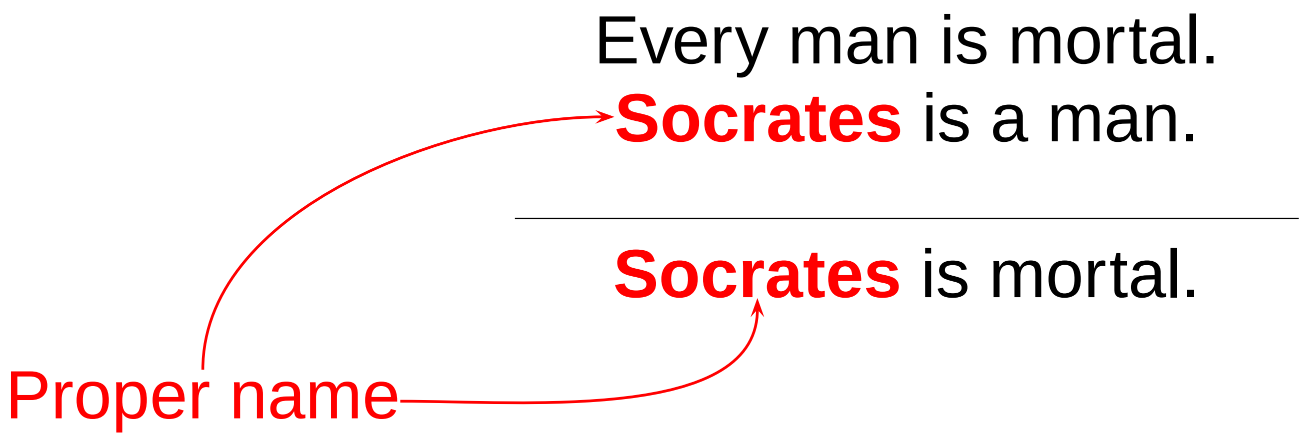
Aristotle’s work on logic.

The **Organon**.

- **Categories**: Classification of types of predicates
- **On Interpretation** *(De interpretatione): Basics of philosophy of language, subject-predicate distinction, Square of Oppositions*
- **Prior Analytics**: Syllogistics
- **Posterior Analytics**: More on syllogistics
- **Topics**: Logic except for syllogistics
- **On Sophistical Refutations** *(De Sophisticis Elenchis)*: Fallacies

The most famous syllogism.



Every man is mortal.
Socrates is a man.

Socrates is mortal.

Proper name

A more typical syllogism.

Every animal is mortal.
Every man is an animal.

Every man is mortal.

Every B is an A.
Every C is a B.

Every C is an A.

“Barbara”

“a valid mood”
mood = *modus*

Another valid mood.

Every philosopher is mortal.
Some teacher is a philosopher.

Some teacher is mortal.

Every B is an A.
Some C is a B.

Some C is an A.

“Darii”

A similar but invalid mood.

“Darii”	
Every B is an A.	Every A is a B.
Some C is a B.	Some C is a B.
Some C is an A.	Some C is an A.

Every philosopher is mortal.
Some teacher is mortal.

~~Some teacher is a philosopher.~~

Yet another very similar mood.

“Darii”	The invalid mood	**“Datisi”**
Every B is an A.	Every A is a B.	Every B is a A.
Some C is a B.	Some C is a B.	Some B is a C.
Some C is an A.	Some C is an A.	Some C is an A.

“Some C is a B” and “Some B is a C”
are intuitively equivalent.
“Every B is an A” and “Every A is a B” aren’t.

A first conversion rule.

This yields a simple formal (syntactical) conversion rule:

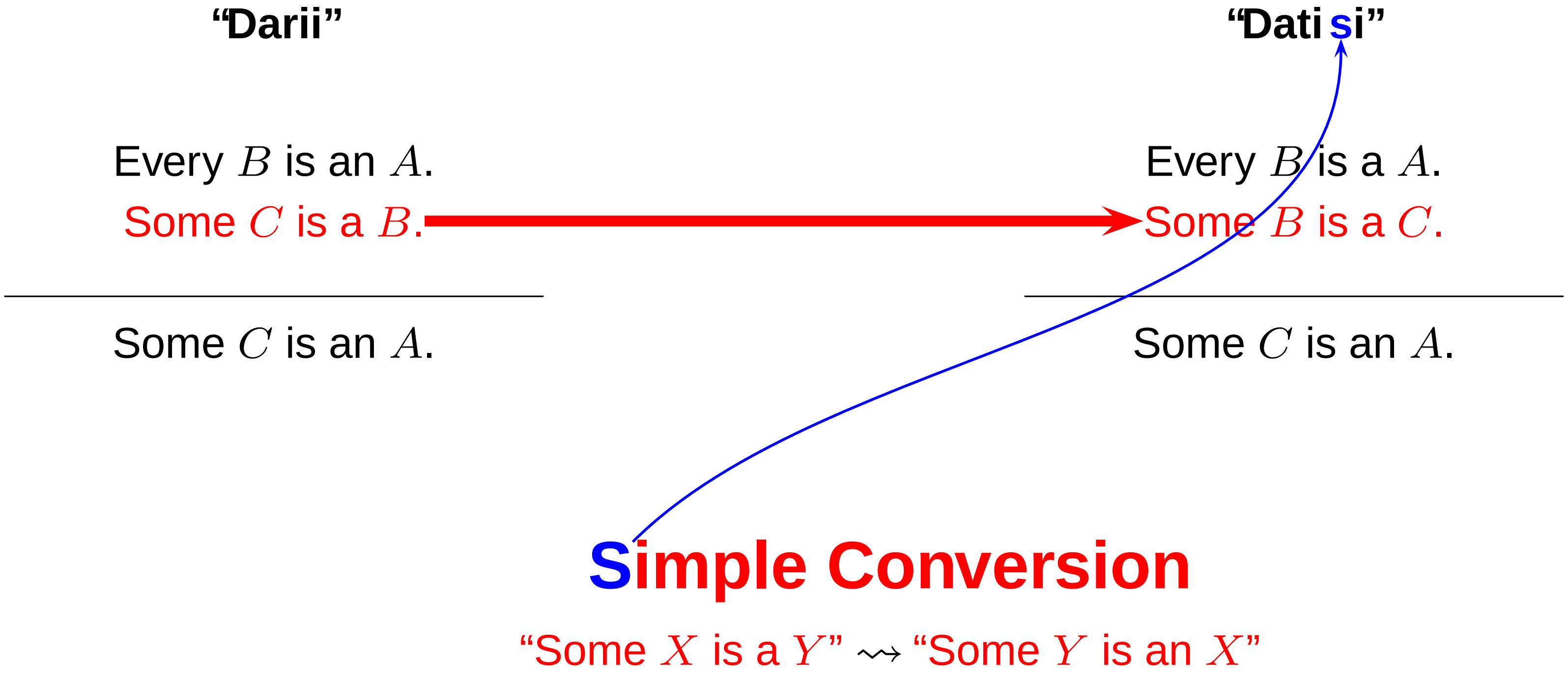
“Some X is a Y”

can be converted to

“Some Y is an X.”

This rule is validity-preserving and syntactical.

Back to *Darii* and *Datisi*.



“Darii”

Every B is an A.
Some C is a B.

Some C is an A.

“Datisi”

Every B is a A.
Some B is a C.

Some C is an A.

Simple Conversion

“Some X is a Y” ⇝ “Some Y is an X”

Methodology of Syllogistics.

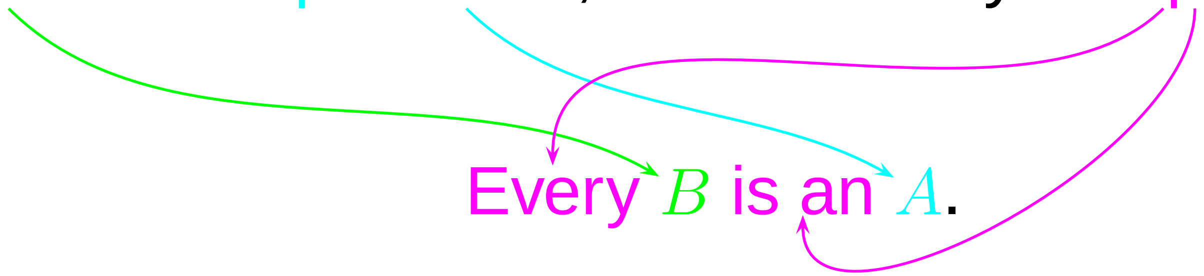
- Start with a list of obviously valid moods (perfect syllogisms $\cong$ “axioms”)...
- ...and a list of conversion rules,
- derive all valid moods from the perfect syllogisms by conversions,
- and find counterexamples for all other moods.

Notation (1).

Syllogistics is a term logic, not propositional or predicate logic.

We use capital letters A, B, and C for terms, and sometimes X and Y for variables for terms.

