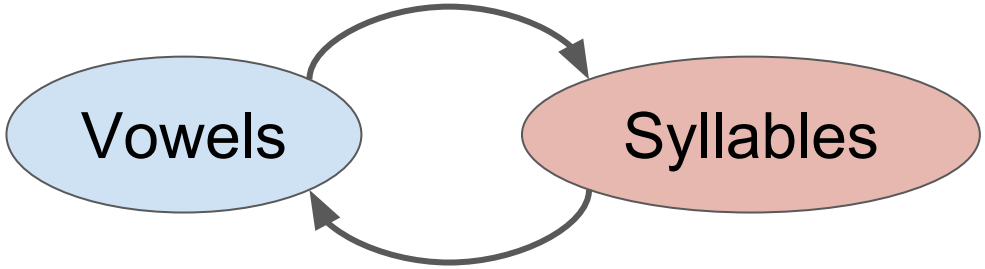




Rule: Join vowels to form diphthongs

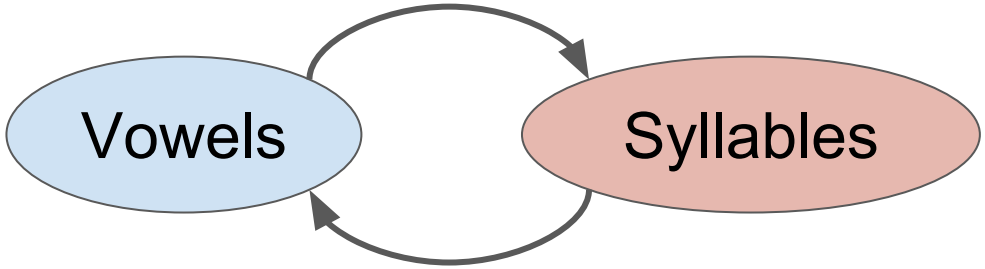
αιου ↔ αι + ου δικ**αίου**ς ↔ δικ**αί + ου**ς



Rule: Join ambiguous diphthongs on the right—no diaeresis

αυι ↔ α + υι (not αυ + ι) Δ**αυί**δ ↔ Δ**α** + **υί**δ (not Δ**αυ** + **ί**δ)

ευι ↔ ε + υι (not ευ + ι) Νιν**ευῖ**ται ↔ Νιν**ε** + **υῖ**ται (not Νιν**ευ** + **ῖ**ται)



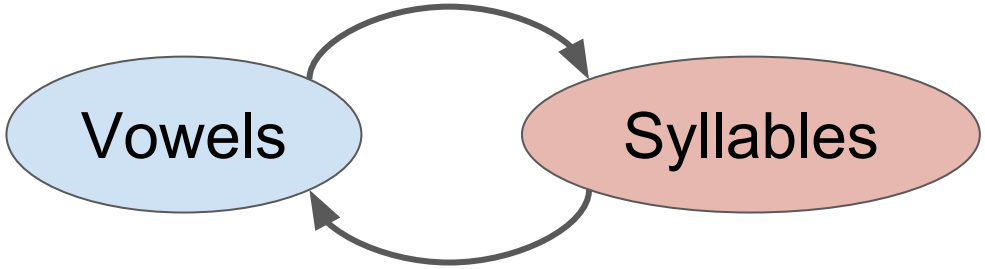
Rule: Vowels with an iota subscript are a syllable

ιῃ ↔ ι + ῃ πίῃ ↔ πί + ῃ

ἰδί + ᾳ ↔ ἰδί + ᾳ

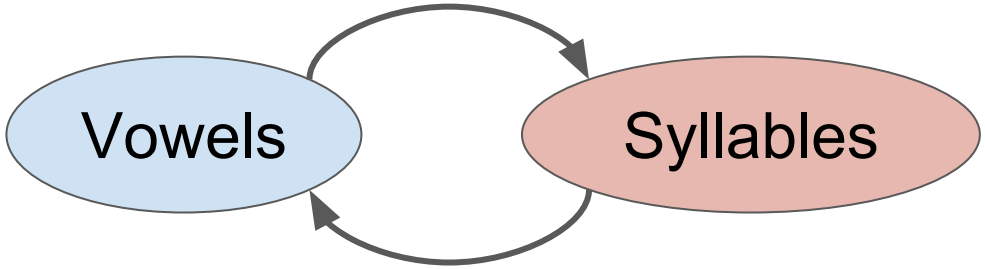
παλα + ι + ῷ ↔ παλαι + ῷ

εἰσῄ + ε + ι ↔ εἰσῄ + ει



Rule: Capital vowels with breathing on first vowel are an iota subscript syllable

Ἅι ↔ ᾷ	**Ἅι**δου ↔ **ᾷ** + δου
Ἠι ↔ ᾐ	**Ἠι**όνα ↔ **ᾐ** + όνα
Ὠι ↔ ᾠ	**Ὠι**δείῳ ↔ **ᾠ** + δείῳ



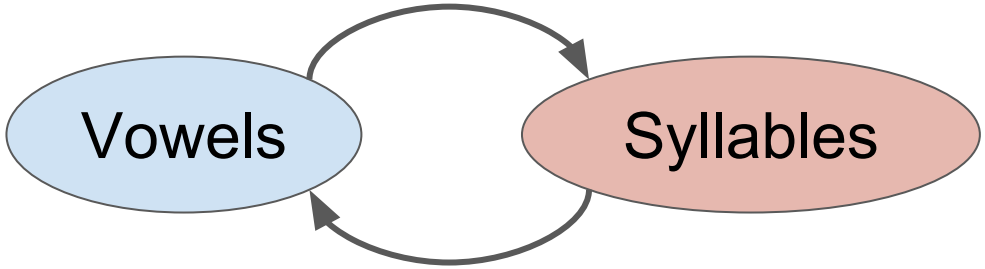
Rule: Diaeresis distinguishes syllables

Diaeresis Convention: Use diaeresis to distinguish syllables

ΰϊ ↔ ΰ + ι ἰσχ**ΰϊ** ↔ ἰσχ**ΰ + ι**

οἰσ**ΰϊ**να ↔ οἰσ**ΰ + ι**να

ώϊ ↔ ώ + ι πρ**ώϊ**μος ↔ πρ**ώ + ι**μος



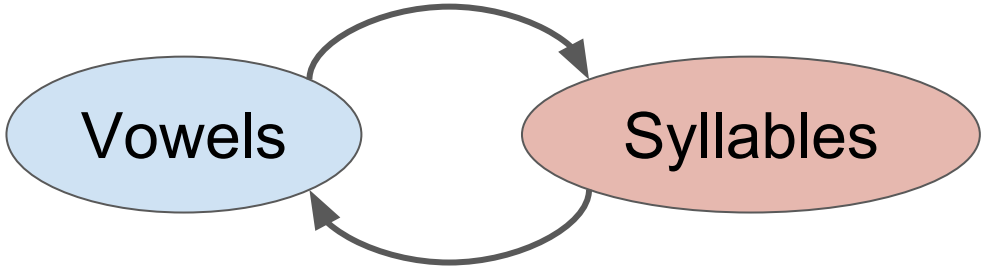
Rule: Accent on first vowel of potential diphthong indicates separate syllables

Diaeresis Convention: Accent can distinguish syllables

ύι ↔ ύ + ι ἰσχ**ύι** ↔ ἰσχ**ύ + ι**

οἰσ**ύι**να ↔ οἰσ**ύ + ι**να

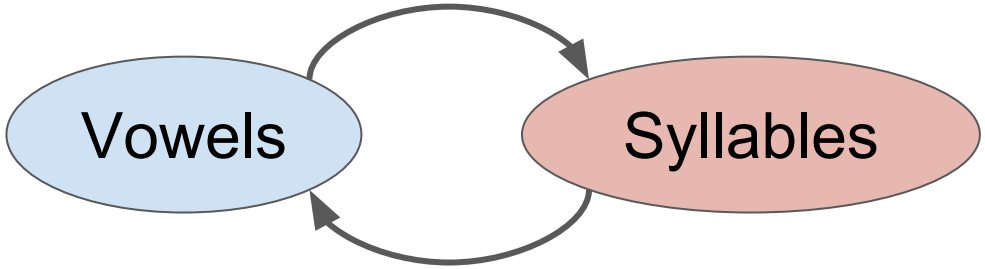
ώι ↔ ώ + ι πρ**ώι**μος ↔ πρ**ώ + ι**μος



Rule: Breathing on first vowel of potential diphthong indicates separate syllables

