How to Solve the Zebra Problem

M.R.C. van Dongen

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Problem Formulation

There are five houses of different colours, inhabited by different nationals, with different pets, drinks, and sports.

Furthermore, there are the following 14 additional constraints which I have changed for the occasion:

1. The Englishman lives in the red house.
2. The Spaniard owns a dog.
3. The man in the green house drinks coffee.
4. The Irishman drinks tea.
5. The green house is to the right of the ivory house.

6. The Go player owns snails.
7. The man in the yellow house plays cricket.
8. The guy in the house int he middle drinks milk.
9. The Nigerian lives in the first house.[1]
10. The judo player lives next to the man who has a fox.
11. The cricketer lives next to the man who has a horse.
12. The poker player drinks orange juice.
13. The Japanese plays polo.

[1] Originally, this was “at the end” but this would make the problem too easy.

14. The Nigerian lives next to the blue house.

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The question is:

14. The Nigerian lives next to the blue house.

The question is: Who owns the zebra

14. The Nigerian lives next to the blue house.

The question is: Who owns the zebra and who drinks Guinness?

Some History

According to folklore, the Zebra Problem was designed by the English logician Charles Lutwidge Dodgson (a.k.a. Lewis Carroll. Born: 27 Jan 1832, Died: 14 Jan 1898).

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Modeling the Problem

We can model the problem as a CSP. We number the houses (left to right) from 1 to 5. We then assign houses to things and we reduce the problem to the following:

- The number assigned to the person who drinks Guinness is the same as the number assigned to Guinness;
- The number assigned to the person who owns the zebra is the same as the number assigned to the zebra.

nationalities Englishman $= A_1$, Spaniard $= A_2$, Irishman $= A_3$, Nigerian $= A_4$, Japanese $= A_5$.

plays go $= B_1$, cricket $= B_2$, judo $= B_3$, poker $= B_4$, polo $= B_5$.

drinks coffee $= C_1$, tea $= C_2$, milk $= C_3$, orange juice $= C_4$, Guinness $= C_5$,

pets dog $= D_1$, snails $= D_2$, fox $= D_3$, horse $= D_4$, zebra $= D_5$.

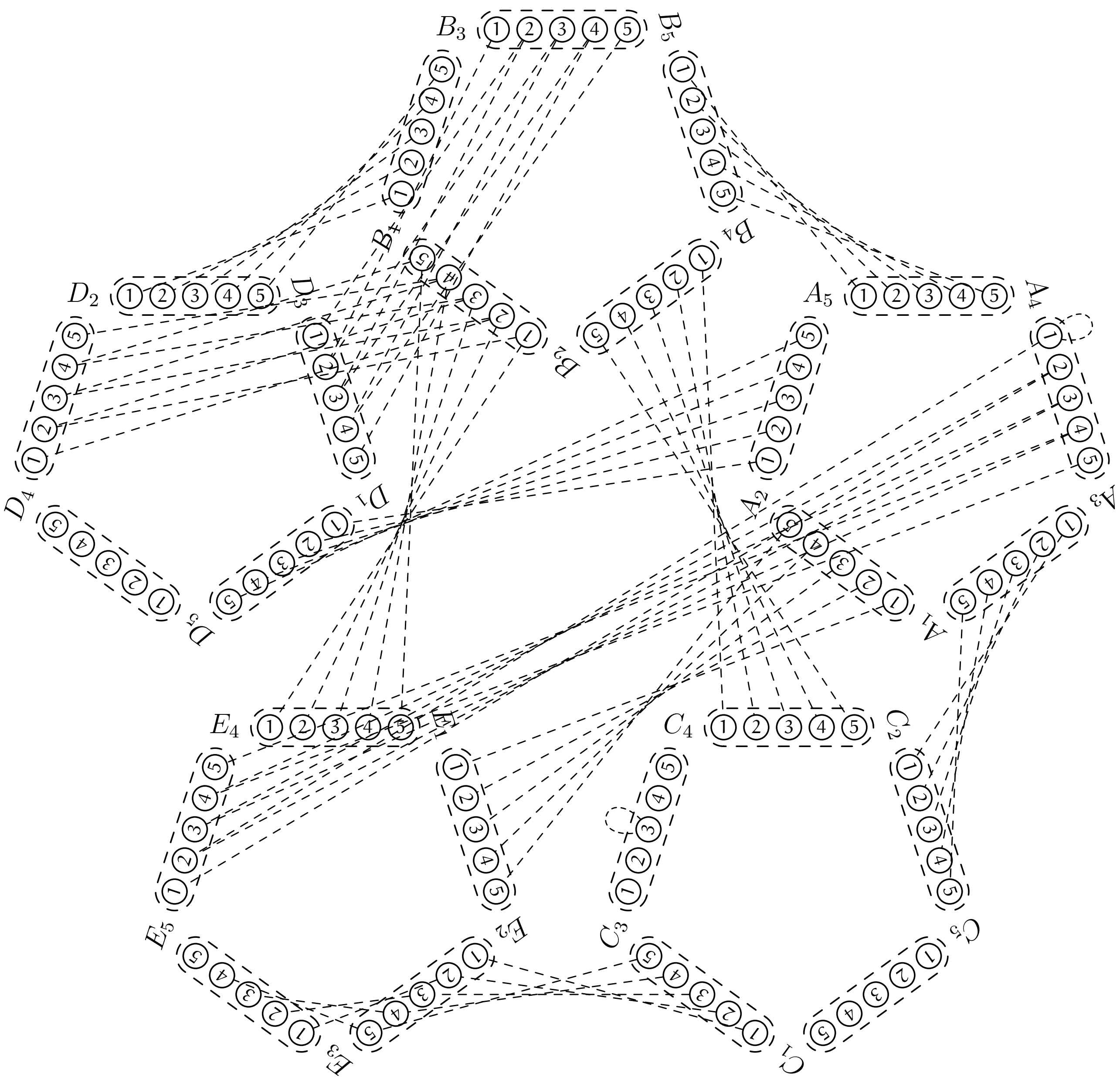
colours red $= E_1$, green $= E_2$, ivory $= E_3$, yellow $= E_4$, blue $= E_5$.

If X is a letter then $X_i \neq X_j \iff i \neq j$. Furthermore, we have:

1. The Englishman (A_1) lives in the red (E_1) house: $A_1 = E_1$.
2. The Spaniard (A_2) owns a dog (D_1): $A_2 = D_1$.
3. The man in the green (E_2) house drinks coffee (C_1): $E_2 = C_1$.
4. The Irishman (A_3) drinks tea (C_2): $A_3 = C_2$.
5. The green (E_2) house is to the right of the ivory (E_3) house: $E_2 - E_3 = 1$.
6. The Go (B_1) player owns snails (D_2): $B_1 = D_2$.
7. The man in the yellow (E_4) house plays cricket (B_2): $E_4 = B_2$.