Terms (*termini*) form part of a categorical proposition. Each categorical proposition has two terms:
a subject and a predicate, connected by a copula.



Every B is an A.

Notation (2).

There are four copulae:

- The universal affirmative: Every — is a —. a
- The universal negative: No — is a —. e
- The particular affirmative: Some — is a —. i
- The particular negative: Some — is not a —. o

Every B is an A. $\rightsquigarrow$ AaB
No B is an A. $\rightsquigarrow$ AeB
Some B is an A. $\rightsquigarrow$ AiB
Some B is not an A. $\rightsquigarrow$ AoB

Contradictories: a–o & e–i.

Notation (3).

$$\textbf{Barbara}\quad \begin{array}{ll} \text{Every } B \text{ is an } A & A\text{a } B \\ \text{Every } C \text{ is a } B & B\text{a } C \\ \hline \text{Every } C \text{ is an } A & A\text{a } C \end{array}$$

Each syllogism contains three terms and three categorial propositions. Each of its categorial propositions contains two of its terms. Two of the categorial propositions are premises, the other is the conclusion.
The term which is the predicate in the conclusion, is called the major term, the subject of the conclusion is called the minor term, the term that doesn't occur in the conclusion is called the middle term.

Notation (4).

Barbara	Every B is an A	A a B
	Every C is a B	B a C
	Every C is an A	A a C

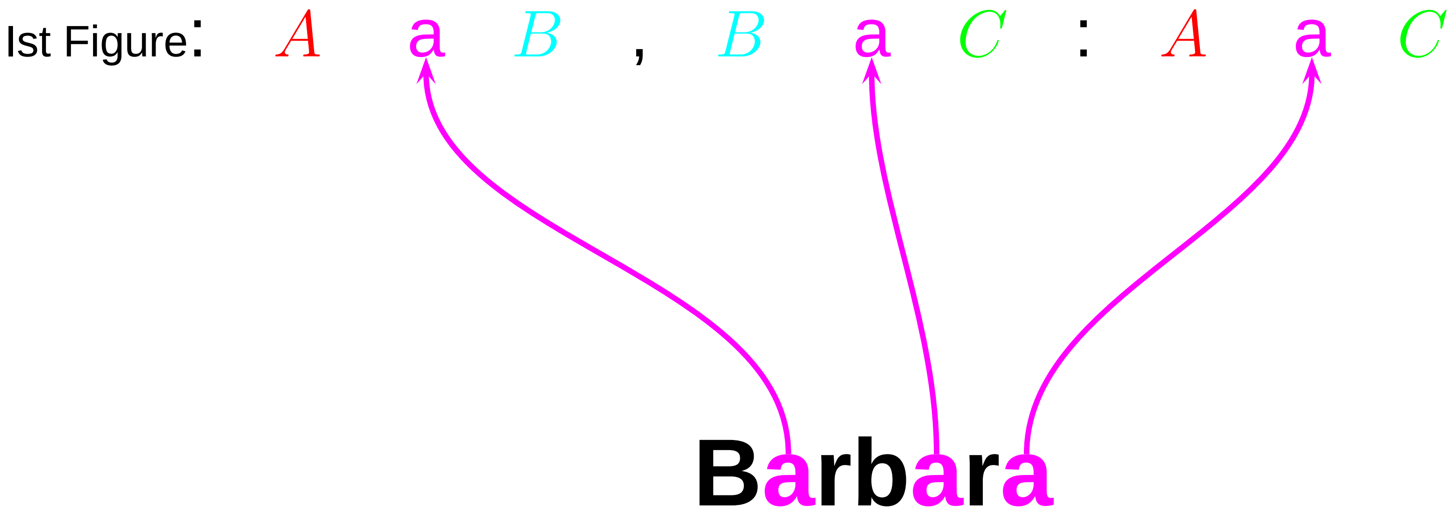
Major term / Minor term / Middle term

Only one of the premises contains the major term. This one is called the major premise, the other one the minor premise.

Ist Figure	IInd Figure
$A \text{ — } B, B \text{ — } C : A \text{ — } C$	$B \text{ — } A, B \text{ — } C : A \text{ — } C$
IIIrd Figure	**IVth Figure**
$A \text{ — } B, C \text{ — } B : A \text{ — } C$	$B \text{ — } A, C \text{ — } B : A \text{ — } C$

Notation (5).

If you take a figure, and insert three copulae, you get a mood.



Ist Figure: A a B , B a C : A a C

Barbara

Combinatorics of moods.