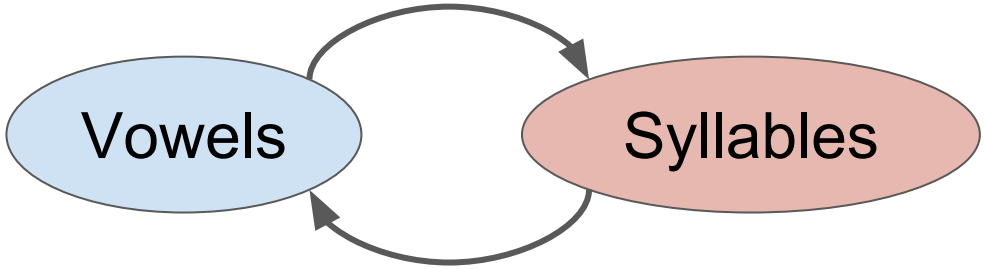
Diaeresis Convention: Breathing and/or accent can distinguish syllables

ἀί ↔ ἀ + ί	**ἀί**διον ↔ **ἀ + ί**διον
ἐυ ↔ ἐ + υ	**ἐυ**ξέστου ↔ **ἐ + υ**ξέστου
ὐι ↔ ὐ + ι	**ὐι**κὸν ↔ **ὐ + ι**κὸν
εὐι ↔ εὐ + ι	**εὐι**ππότην ↔ **εὐι**ππότην



Rule: Diaeresis goes in middle of three syllables

ουϊά ↔ ου + ι + ά Ἀλληλ**ουϊά** ↔ Ἀλληλ**ου + ι + ά**

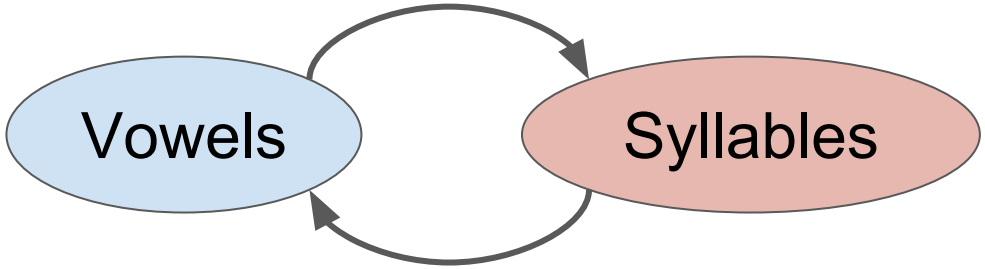


Rule: Vowels that don’t form a diphthong don’t need a diaeresis

Diaeresis Convention: Omit unnecessary diaereses

ηὶ ↔ η + ὶ νη**ὶ** ↔ νη **+ ὶ**

ιὶ ↔ ι + ὶ Δι**ὶ** ↔ Δι **+ ὶ**

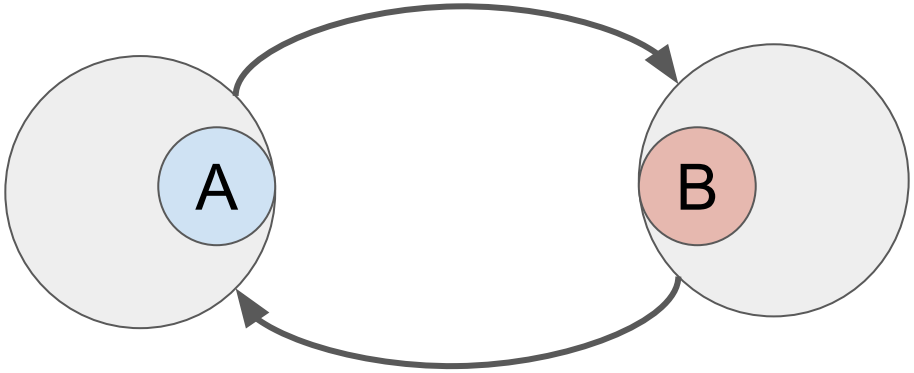


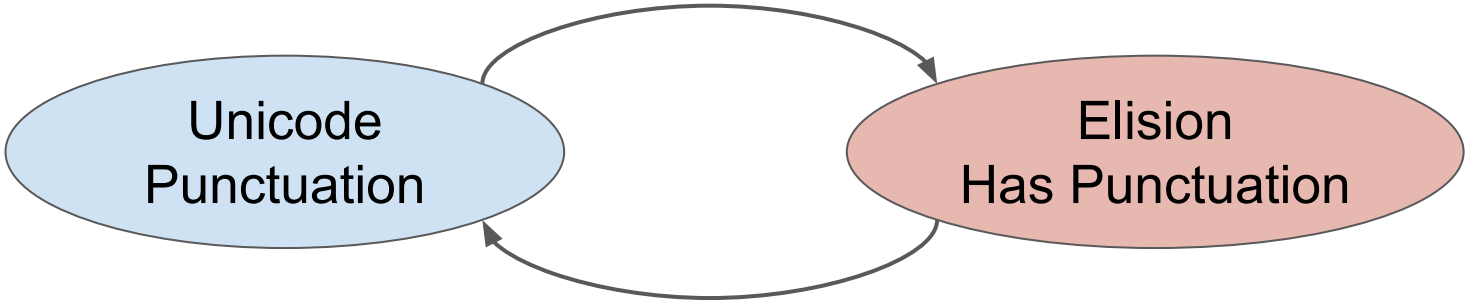
Rule: Use a diaeresis on a second iota or upsilon

Diaeresis Convention: Use diaeresis on all iota/upsilon vowel pairs

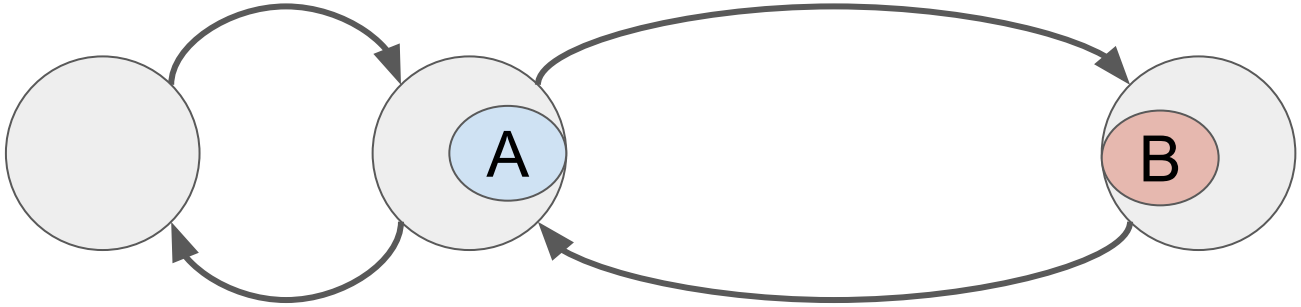
ωϋ ↔ ω + υ	Μ**ωϋ**σῆς ↔ Μ**ω + υ**σῆς
ιϋ ↔ ι + υ	δ**ιϋ**λίζοντες ↔ δ**ι + υ**λίζοντες
ιϊ ↔ ι + ι	δ**ιϊ**σχυρίζετο ↔ δ**ι + ι**σχυρίζετο
οιΐ́α ↔ οι + ί + α	εὐπ**οιΐ́α**ς ↔ εὐπ**οι + ί + α**ς