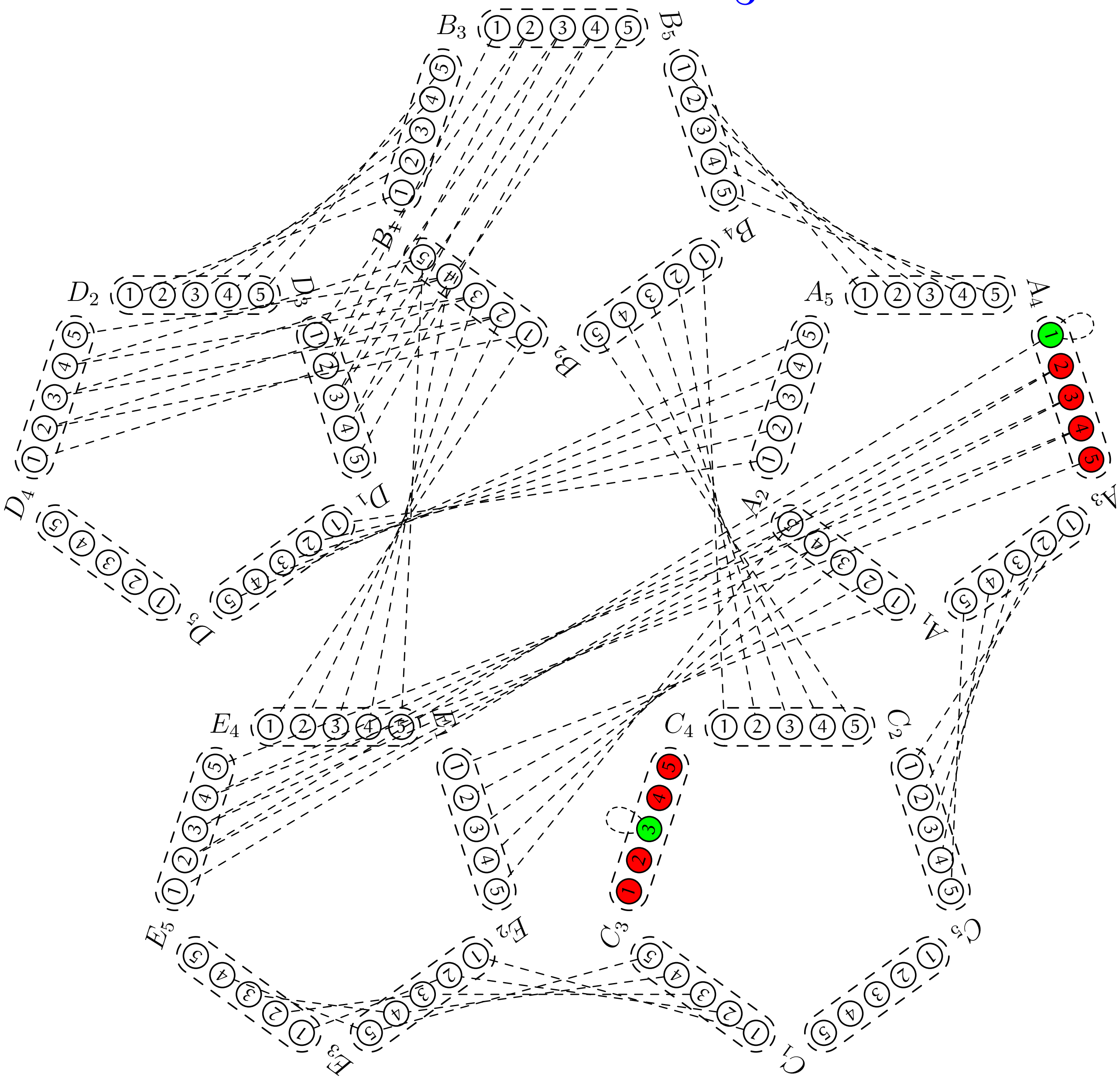
8. The guy in the house in the middle drinks milk (C_3): $C_3 = 3$.
9. The Nigerian (A_4) lives in the first house: $A_4 = 1$.
10. The Judo (B_3) player lives next to the man who has a fox (D_3): $|\,B_3 - D_3\,| = 1$.
11. The cricketer (B_2) lives next to the man who has a horse (D_4): $|\,B_2 - D_4\,| = 1$.
12. The poker (B_4) player drinks orange juice (C_4): $B_4 = C_4$.
13. The Japanese (A_5) plays polo (B_5): $A_5 = B_5$.
14. The Nigerian (A_4) lives next to the blue (E_5) house: $|\,A_4 - E_5\,| = 1$.

Initial CSP.



A_1	Englishman
A_2	Spaniard
A_3	Irishman
A_4	Nigerian
A_5	Japanese
B_1	go
B_2	cricket
B_3	judo
B_4	poker
B_5	polo
C_1	coffee
C_2	tea
C_3	milk
C_4	orange juice
C_5	Guinness
D_1	dog
D_2	snails
D_3	fox
D_4	horse
D_5	zebra
E_1	red
E_2	green
E_3	ivory
E_4	yellow
E_5	blue

Because of the **unary** constraints (Rules 8 and 9) A_4 must be 1 and C_3 must be 3.



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E_1	red
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E_4	yellow
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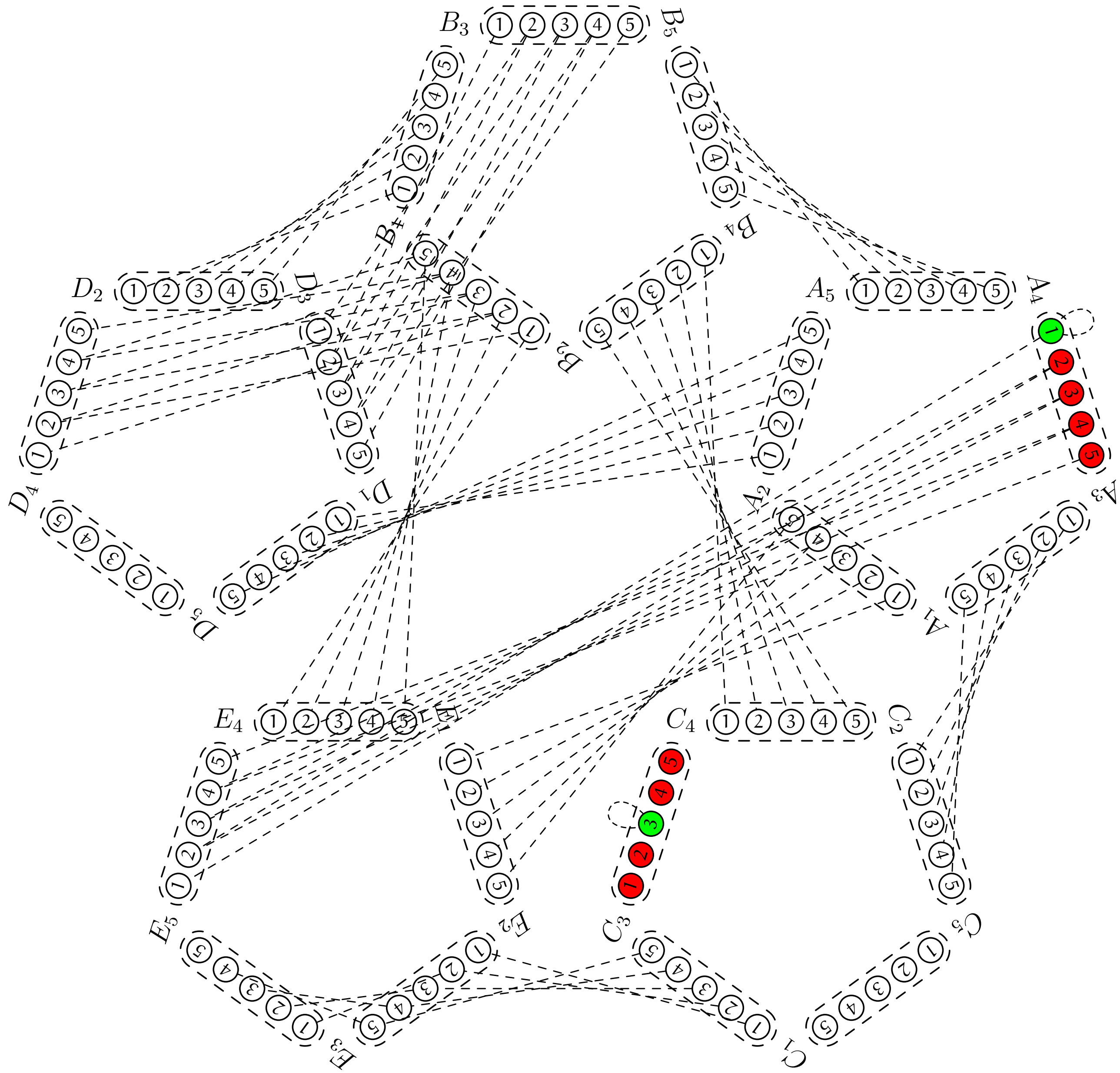
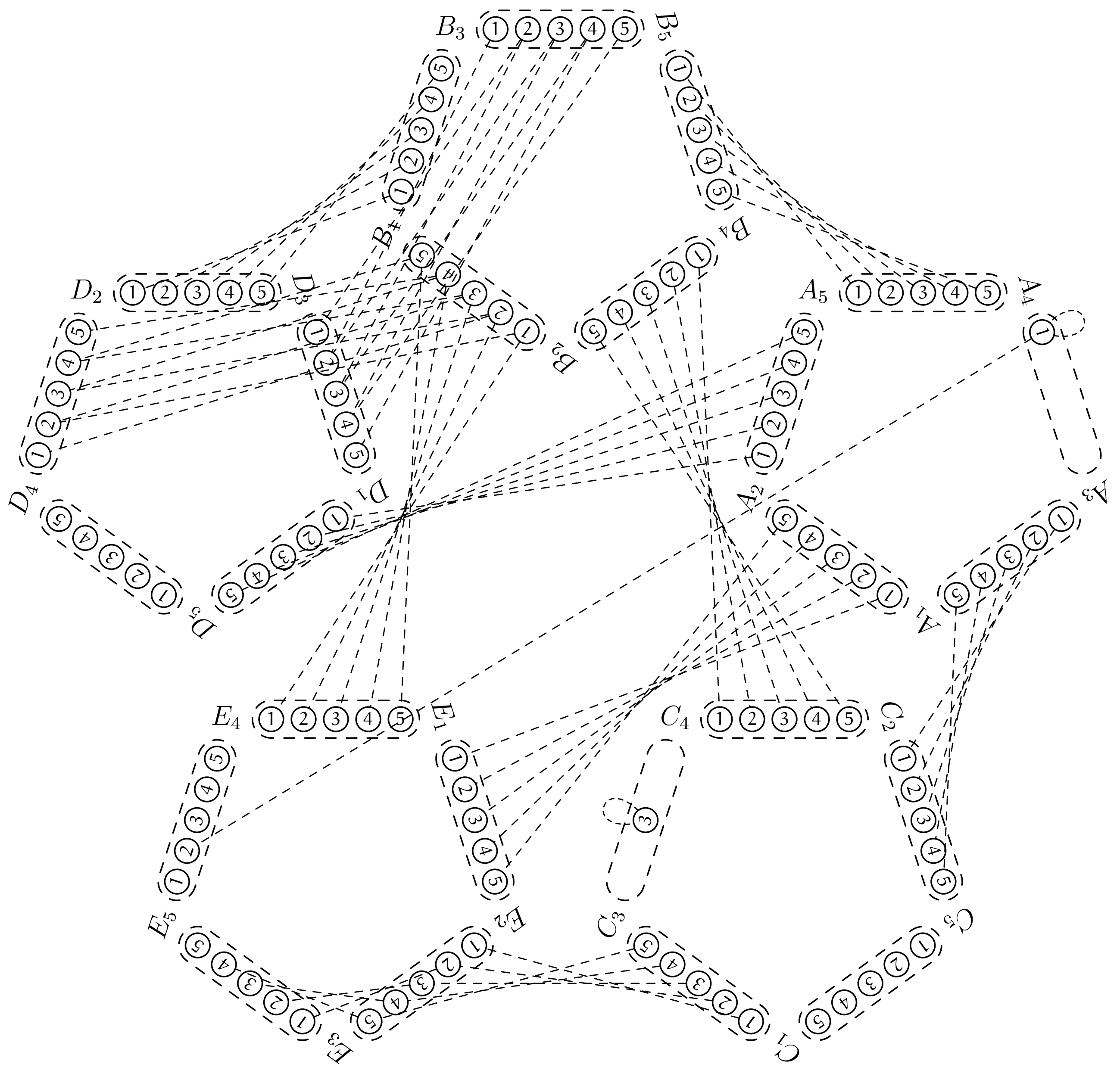
We can remove the red values.