With four copulae and three slots, we get

$$4^3 = 64$$

moods from each figure, *i.e.*, $4 \times 64 = 256$ in total.
Of these, 24 have been traditionally seen as valid.

A	a	B	,	B	i	C	:	A	i	C	
D	**a**	r			**i**				**i**		$\rightsquigarrow$ **Darii**

A	a	B	,	C	i	B	:	A	i	C	
D	**a**	t			**i**	s			**i**		$\rightsquigarrow$ **Datisi**

The 24 valid moods (1).

Ist figure	$A\mathrm{a}B$	,	$B\mathrm{a}C$	:	$A\mathrm{a}C$	**Barbara**
	$A\mathrm{e}B$	,	$B\mathrm{a}C$	:	$A\mathrm{e}C$	**Celarent**
	$A\mathrm{a}B$	,	$B\mathrm{i}C$	:	$A\mathrm{i}C$	**Darii**
	$A\mathrm{e}B$	,	$B\mathrm{i}C$	:	$A\mathrm{o}C$	**Ferio**
	$A\mathrm{a}B$	,	$B\mathrm{a}C$	:	$A\mathrm{i}C$	**Barbari**
	$A\mathrm{e}B$	,	$B\mathrm{a}C$	:	$A\mathrm{o}C$	**Celaront**
IInd figure	$B\mathrm{e}A$	,	$B\mathrm{a}C$	:	$A\mathrm{e}C$	**Cesare**
	$B\mathrm{a}A$	,	$B\mathrm{e}C$	:	$A\mathrm{e}C$	**Camestres**
	$B\mathrm{e}A$	,	$B\mathrm{i}C$	:	$A\mathrm{o}C$	**Festino**
	$B\mathrm{a}A$	,	$B\mathrm{o}C$	:	$A\mathrm{o}C$	**Baroco**
	$B\mathrm{e}A$	,	$B\mathrm{a}C$	:	$A\mathrm{o}C$	**Cesaro**
	$B\mathrm{a}A$	,	$B\mathrm{e}C$	:	$A\mathrm{o}C$	**Camestrop**

The 24 valid moods (2).

IIIrd figure	$A\mathrm{a}B$	,	$C\mathrm{a}B$	:	$A\mathrm{i}C$	**Darapti**
	$A\mathrm{i}B$	,	$C\mathrm{a}B$	:	$A\mathrm{i}C$	**Disamis**
	$A\mathrm{a}B$	,	$C\mathrm{i}B$	:	$A\mathrm{i}C$	**Datisi**
	$A\mathrm{e}B$	,	$C\mathrm{a}B$	:	$A\mathrm{o}C$	**Felapton**
	$A\mathrm{o}B$	,	$C\mathrm{a}B$	:	$A\mathrm{o}C$	**Bocardo**
	$A\mathrm{e}B$	,	$C\mathrm{i}B$	:	$A\mathrm{o}C$	**Ferison**
IVth figure	$B\mathrm{a}A$	,	$C\mathrm{a}B$	:	$A\mathrm{i}C$	**Bramantip**
	$B\mathrm{a}A$	,	$C\mathrm{e}B$	:	$A\mathrm{e}C$	**Camenes**
	$B\mathrm{i}A$	,	$C\mathrm{a}B$	:	$A\mathrm{i}C$	**Dimaris**
	$B\mathrm{e}A$	,	$C\mathrm{a}B$	:	$A\mathrm{o}C$	**Fesapo**
	$B\mathrm{e}A$	,	$C\mathrm{i}B$	:	$A\mathrm{o}C$	**Fresison**
	$B\mathrm{a}A$	,	$C\mathrm{e}B$	:	$A\mathrm{o}C$	**Camenop**

Reminder.

In syllogistics, all terms are nonempty.

Barbari. AaB, BaC: AiC.

Every unicorn is a white horse.
Every white horse is white.

Some unicorn is white.

In particular, this white unicorn exists.

The perfect moods.

> Τέλειον μὲν οὖν καλῶ συλλογισμὸν
> τὸν μηδενὸς ἄλλου προσδεόμενον παρὰ
> τὰ εἰλημμένα πρὸς τὸ φανῆναι τὸ
> ἀναγκαῖον. *(An.Pr. I.i)*

Aristotle discusses the first figure in *Analytica Priora* I.iv, identifies **Barbara**, **Celarent**, **Darii** and **Ferio** as *perfect* and then concludes

> Δῆλον δὲ καὶ ὅτι πάντες οἱ ἐν αὐτῷ
> συλλογισμοὶ τέλειοί εἰσι ... καλῶ δὲ
> τὸ τοιοῦτον σχῆμα πρῶτον. *(An.Pr. I.iv)*

Axioms of Syllogistics.