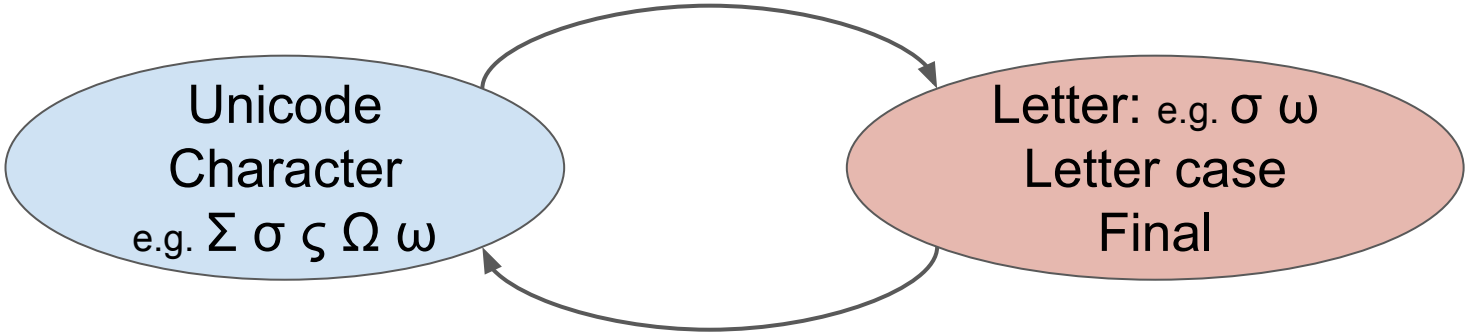
Script Stages: Elision, Punctuation



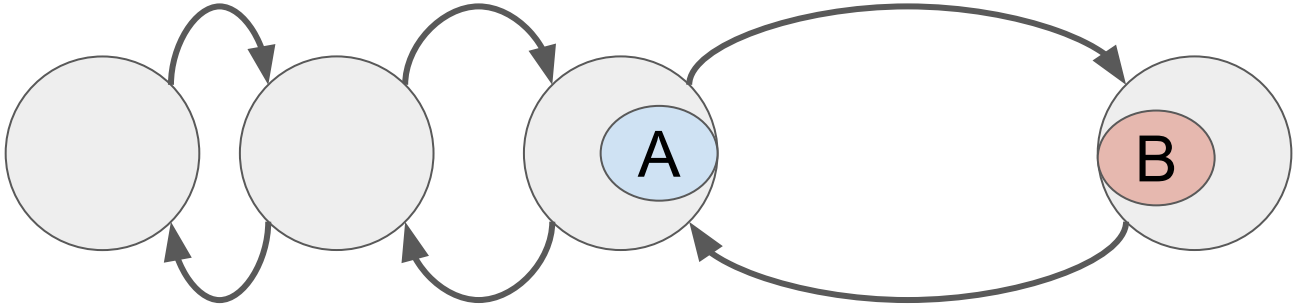


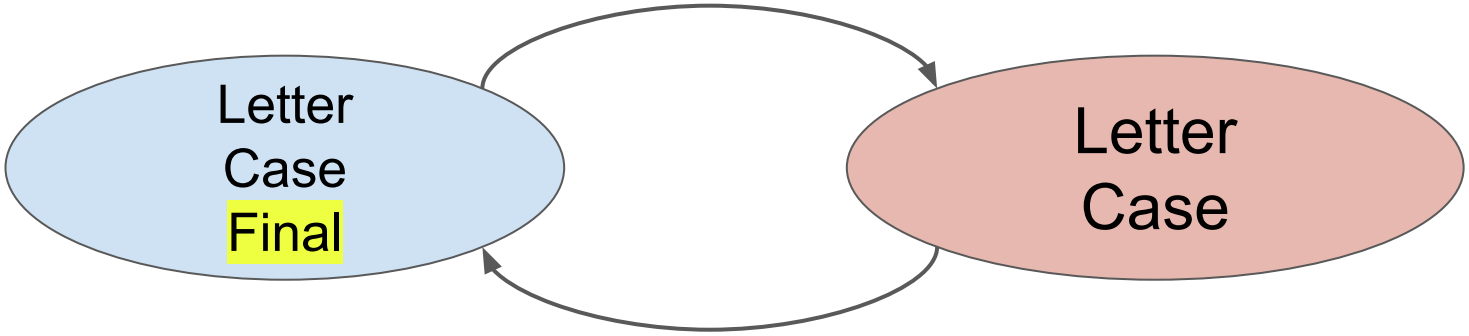
Script Stages: Letter, Case, Final Forms