A_1 Englishman
A_2 Spaniard
A_3 Irishman
A_4 Nigerian
A_5 Japanese
B_1 go
B_2 cricket
B_3 judo
B_4 poker
B_5 polo
C_1 coffee
C_2 tea
C_3 milk
C_4 orange juice
C_5 Guinness
D_1 dog
D_2 snails
D_3 fox
D_4 horse
D_5 zebra
E_1 red
E_2 green
E_3 ivory
E_4 yellow
E_5 blue

The resulting CSP is called **Node-Consistent**.



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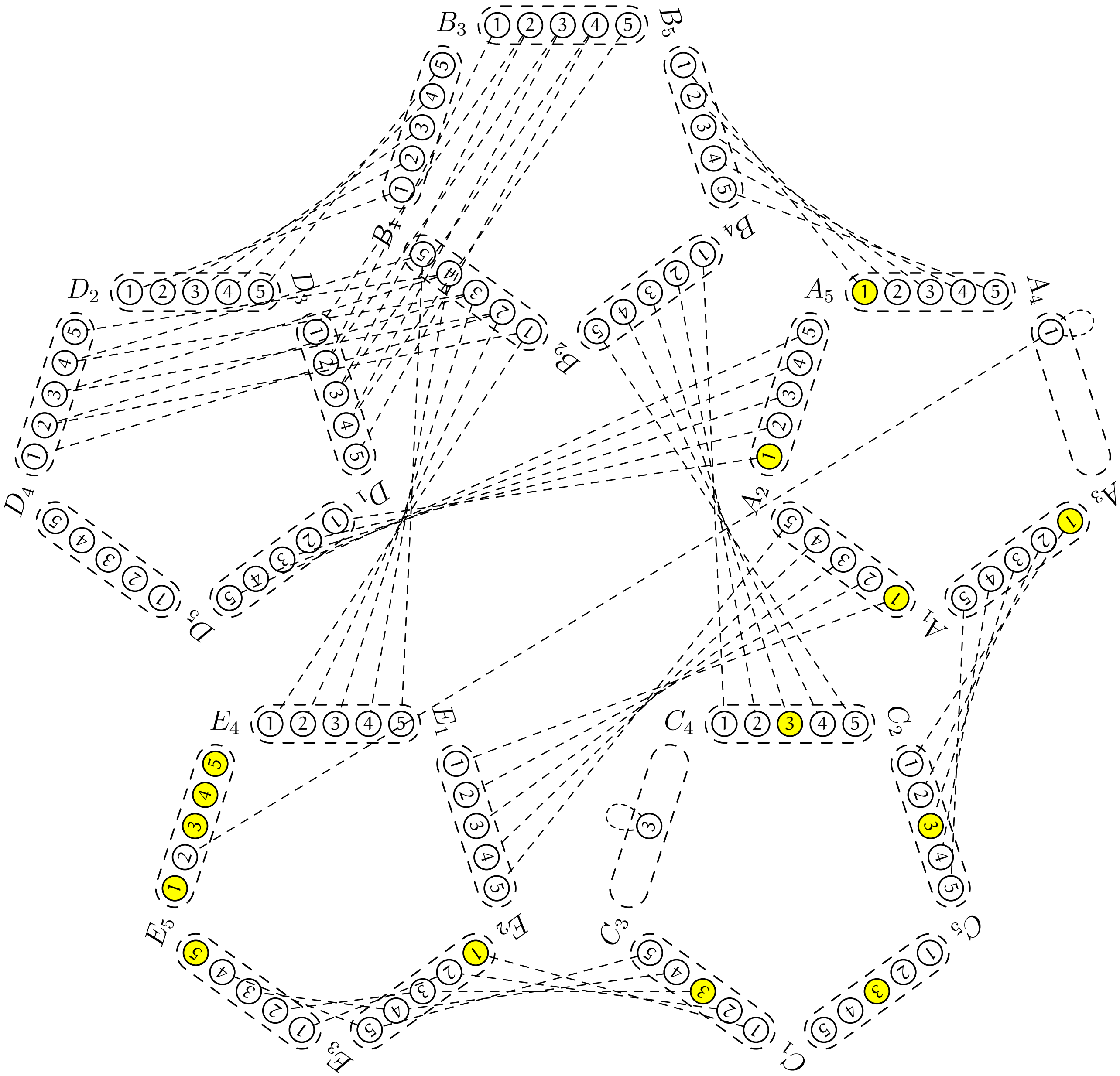
D_1	dog
D_2	snails
D_3	fox
D_4	horse
D_5	zebra
E_1	red
E_2	green
E_3	ivory
E_4	yellow
E_5	blue

Some Values have no Support.



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D_5	zebra
E_1	red
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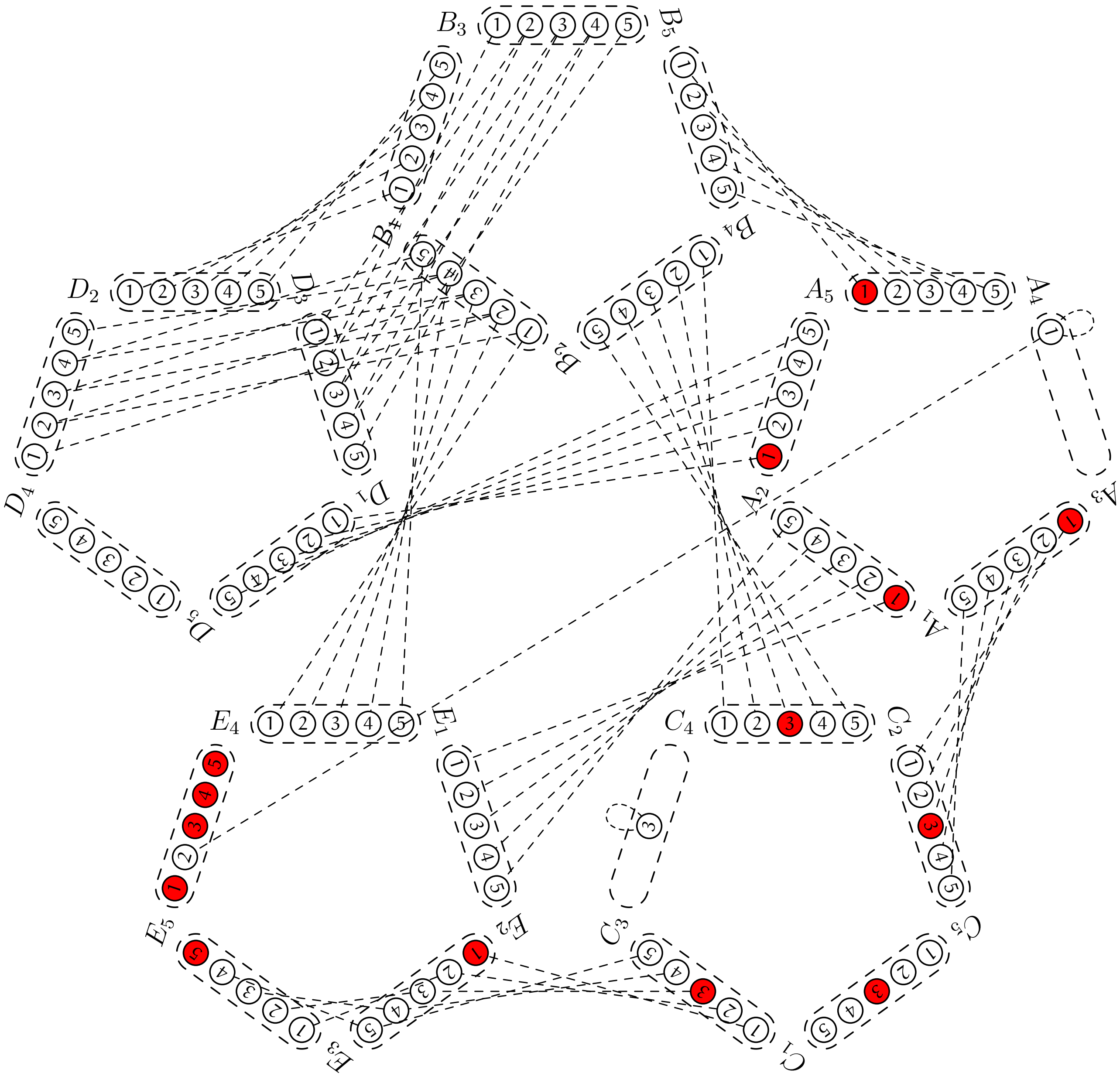
E_4	yellow
E_5	blue