So the Axioms of Syllogistics according to Aristotle are:

Barbara. AaB, BaC : AaC
Celarent. AeB, BaC: AeC
Darii. AaB, BiC : AiC
Ferio. AeB, BiC: AoC

Simple and accidental conversion.

- Simple (*simpliciter*).
  - Xi$Y \rightsquigarrow Y$iX.
  - Xe$Y \rightsquigarrow Y$eX.
- Accidental (*per accidens*).
  - Xa$Y \rightsquigarrow X$iY.
  - Xe$Y \rightsquigarrow X$oY.

Syllogistic proofs (1).

We use the letters t_{ij} for terms and the letters k_i stand for copulae. We write a mood in the form

$$\frac{\begin{array}{c} t_{11}\ k_1\ t_{12} \\ t_{21}\ k_2\ t_{22} \end{array}}{t_{31}\ k_3\ t_{32}},$$

for example,

$$\frac{\begin{array}{c} \text{AaB} \\ \text{BaC} \end{array}}{\text{AaC}}$$

for **Barbara**. We write M_i for $t_{i1}\ k_i\ t_{i2}$ and define some operations on moods.

Syllogistic proofs (2).

- For $i \in \{1, 2, 3\}$, the operation s_i can only be applied if k_i is either ‘i’ or ‘e’. In that case, s_i interchanges t_{i1} and t_{i2}.

$$\begin{array}{c} \text{AaB} \\ \text{BiC} \\ \hline \text{CiA} \end{array} \xrightarrow{\mathsf{s}_3} \begin{array}{c} \text{AaB} \\ \text{BiC} \\ \hline \text{AiC} \end{array}$$

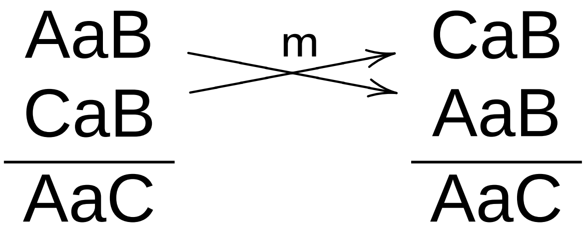
Syllogistic proofs (2).

- For $i \in \{1,2,3\}$, the operation s_i can only be applied if k_i is either ‘i’ or ‘e’. In that case, s_i interchanges t_{i1} and t_{i2}.
- For $i \in \{1,2\}$, let p_i be the operation that changes k_i to its subaltern (if it has one), while p_3 is the operation that changes k_3 to its superaltern (if it has one).

$$\begin{array}{c} \mathsf{AaB} \\ \mathsf{AaB} \\ \hline \mathsf{AaC} \end{array} \xrightarrow{\mathsf{p}_1} \begin{array}{c} \mathsf{AiB} \\ \mathsf{AaB} \\ \hline \mathsf{AaC} \end{array}$$

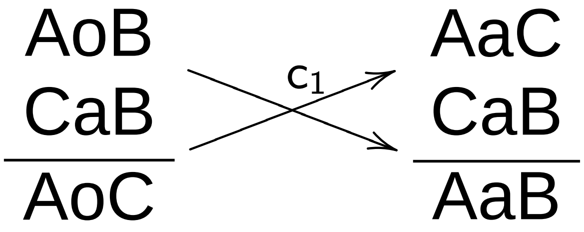
Syllogistic proofs (2).

- For $i \in \{1, 2, 3\}$, the operation s_i can only be applied if k_i is either ‘i’ or ‘e’. In that case, s_i interchanges t_{i1} and t_{i2}.
- For $i \in \{1, 2\}$, let p_i be the operation that changes k_i to its subaltern (if it has one), while p_3 is the operation that changes k_3 to its superaltern (if it has one).
- Let m be the operation that exchanges M_1 and M_2.



Syllogistic proofs (2).

- For $i \in \{1, 2, 3\}$, the operation s_i can only be applied if k_i is either ‘i’ or ‘e’. In that case, s_i interchanges t_{i1} and t_{i2}.
- For $i \in \{1, 2\}$, let p_i be the operation that changes k_i to its subaltern (if it has one), while p_3 is the operation that changes k_3 to its superaltern (if it has one).
- Let m be the operation that exchanges M_1 and M_2.
- For $i \in \{1, 2\}$, let c_i be the operation that first changes k_i and k_3 to their contradictories and then exchanges M_i and M_3.