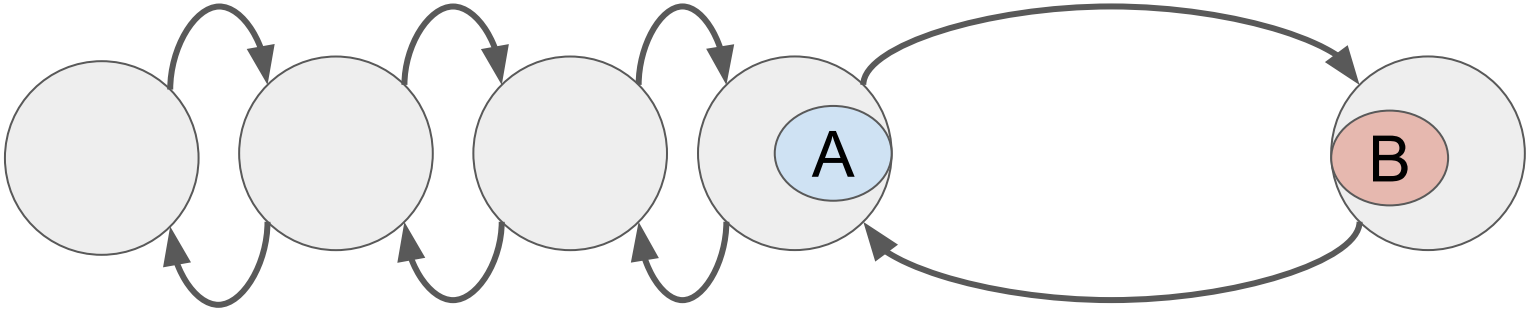


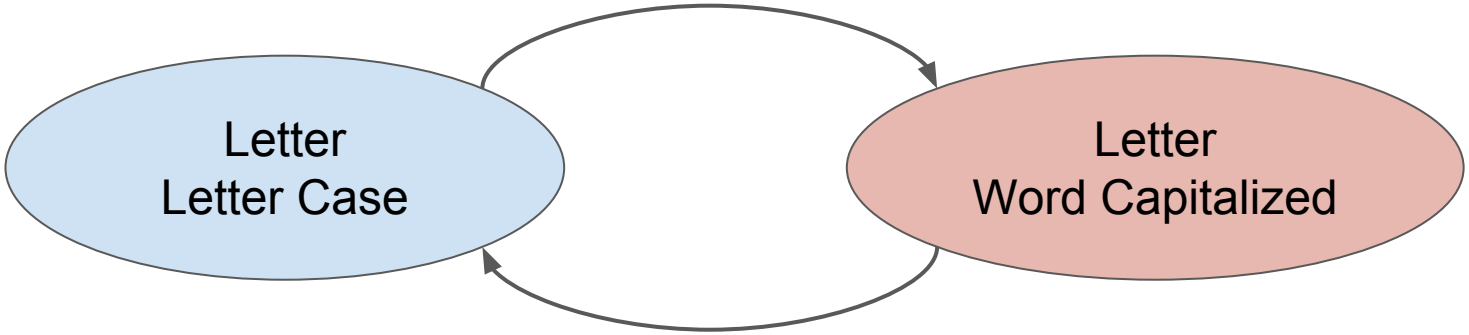
Script Stages: Validate Final Forms



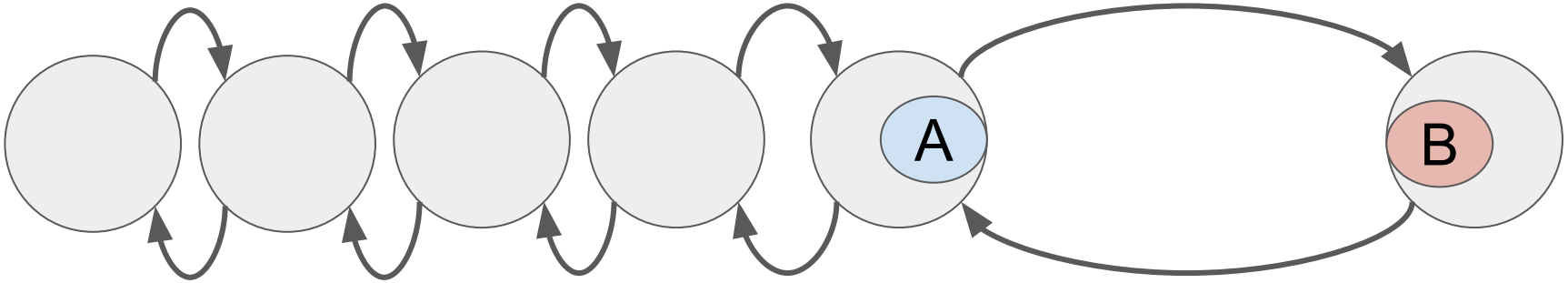


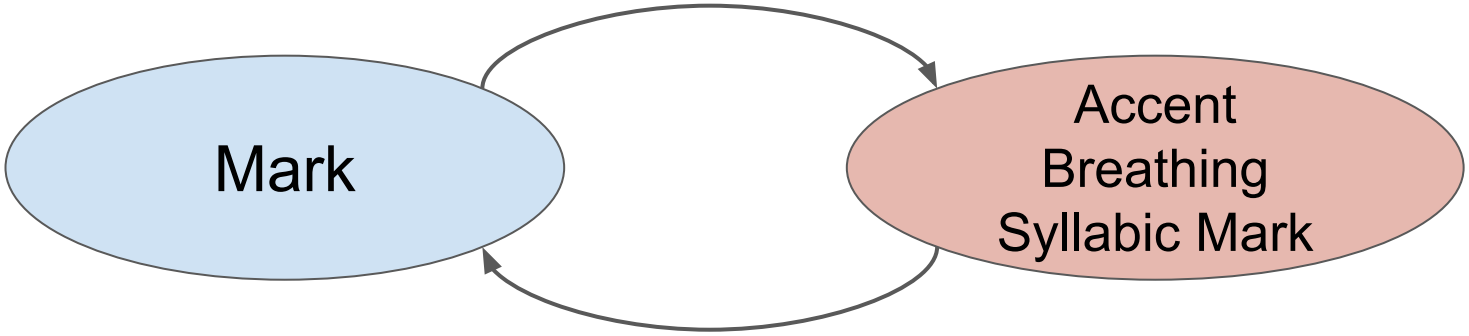
Script Stages: Word Capitalization



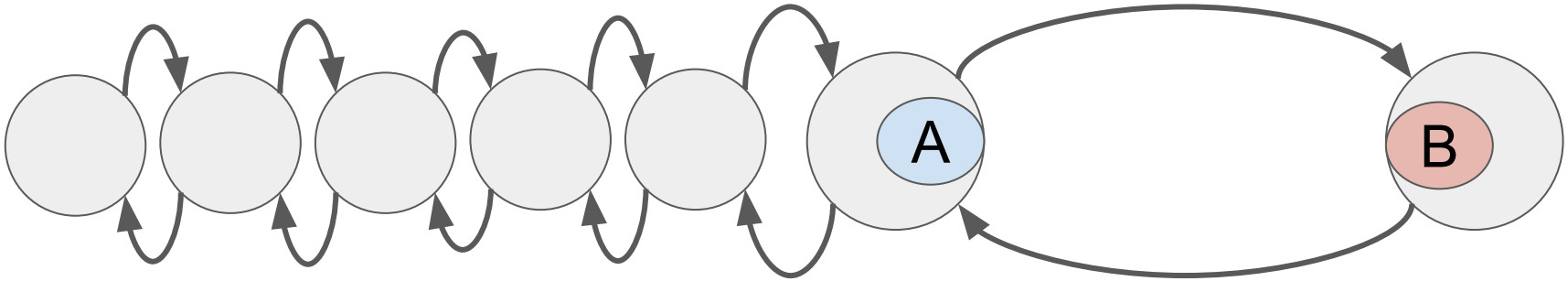


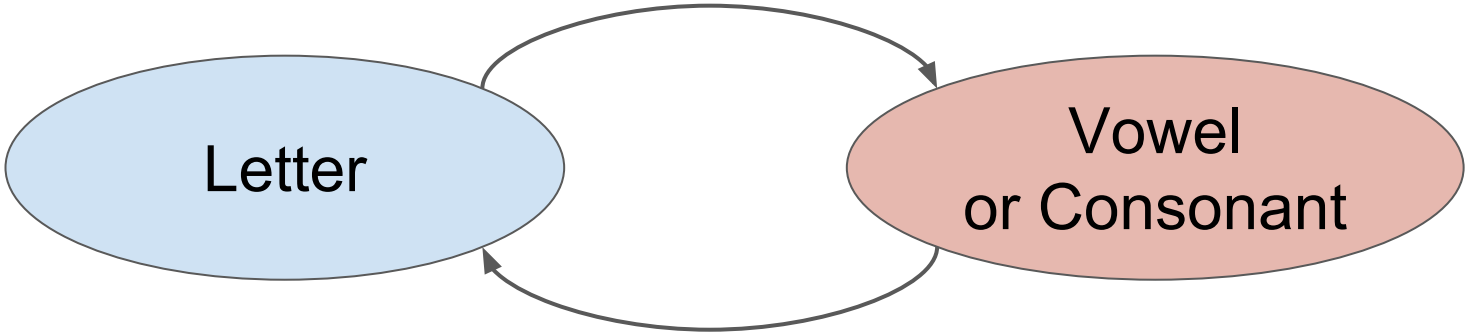
Script Stages: Marks: Accent, Breathing…