Let's mark them for removal and colour them red.



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D_5	zebra
E_1	red
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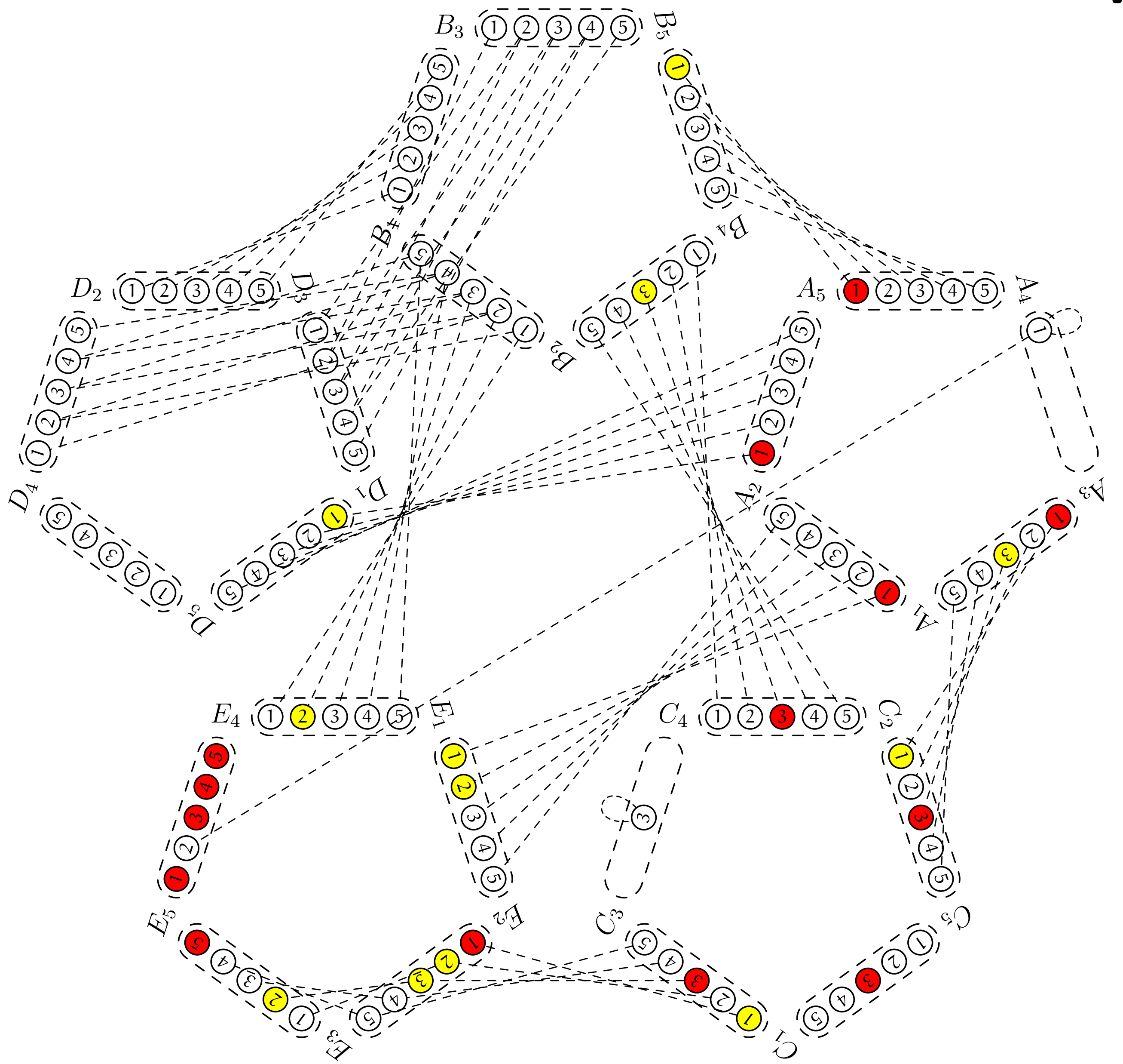
E_3	ivory
E_4	yellow
E_5	blue

If we **propagate** the consequences of removing the red values, more values will lose support.



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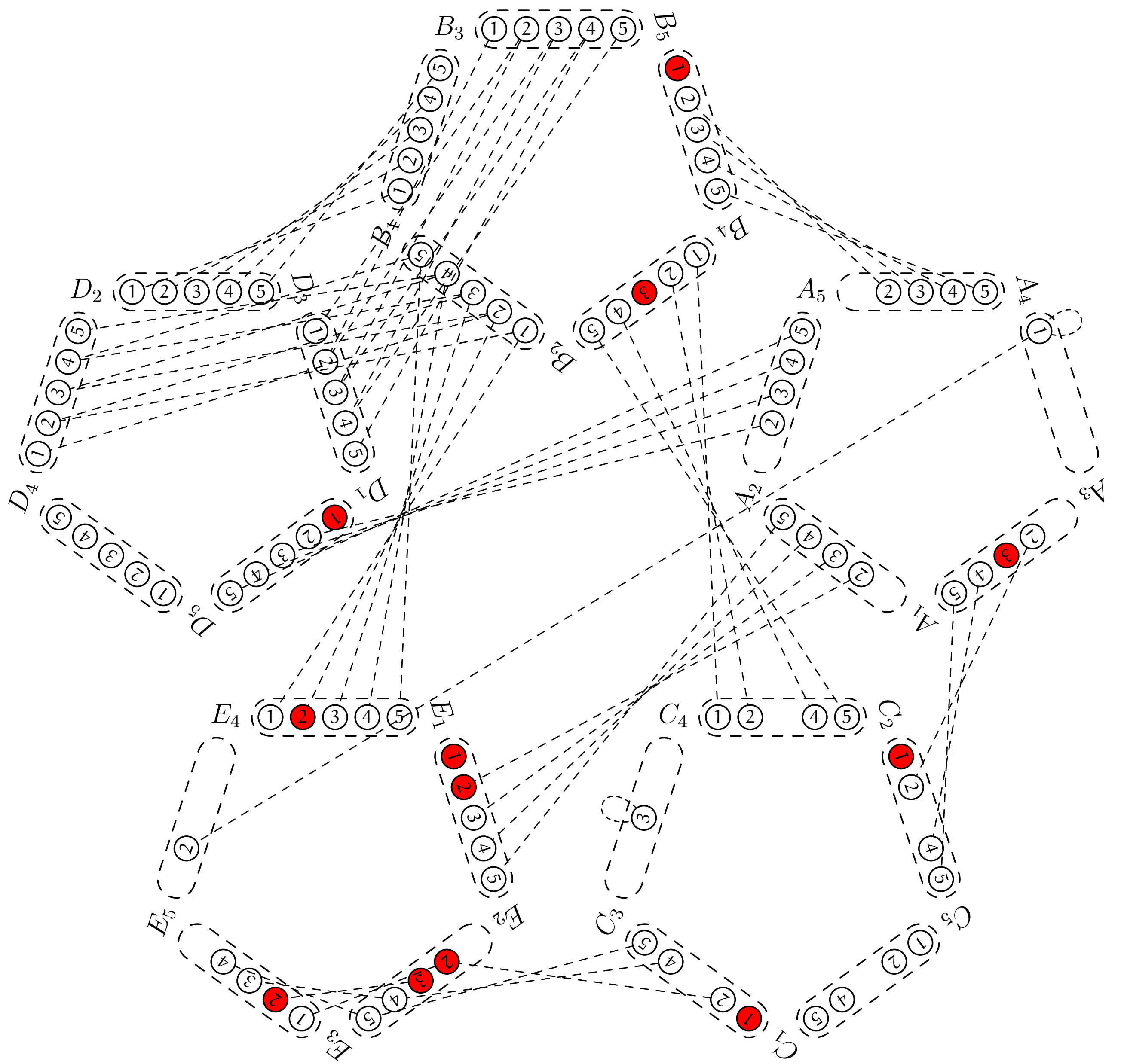
Remove