AoB
CaB
AoC

c_1

AaC
CaB
AaB

Syllogistic proofs (2).

- For $i \in \{1,2,3\}$, the operation s_i can only be applied if k_i is either ‘i’ or ‘e’. In that case, s_i interchanges t_{i1} and t_{i2}.
- For $i \in \{1,2\}$, let p_i be the operation that changes k_i to its subaltern (if it has one), while p_3 is the operation that changes k_3 to its superaltern (if it has one).
- Let m be the operation that exchanges M_1 and M_2.
- For $i \in \{1,2\}$, let c_i be the operation that first changes k_i and k_3 to their contradictories and then exchanges M_i and M_3.
- Let per_π be the permutation π of the letters A, B, and C, applied to the mood.

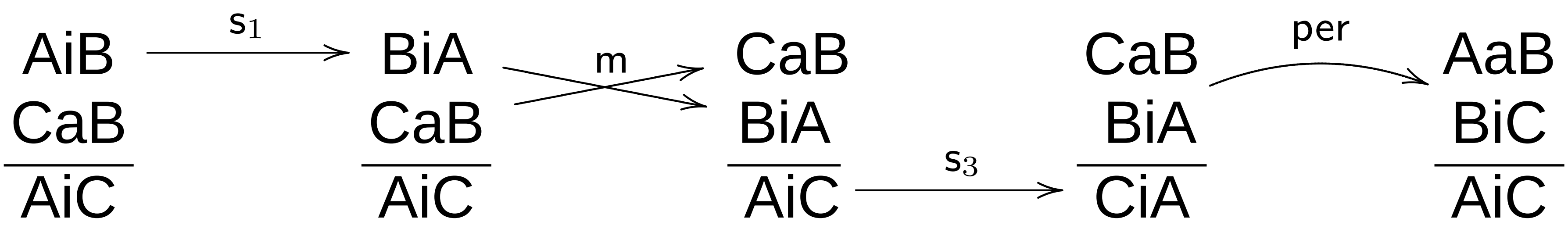
Syllogistic proofs (3).

Given any set $\mathfrak{B}$ of “basic moods”, a $\mathfrak{B}$-**proof** of a mood $M = M_1, M_2{:}M_3$ is a sequence $\langle \mathsf{o}_1, ..., \mathsf{o}_n \rangle$ of operations such that

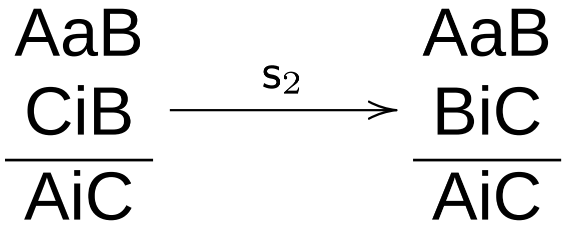
- Only o_1 can be of the form c_1 or c_2 (but doesn’t have to be).
- The sequence of operations, if applied to M, yields an element of $\mathfrak{B}$.

Syllogistic proofs (4).

$\langle \mathsf{s}_1, \mathsf{m}, \mathsf{s}_3, \mathsf{per}_{AC} \rangle$ is a proof of **Disamis** (from **Darii**) :

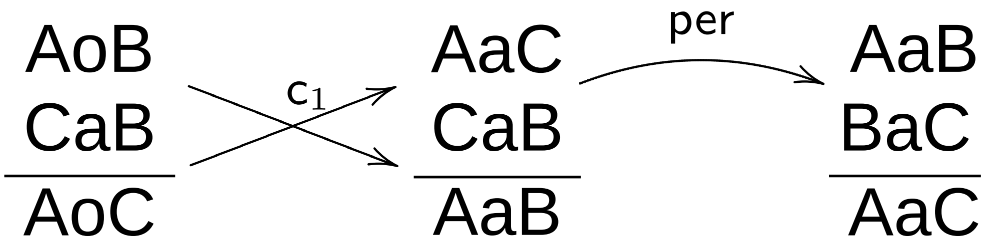


$\langle \mathsf{s}_2 \rangle$ is a proof of **Datisi** (from **Darii**) :



Syllogistic proofs (5).

$\langle \mathsf{c}_1, \mathsf{per}_{\mathrm{BC}} \rangle$ is a proof of **Bocardo** by contradiction (from **Barbara**) :



AoB
CaB
AoC

AaC
CaB
AaB

AaB
BaC
AaC

Syllogistic proofs (6).