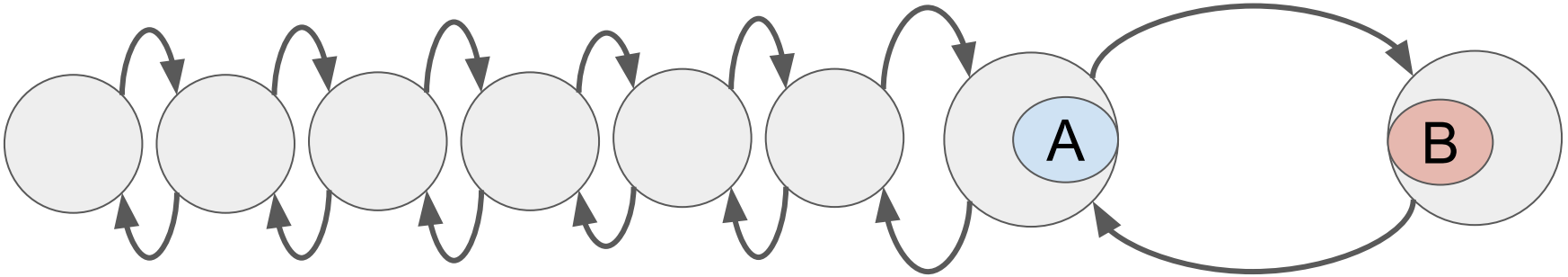


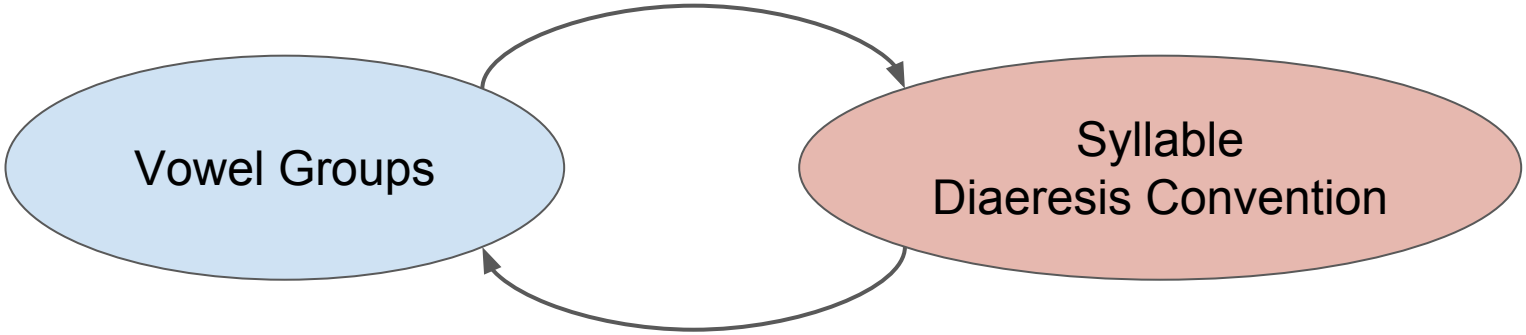
Script Stages: Vowel, Consonant



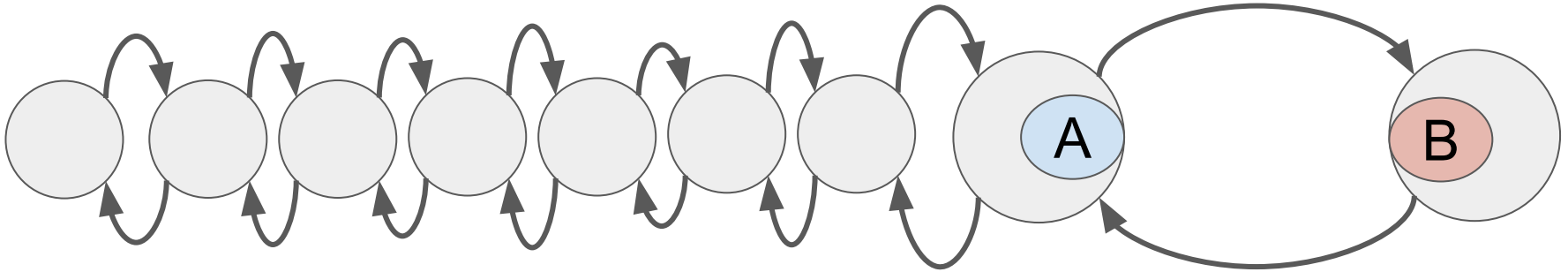


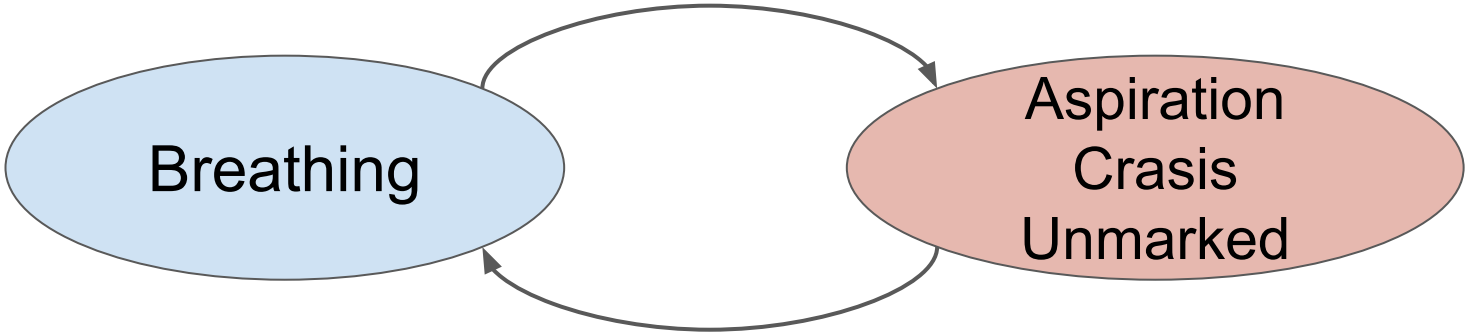
Script Stages: Syllable



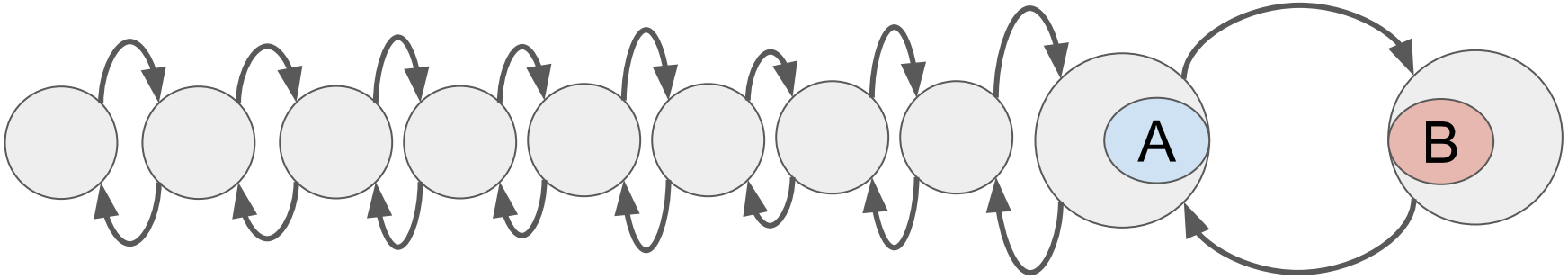


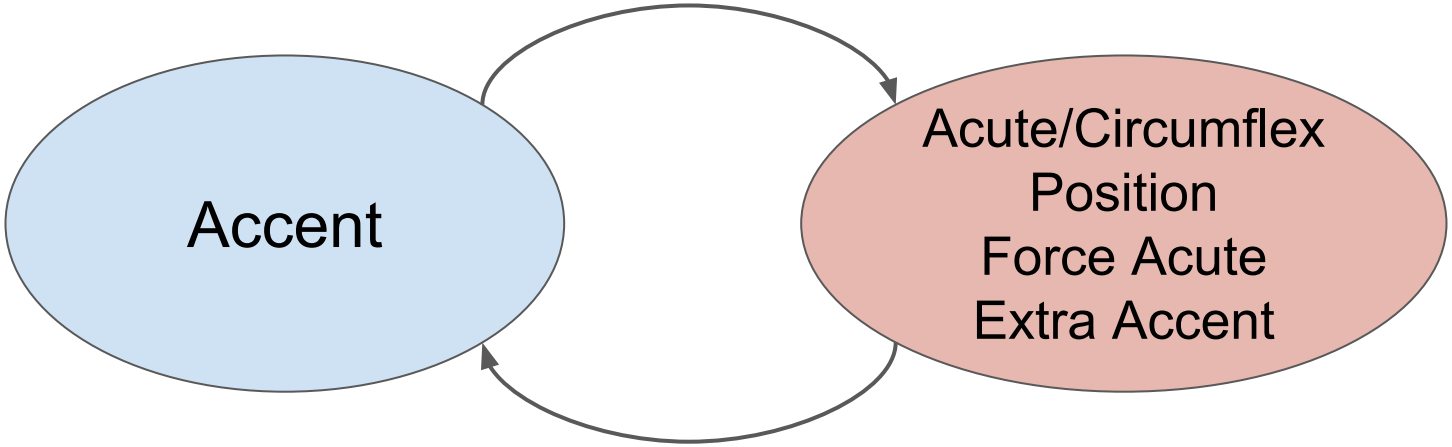
Script Stages: Breathing





Script Stages: Accent

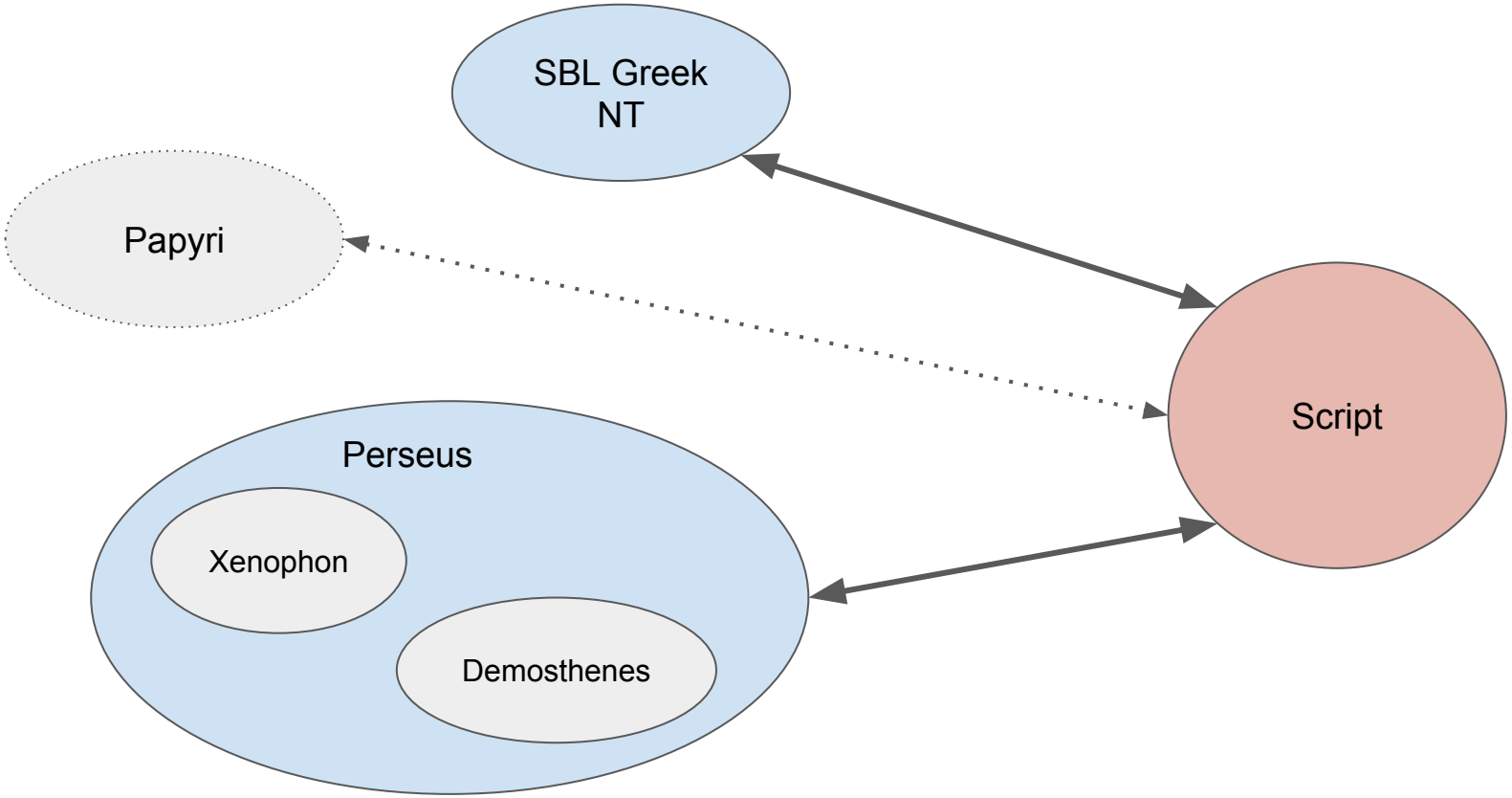




Script: Summary of Word Properties

1. Initial Aspiration: yes / no
2. Syllables, each of which consist of:
   a. Initial consonants
   b. Single vowel, diphthong, or improper diphthong
3. Final Consonants
4. Optional Accent with properties:
   a. Acute or circumflex
   b. Position: Ultima, penult, or antepenult
   c. Force acute: yes / no
   d. Extra accent: yes / no
5. Diaeresis convention
   a. Accent/breathing distinguishes syllables: yes / no
   b. Always use diaeresis with ι,υ: yes / no
6. Crasis: yes with position / no
7. Elision: yes / no
8. Unmarked: yes / no
9. Capitalized: yes / no
10. Has punctuation: yes / no