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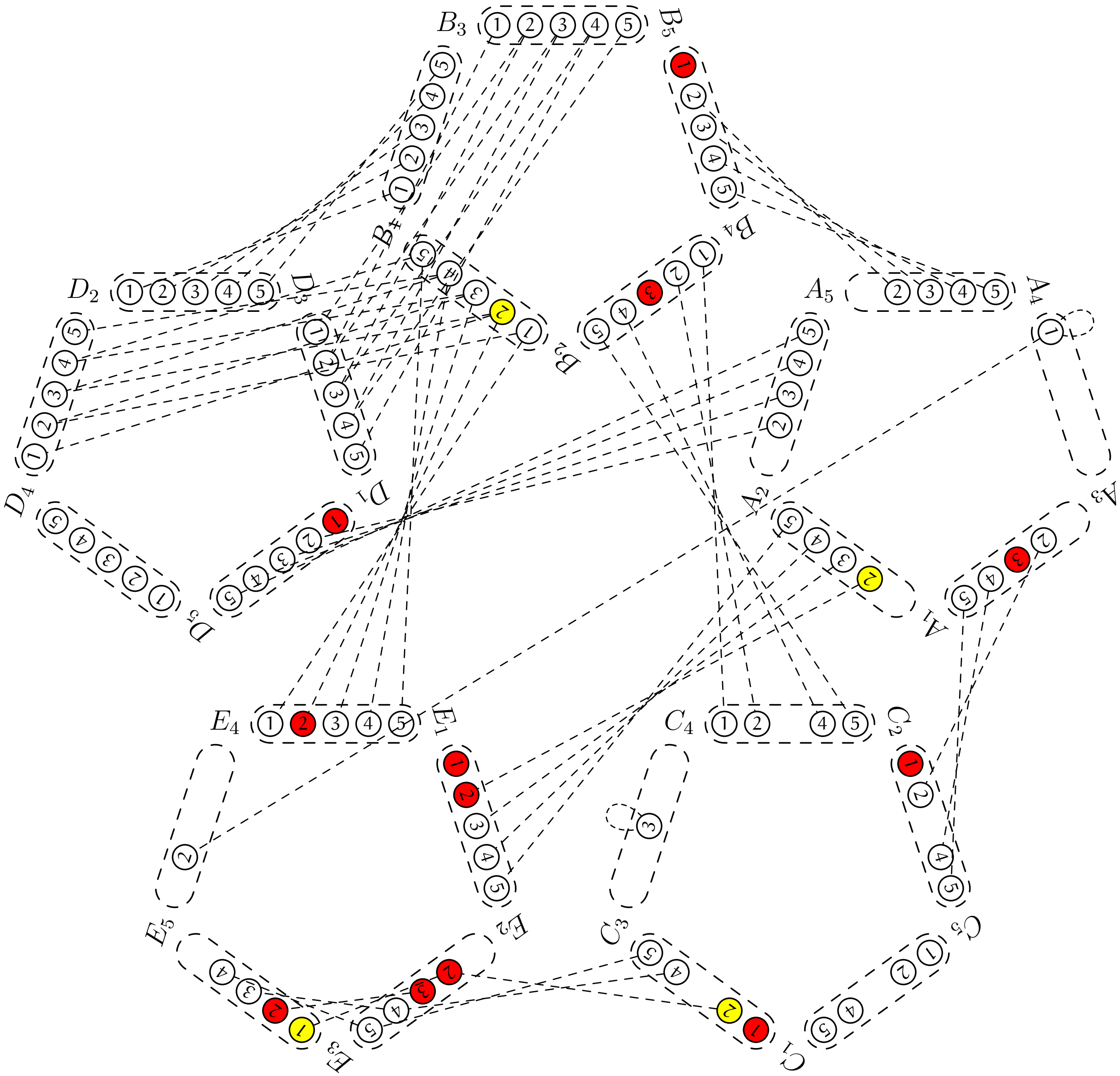
and Propagate.



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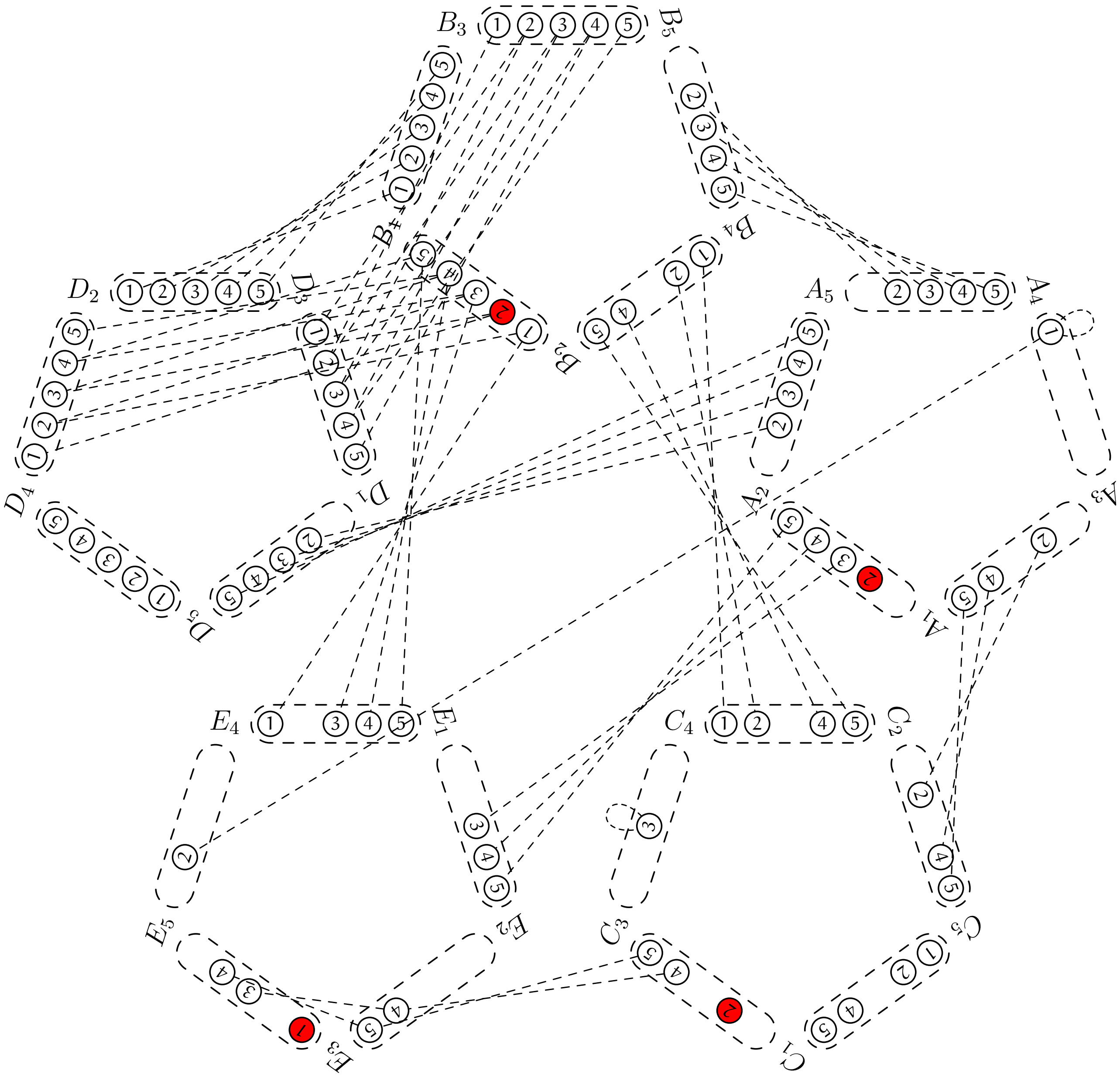
More Propagation.