Let $\mathfrak{B}$ be a set of moods and M be a mood. We write $\mathfrak{B} \vdash M$ if there is $\mathfrak{B}$-proof of M.

Mnemonics (1).

Bárbara, Célarént, Darií, Ferióque prióris,
Césare, Cámestrés, Festíno, Baróco secúndae.
Tértia Dáraptí, Disámis, Datísi, Felápton,
Bocárdo, Feríson habét. Quárta ínsuper áddit
Brámantíp, Camenés, Dimáris, Fesápo, Fresíson.

“These words are more full of meaning than any that were ever made.” (Augustus de Morgan)

Mnemonics (2).

- The first letter indicates to which one of the four perfect moods the mood is to be reduced: ‘B’ to Barbara, ‘C’ to Celarent, ‘D’ to Darii, and ‘F’ to Ferio.
- The letter ‘s’ after the ith vowel indicates that the corresponding proposition has to be simply converted, *i.e.*, a use of s_i.
- The letter ‘p’ after the ith vowel indicates that the corresponding proposition has to be accidentally converted (“*per accidens*”), *i.e.*, a use of p_i.
- The letter ‘c’ after the first or second vowel indicates that the mood has to be proved indirectly by proving the contradictory of the corresponding premiss, *i.e.*, a use of c_i.
- The letter ‘m’ indicates that the premises have to be interchanged (“moved”), *i.e.*, a use of m.
- All other letters have only aesthetic purposes.

A metatheorem.

We call a proposition negative if it has either ‘e’ or ‘o’ as copula.

Theorem (Aristotle). If M is a mood with two negative premises, then

$$\mathfrak{B}_{\mathrm{BCDF}} \not\vdash M.$$

Metaproof (1).

Suppose $\mathsf{o} := \langle \mathsf{o}_1, ..., \mathsf{o}_n \rangle$ is a $\mathfrak{B}_{\mathrm{BCDF}}$-proof of M.

- The s-rules don't change the copula, so if M has two negative premises, then so does $\mathsf{s}_i(M)$.
- The superaltern of a negative proposition is negative and the superaltern of a positive proposition is positive. Therefore, if M has two negative premises, then so does $\mathsf{p}_i(M)$.
- The m-rule and the per-rules don't change the copula either, so if M has two negative premises, then so do $\mathsf{m}(M)$ and $\mathsf{per}_\pi(M)$.

As a consequence, if $\mathsf{o}_1 \neq \mathsf{c}_i$, then $\mathsf{o}(M)$ has two negative premisses.We check that none of **Barbara**, **Celarent**, **Darii** and **Ferio** has two negative premisses, and are done, as o cannot be a proof of M.

Metaproof (2).

So, $\mathsf{o}_1 = \mathsf{c}_i$ for either $i = 1$ or $i = 2$. By definition of c_i, this means that the contradictory of one of the premisses is the conclusion of $\mathsf{o}_1(M)$. Since the premisses were negative, the conclusion of $\mathsf{o}_1(M)$ is positive. Since the other premiss of M is untouched by o_1, we have that $\mathsf{o}_1(M)$ has at least one negative premiss and a positive conclusion. The rest of the proof $\langle \mathsf{o}_2, ..., \mathsf{o}_n \rangle$ may not contain any instances of c_i.

Note that none of the rules s, p, m and per change the copula of the conclusion from positive to negative.

So, $\mathsf{o}(M)$ still has at least one negative premiss and a positive conclusion. Checking **Barbara**, **Celarent**, **Darii** and **Ferio** again, we notice that none of them is of that form. Therefore, o is not a $\mathfrak{B}_{\mathrm{BCDF}}$-proof of M. Contradiction. q.e.d.

Other metatheoretical results.

- If M has two particular premises (i.e., with copulae ‘i’ or ‘o’), then $\mathrm{BCDF} \not\vdash M$ (**Exercise 8**).
- If M has a positive conclusion and one negative premiss, then $\mathrm{BCDF} \not\vdash M$.
- If M has a negative conclusion and one positive premiss, then $\mathrm{BCDF} \not\vdash M$.
- If M has a universal conclusion (i.e., with copula ‘a’ or ‘e’) and one particular premiss, then $\mathrm{BCDF} \not\vdash M$.

Aristotelian modal logic.

Modalities.

- $\mathbf{A}p \doteq$ "p" (no modality, "assertoric").
- $\mathbf{N}p \doteq$ "necessarily p".
- $\mathbf{P}p \doteq$ "possibly p" (equivalently, "not necessarily not p").
- $\mathbf{C}p \doteq$ "contingently p" (equivalently, "not necessarily not p and not necessarily not p").