Script: Primary Sources



Error Correction

SBL Greek NT

- Fixed 12 grave accents with punctuation
  - e.g. αὐτὸν. → αὐτόν.
- Fixed 4 double accent errors
  - e.g. θέλοντές. → θέλοντες.

Error Correction

SBL Greek NT

- Fixed 12 grave accents with punctuation
- Fixed 4 double accent errors

Perseus

- Fixed 1 grave accent error.
  - δὲ, → δέ,
- Final sigmas
  - †δραχμῆσ† Λακεδαιμονίουσς
- Parentheses errors from beta code errors
  - e.g. ἑἶχε δὲ καλόν’ → (εἶχε δὲ καλόν)
- XML errors
  - e.t. ltἂνgt → <ἂν> → <ἂν>
- Paragraph error—no Greek text
- 10+ pull requests, ~50 corrections

Model/Rule Correction

Rule: Use ς for σ at the end of a word (final sigma)

Model/Rule Correction

Rule: Use ς for σ at the end of a word (final sigma)

But… καὶ ὃσ’ εἰς ἡμᾶς ἐβλασφήμησαν

Model/Rule Correction

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Rule: Circumflex cannot go on the antepenult

Model/Rule Correction

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Rule: Circumflex cannot go on the antepenult

But… ᾧτινι, οἵάπερ

(cf. Smyth 186)

Model/Rule Correction

Rule: Use ς for σ at the end of a word (final sigma)

But… καὶ ὅσ’ εἰς ἡμᾶς ἐβλασφήμησαν

Rule: Circumflex cannot go on the antepenult

But… ᾧτινι, οἵἁπερ

(cf. Smyth 186)

Rule: Crasis only occurs on first syllable (e.g. κἀγὼ)

Model/Rule Correction

Rule: Use ς for σ at the end of a word (final sigma)

But… καὶ ὅσ’ εἰς ἡμᾶς ἐβλασφήμησαν

Rule: Circumflex cannot go on the antepenult

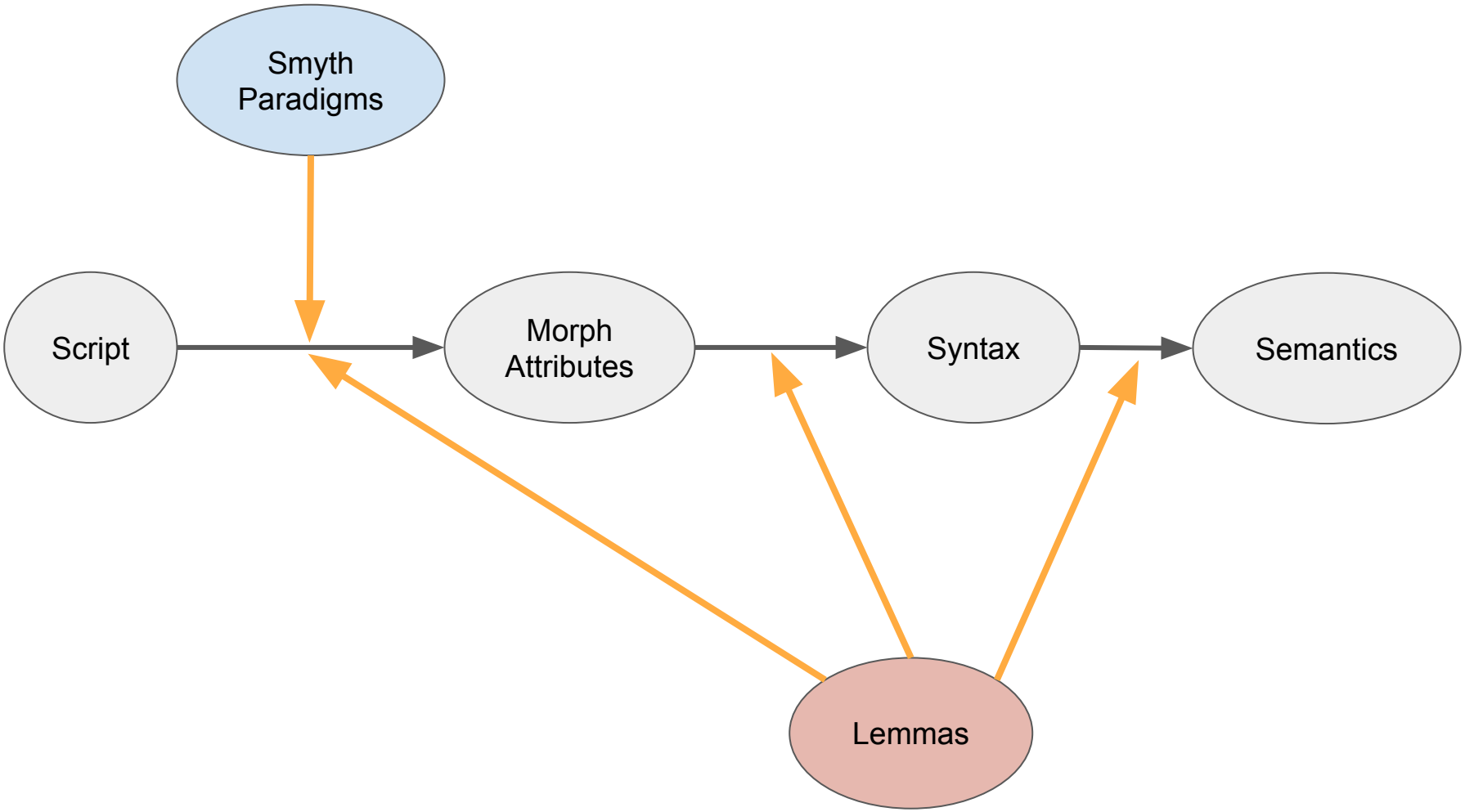
But… ᾧτινι, οἵἅπερ

(cf. Smyth 186)