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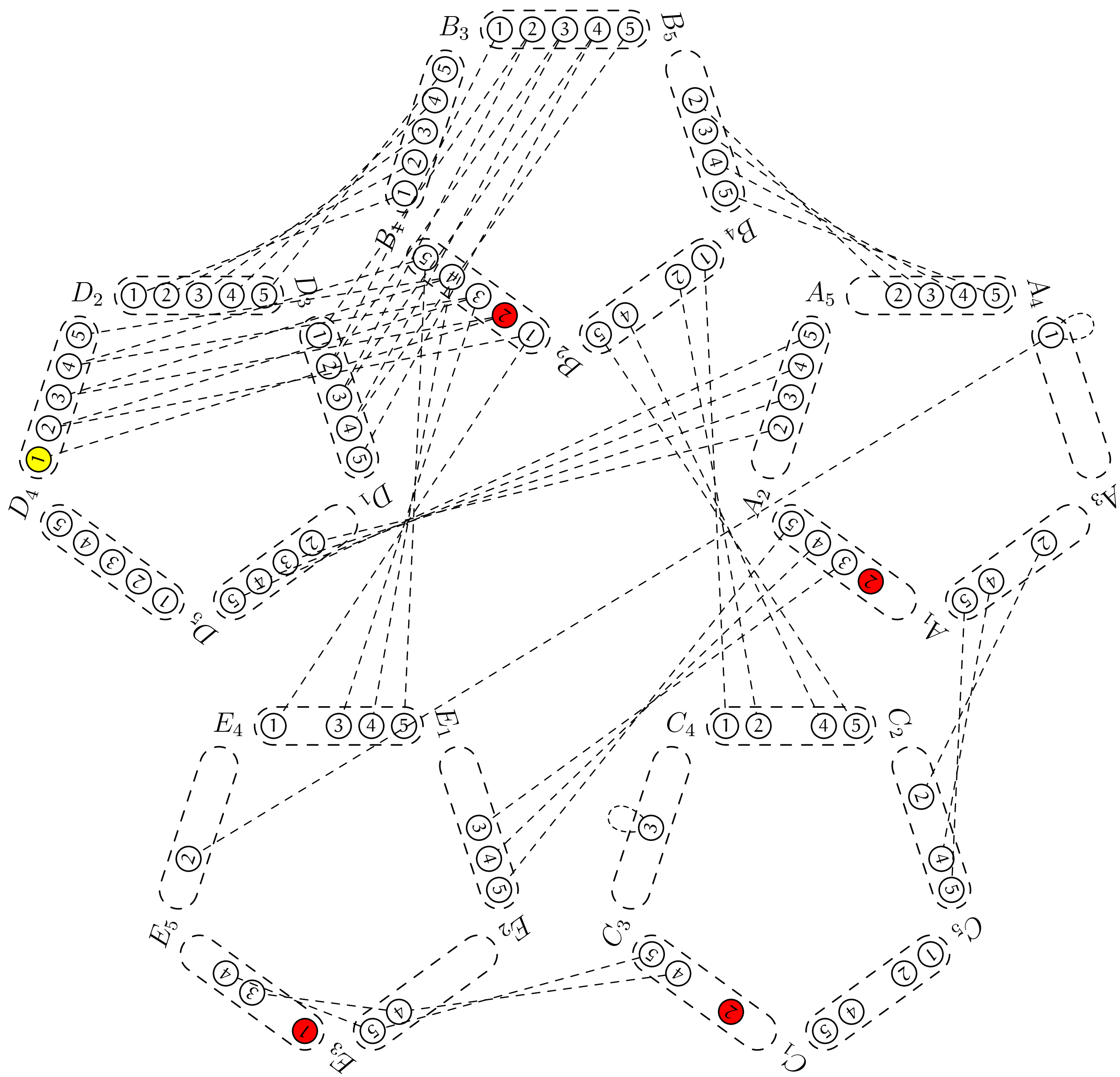
More Values will lose Support.



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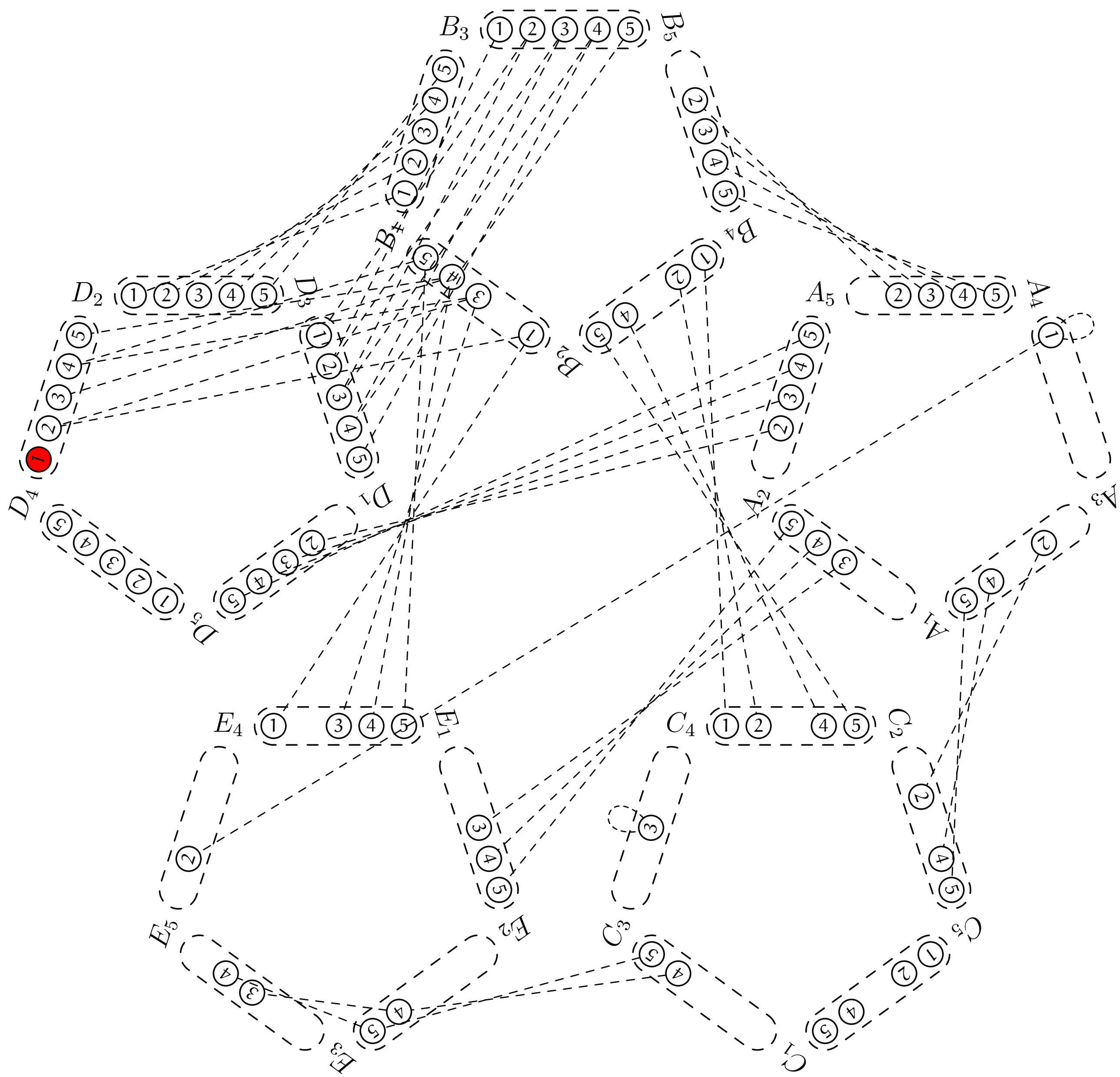