Every (assertoric) mood $p, q : r$ represents a modal mood $\mathbf{A}p, \mathbf{A}q : \mathbf{A}r$. For each mood, we combinatorially have $4^3 = 64$ modalizations, i.e., $256 \times 64 = 16384$ modal moods.

Modal conversions.

- **Simple.**
  - $\mathbf{N}X\mathrm{e}Y \rightsquigarrow \mathbf{N}Y\mathrm{e}X$
  - $\mathbf{N}X\mathrm{i}Y \rightsquigarrow \mathbf{N}Y\mathrm{i}X$
  - $\mathbf{C}X\mathrm{e}Y \rightsquigarrow \mathbf{C}Y\mathrm{e}X$
  - $\mathbf{C}X\mathrm{i}Y \rightsquigarrow \mathbf{C}Y\mathrm{i}X$
  - $\mathbf{P}X\mathrm{e}Y \rightsquigarrow \mathbf{P}Y\mathrm{e}X$
  - $\mathbf{P}X\mathrm{i}Y \rightsquigarrow \mathbf{P}Y\mathrm{i}X$
- **Accidental.**
  - $\mathbf{N}X\mathrm{a}Y \rightsquigarrow \mathbf{N}X\mathrm{i}Y$
  - $\mathbf{C}X\mathrm{a}Y \rightsquigarrow \mathbf{C}X\mathrm{i}Y$
  - $\mathbf{P}X\mathrm{a}Y \rightsquigarrow \mathbf{P}X\mathrm{i}Y$
  - $\mathbf{N}X\mathrm{e}Y \rightsquigarrow \mathbf{N}X\mathrm{o}Y$
  - $\mathbf{C}X\mathrm{e}Y \rightsquigarrow \mathbf{C}X\mathrm{o}Y$
  - $\mathbf{P}X\mathrm{e}Y \rightsquigarrow \mathbf{P}X\mathrm{o}Y$
- **Relating to the symmetric nature of contingency.**
  - $\mathbf{C}X\mathrm{i}Y \rightsquigarrow \mathbf{C}X\mathrm{e}Y$
  - $\mathbf{C}X\mathrm{e}Y \rightsquigarrow \mathbf{C}X\mathrm{i}Y$
  - $\mathbf{C}X\mathrm{a}Y \rightsquigarrow \mathbf{C}X\mathrm{o}Y$
  - $\mathbf{C}X\mathrm{o}Y \rightsquigarrow \mathbf{C}X\mathrm{a}Y$
- $\mathbf{N}X\mathrm{x}Y \rightsquigarrow \mathbf{A}X\mathrm{x}Y$
  (Axiom $\mathbf{T}$: $\Box\varphi \rightarrow \varphi$)

Modal axioms.

What are the “perfect modal syllogisms”?

- Valid assertoric syllogisms remain valid if $\mathbf{N}$ is added to all three propositions.

  Barbara $(A\mathrm{a}B, B\mathrm{a}C{:}A\mathrm{a}C) \rightsquigarrow$ **NNN Barbara** $(\mathbf{N}A\mathrm{a}B, \mathbf{N}B\mathrm{a}C{:}\mathbf{N}A\mathrm{a}C)$.

  First complications in the arguments for **Bocardo** and **Baroco**.

- By our conversion rules, the following can be added to valid assertoric syllogisms:
  - $\mathbf{NNA}$,
  - $\mathbf{NAA}$,
  - $\mathbf{ANA}$.
- Anything else is problematic.

The “two Barbaras”.

NAN Barbara

$$\begin{array}{c} \mathbf{N}A\mathrm{a}B \\ \mathbf{A}B\mathrm{a}C \\ \hline \mathbf{N}A\mathrm{a}C \end{array}$$

ANN Barbara

$$\begin{array}{c} \mathbf{A}A\mathrm{a}B \\ \mathbf{N}B\mathrm{a}C \\ \hline \mathbf{N}A\mathrm{a}C \end{array}$$

From the modern point of view, both modal syllogisms are invalid, yet Aristotle claims that **NAN Barbara** is valid, but **ANN Barbara** is not.

***De dicto* versus *De re*.**

We interpreted $\mathbf{N}A\mathrm{a}B$ as

"The statement '$A\mathrm{a}B$' is necessarily true.'

(*De dicto* interpretation of necessity.)

Alternatively, we could interpret $\mathbf{N}A\mathrm{a}B$ *de re* (Becker 1933):

"Every B happens to be something which is necessarily an A."