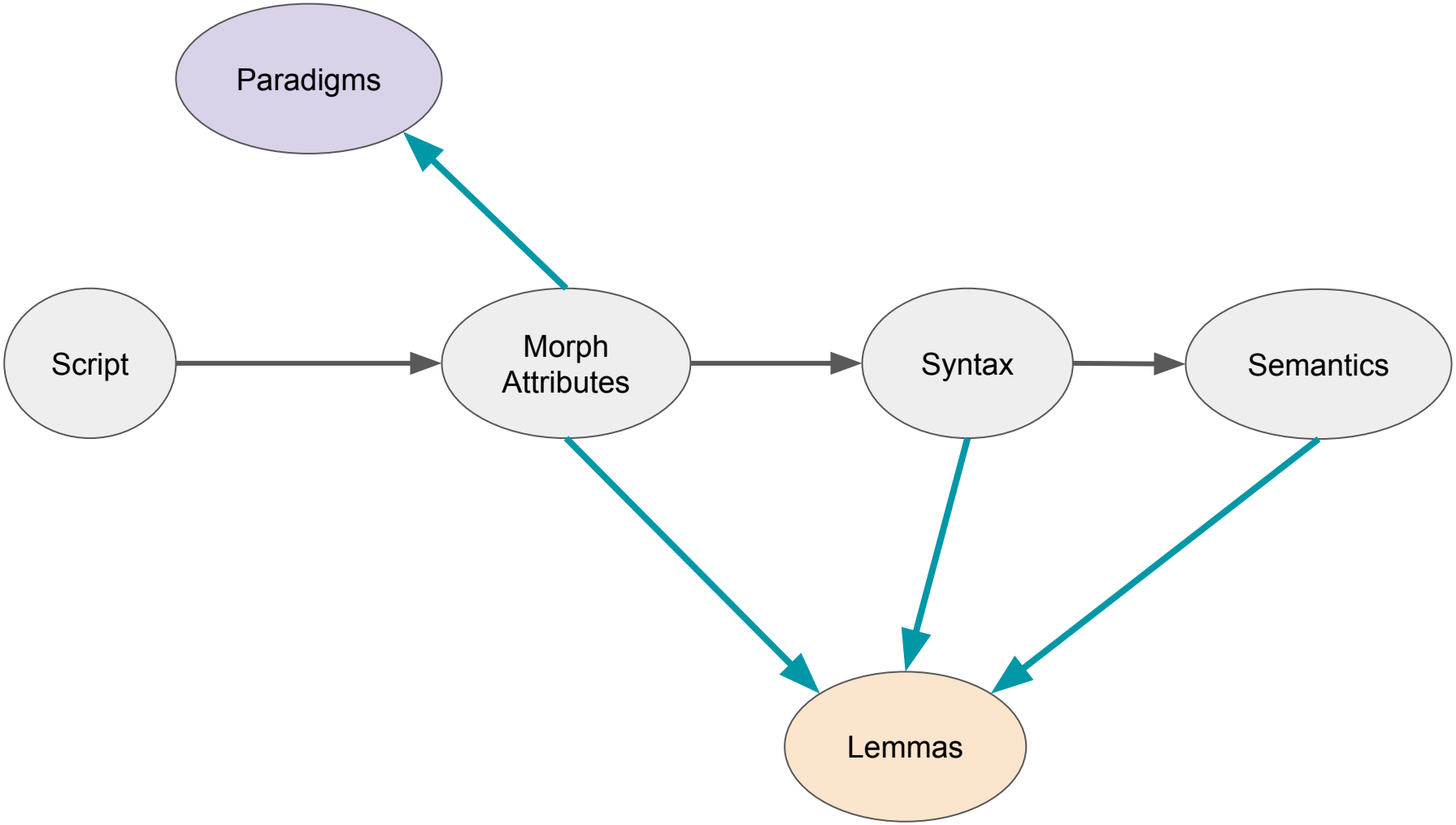
Rule: Crasis only occurs on first syllable (e.g. κἀγὼ)

But… καλοκἀγαθία, ἐγᾦμαι, μεντἂν

Incorporating Existing Analyses



Revising Existing Analyses



Example: First Declension *Feminine* Nouns

216. I. FEMININES

	ἠχώρᾱ (χωπᾱ-)	ἡ νῑκη (νῑκᾱ-)	ἡ φυγή (φυγᾱ-)	ἡ μοῖρα (μοιρᾱ)	ἡ γλῶττα (γλωττᾱ-)	ἡ θάλαττα (θαλαττᾱ)
	land	*victory*	*flight*	*fate*	*tongue*	*sea*
SINGULAR						
Nom.	**χώρᾱ**	**νῑ́κη**	**φυγή**	**μοῖρα**	**γλῶττα**	**φάλαττα**
Gen.	**χώρᾱς**	**νῑ́κης**	**φυγῆς**	**μοίρᾱς**	**γλωιττης**	**φαλάττης**
Dat.	**χώρᾳ**	**νῑ́κῃ**	**φυγῇ**	**μοίρᾳ**	**γλώττῃ**	**φαλάττῃ**
Acc.	**χώρᾱ-ν**	**νῑ́κη-ν**	**φυγή-ν**	**μοῖρα-ν**	**γλῶττα-ν**	**θάλαττα-ν**
Voc.	**χώρᾱ**	**νῑ́κη**	**φυγή**	**μοῖρα**	**γλῶττα**	**θάλαττα**
DUAL						
N. A. V.	**χώρᾱ**	**νῑ́κᾱ**	**φυγᾱ́**	**μοίρᾱ**	**γλώττᾱ**	**φαλάττᾱ**
G. D.	**χώραιν**	**νῑ́καιν**	**φυγαῖν**	**μοίραιν**	**γλώτταιν**	**φαλάτταιν**
PLURAL						
N.V.	**χῶραι**	**νῑ́και**	**φυγαί**	**υοῖραι**	**γλῶτται**	**θάλατται**
Gen.	**χωρῶν**	**νῑκῶν**	**φυγῶν**	**μοιρῶν**	**γλωττῶν**	**φαλαττῶν**
Dat.	**χώραις**	**νῑ́καις**	**φυγαῖς**	**μοίραις**	**γλώτταις**	**θαλάτταις**
Acc.	**χώρᾱς**	**νῑ́κᾱς**	**φυγᾱ́ς**	**μοίρᾱς**	**γλώττᾱς**	**θαλάττᾱς**

Example: *First Declension* Nouns

SUBSTANTIVES

FIRST DECLENSION (STEMS IN **ᾱ**)

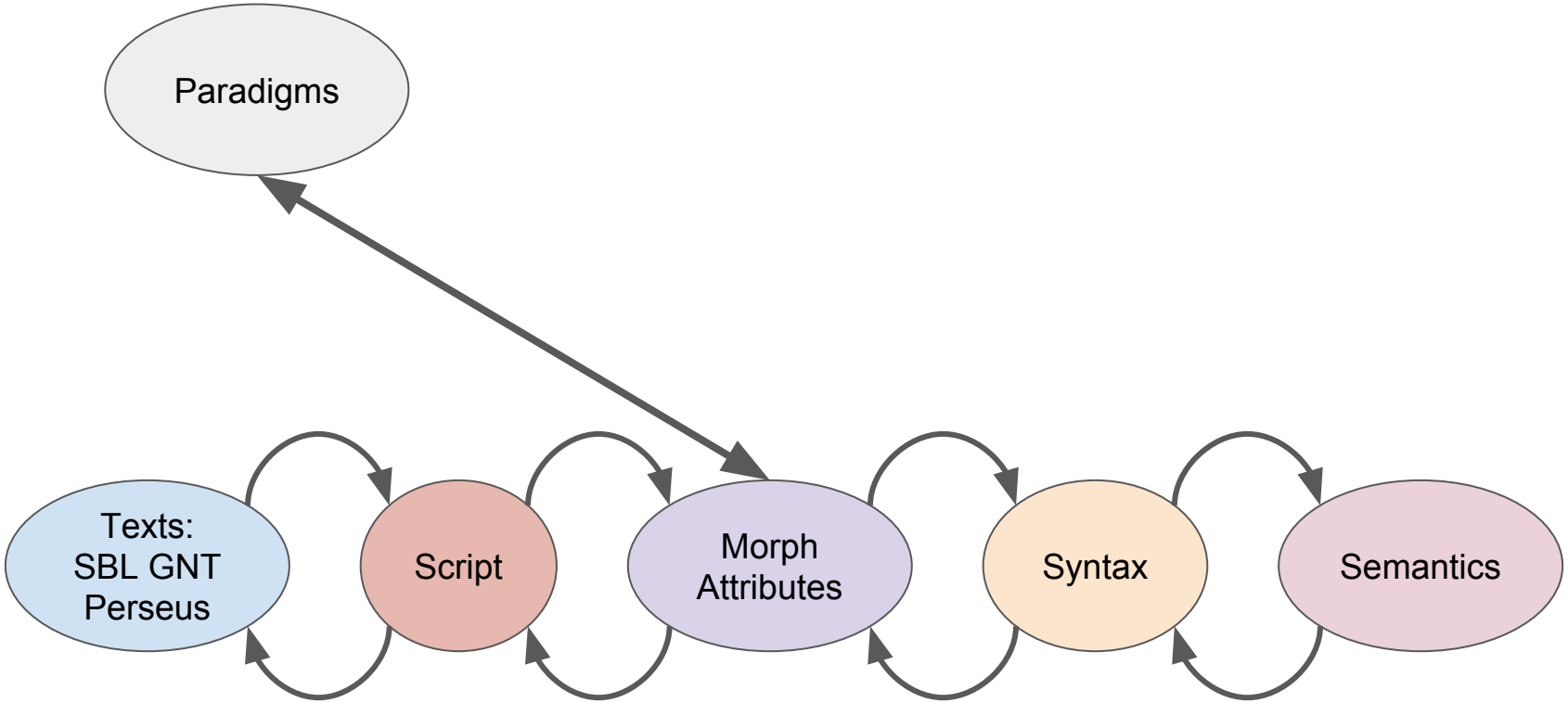
	FEM. SING.		MASC. SING.		MASC. FEM. PL.		MASC.FEM.DUAL	
Nom.	**ᾱ** or **ᾰ**	**η**	**ᾱ-ς**	**η-ς**	**α-ι**	N. A. V.	**ᾱ**	
Gen.	**ᾱ-ς** or **η-ς**	**η-ς**	**ᾱ-ιο** (Hom. **ᾱ-ο**)		**ῶν** (for **έ-ων, ᾱ́-ων**)	G. D.	**α-ιν**	
Dat.	**ᾱ-ι** or **η-ι**	**η-ι**	**ᾱ-ι**	**η-ι**	**α-ις** or **α-ισι** (**ν**)			
Acc.	**ᾱ-ν** or **ᾰ-ν**	**η-ν**	**ᾱ-ν**	**η-ν**	**ᾱς** (for **α-νς**			
Voc.	**ᾱ** or **ᾰ**	**η**	**ᾱ**	**ᾰ** or **η**	**α-ι**			