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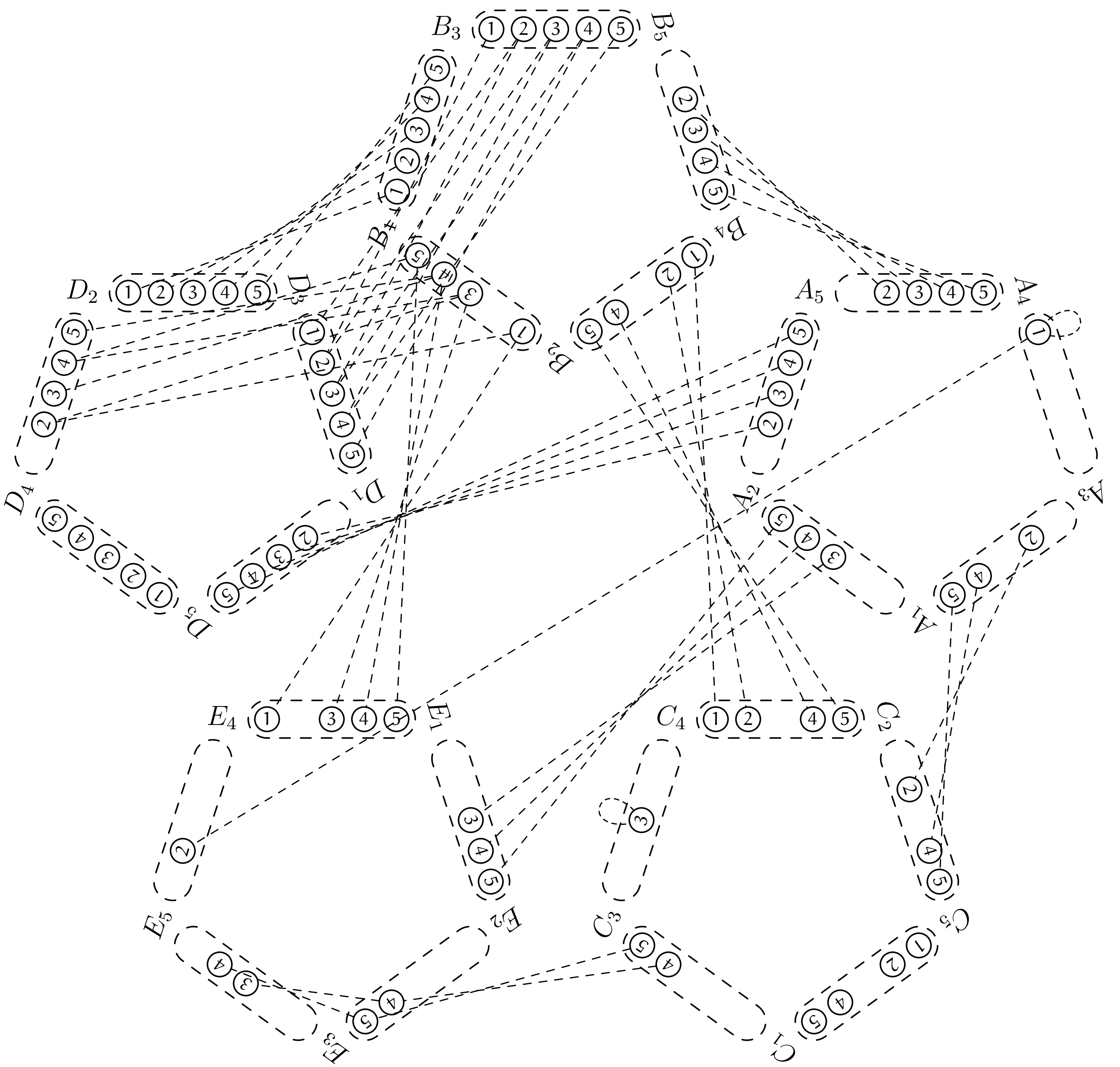
We have reached a Fix-point



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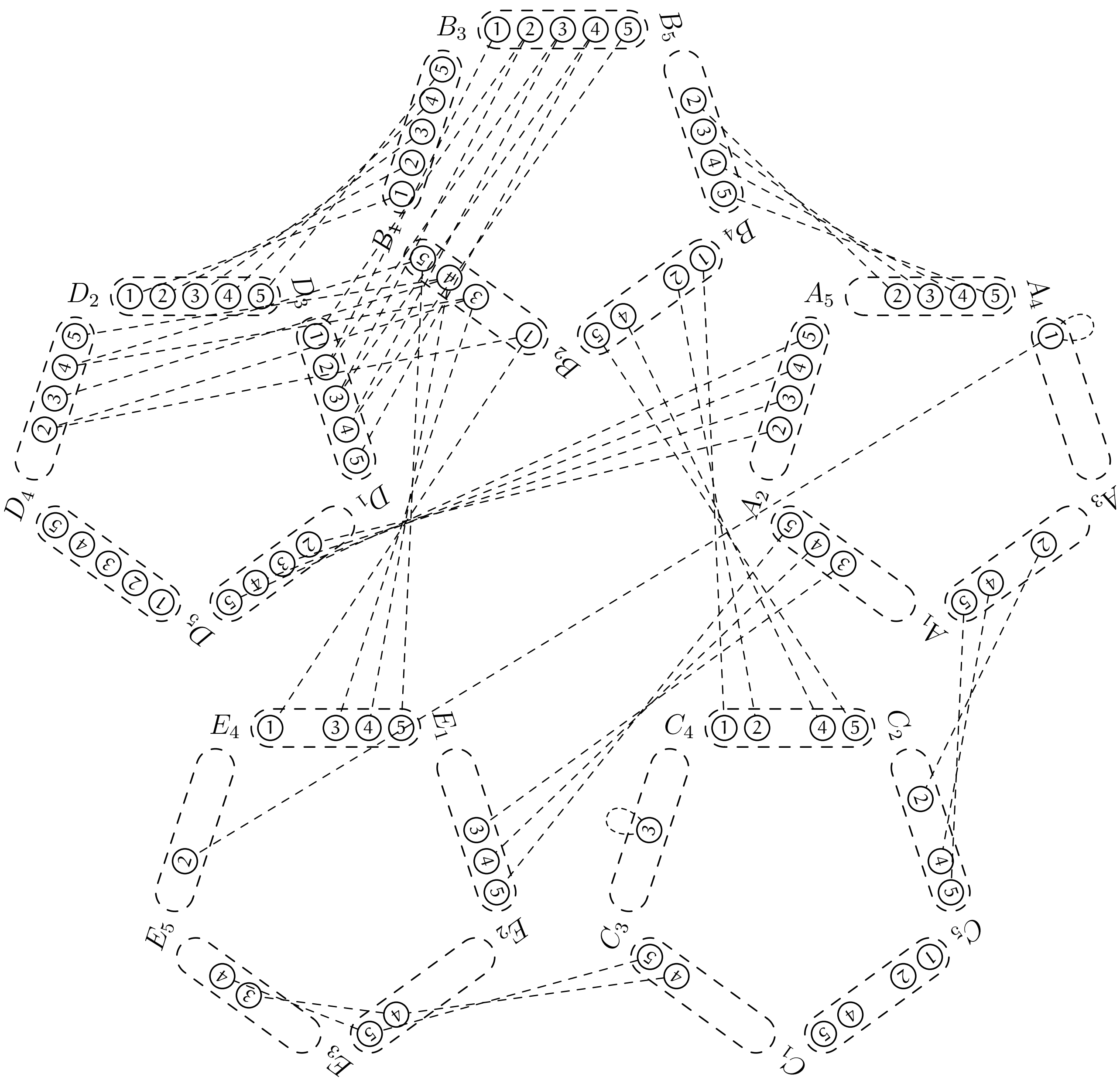
The resulting CSP is called **Arc-consistent**.



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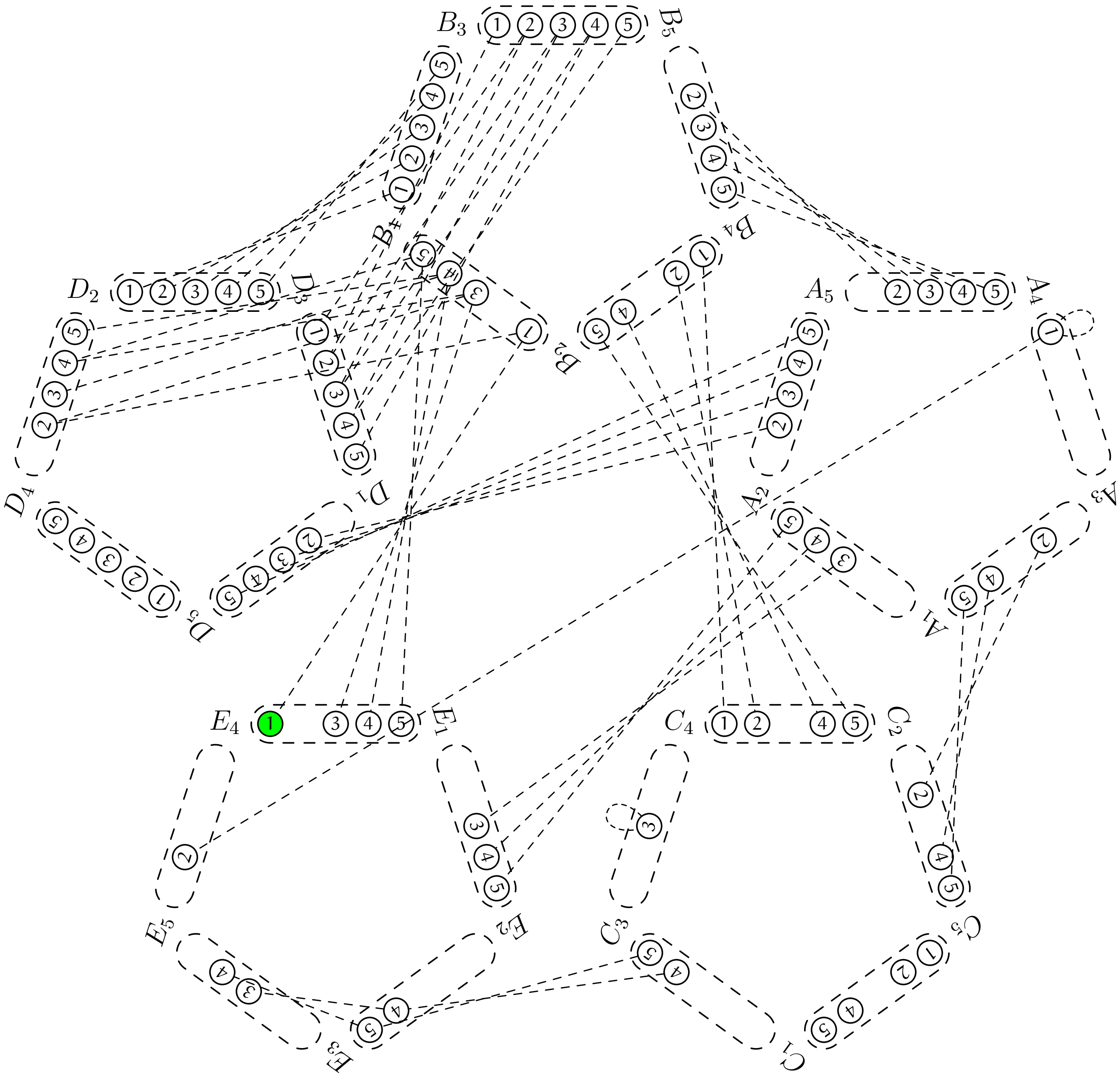
E_4's domain contains 1.