Example: Nouns

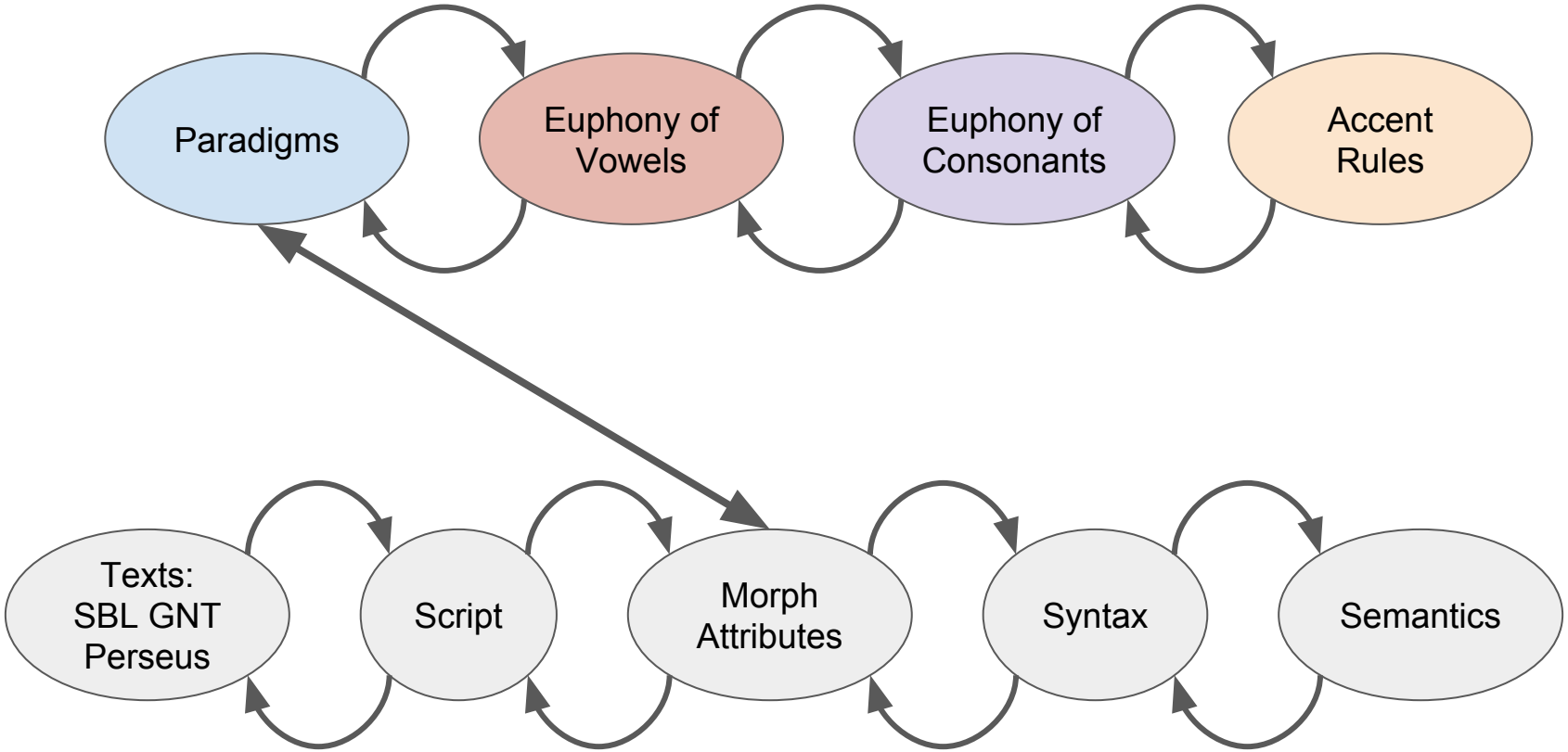
210. CASE ENDINGS OF NOUNS

	VOWEL, DECLENSION		CONSONANT DECLENSION	
	SINGULAR			
	Masc. and Fem.	Neuter	Masc. and Fem.	Neuter
Nom.	-ς or none	-ν	-ς or none	none
Gen.	-ς or -ιο		-ος	
Dat.	-ι		-ι	
Acc.	-ν		-ν or -ᾰ	none
Voc.	none	-ν	none or like Nom.	none
	DUAL			
N. A. V.	none		-ε	
G. D.	-ιν		-οιν	
	PLURAL			
N. V.	-ι	-ᾰ	ε͟ῳ	-ᾰ
Gen.	-ων		-ων	
Dat.	-ις (-ισι)		-σι, -σσι, -εσσι	
Acc.	-νς (-ᾱς)	-ᾰ	-νς, -ᾰς	-ᾰ

Paradigm Analysis



Paradigm Analysis



Example: Word Formation

PART III

FORMATION OF WORDS

839. AGENCY

a. The primary suffixes τᾱ, τηρ, τορ, τρο, ευ, denoting the *agent* or *doer of an action*, are masculine.

1. **τᾱ** (nom. -τή-ς): κρι-τή-ς *judge* (κρῑ́νω *decide*, κρι-), κλέπ-τη-ς *thief* (κλέπ-τ-ω *steal*), ποιη-τή-ς *poet*, i.e. *maker* (ποιέ-ω *make*), αὐλη-τή-ς *flute-player* (αὐλέ-ω *play the flute*), μαθ-η-τή-ς *pupil* (μανθάνω *learn*, μαθ-ε-), ἱκ-έ-τη-ς *suppliant* (ἱκ-νέ-ομαι *come*, ἱκ-).
2. **τηρ** (nom. -τήρ): δο-τήρ *giver* (δί-δω-μι *give*, δο-, δω-), σω-τήρ *saviour* (σῴ-ζω *save*).
3. **τορ** (nom. -τωρ): ῥή-τωρ *orator* (ἐρέω *shall say*, ἐρ-, ῥε-), εἴ-ρη-κα *have spoken*, κτίσ-τωρ *founder* (κτίζω *found*, κτιδ-), σημάντωρ *commander*, poet. (σημαίνω *give a signal*, σημαν-).
4. **τρο** (nom. -τρό-ς): ἰᾱ-τρό-ς *physician* (ἰα-ομαι *heal*).
5. **ευ** (nom, -εύ-ς): γραφ-εύ-ς *writer* (γράφ-ω *write*), τοκ-εύ-ς *father* (τίκτω *beget*, τεκ-).

b. The primary suffixes τριδ, τριᾱ, τειρᾱ, τιδ are feminine.

1. **τριδ** (nom. -τρίς): αὐλη-τρίς *female flute-player*.
2. **τριᾱ** (nom. -τρια): ποίη-τρια *poetess* (late), ψάλ-τρια *female harper* (ψάλλω *play the harp*, ψαλ-).
3. **τειρᾱ** (nom. -τειρα from τερ-ια): σώ-τειρα fem. of σω-τήρ, δό-τειρα fem. of δο-τήρ.
4. **τιδ** (nom. -τις): ἱκ-έ-τις *female suppliant* fem. of ἱκ-έ-της.

Morph Stages

- Decontextualization
  - Elision — How vs When
  - Enclitics as separate words
- Word analysis
  - Enclitic endings
  - Prepositional prefixes
  - Paradigm suffix analysis
  - Augment, reduplication prefix analysis
- Syntactic constituents
  - Preposition + object
  - Conjunctions

Future Work

- More Texts
  - Rest of Perseus
  - Papyri
- More Languages
  - Hebrew
  - Latin
- Deeper analysis
  - Word formation
  - Meter analysis
  - Syntactic constituents
- User Interface
  - Custom language for rules and model
  - Web app