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E_1	red
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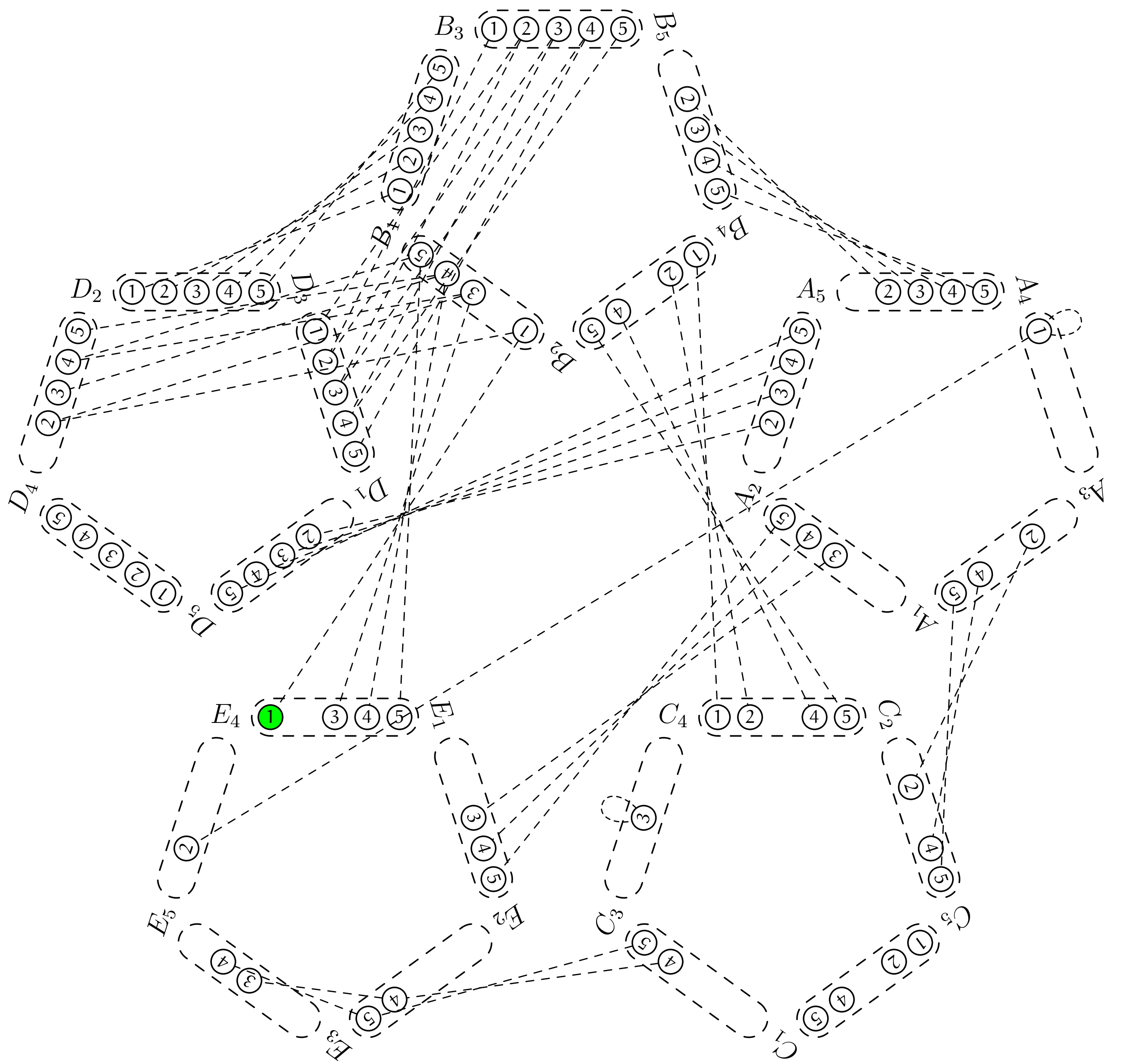
E_4	yellow
E_5	blue

The domains of the other E_i do not contain 1.



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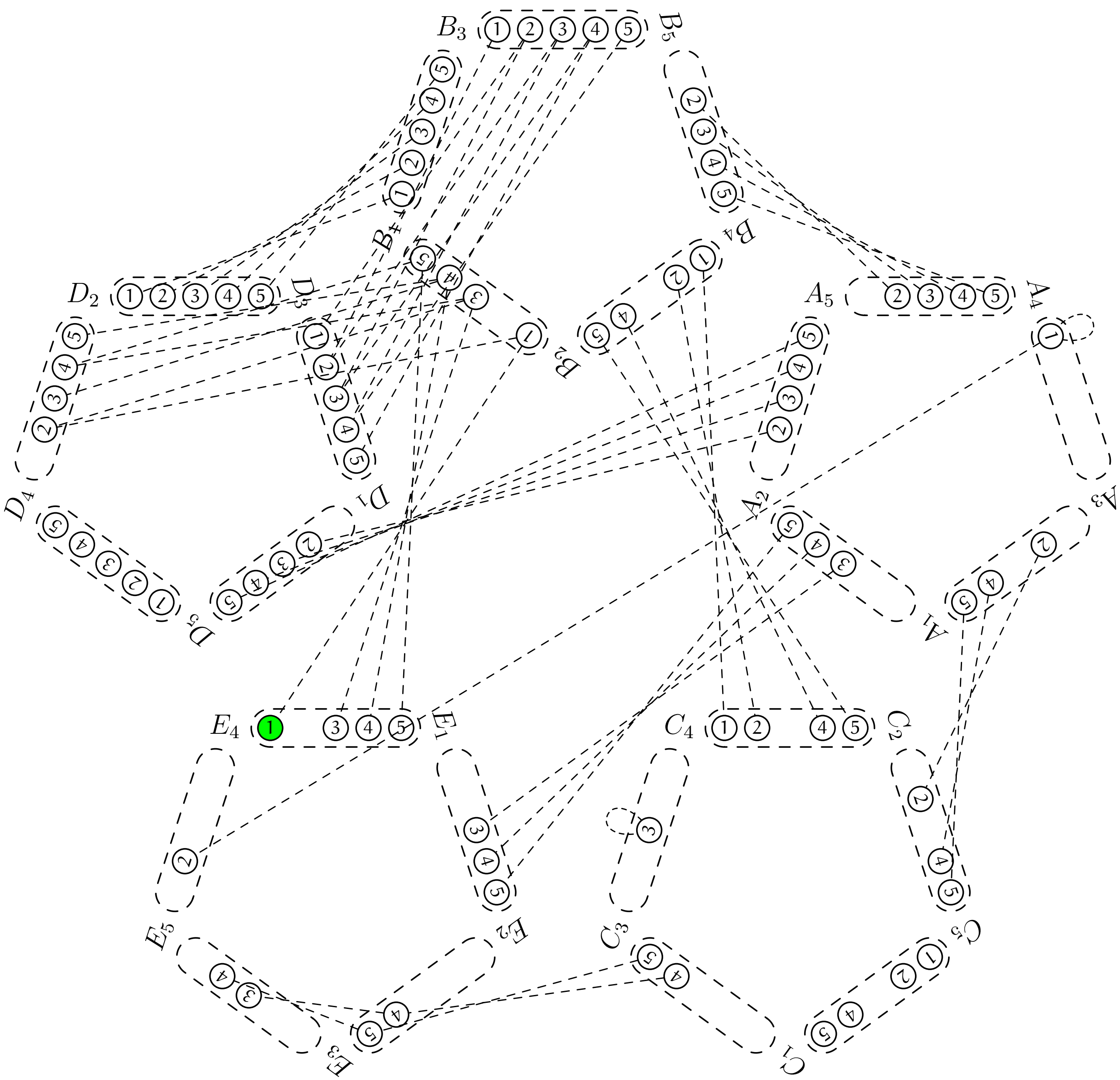
E_4 must be 1.



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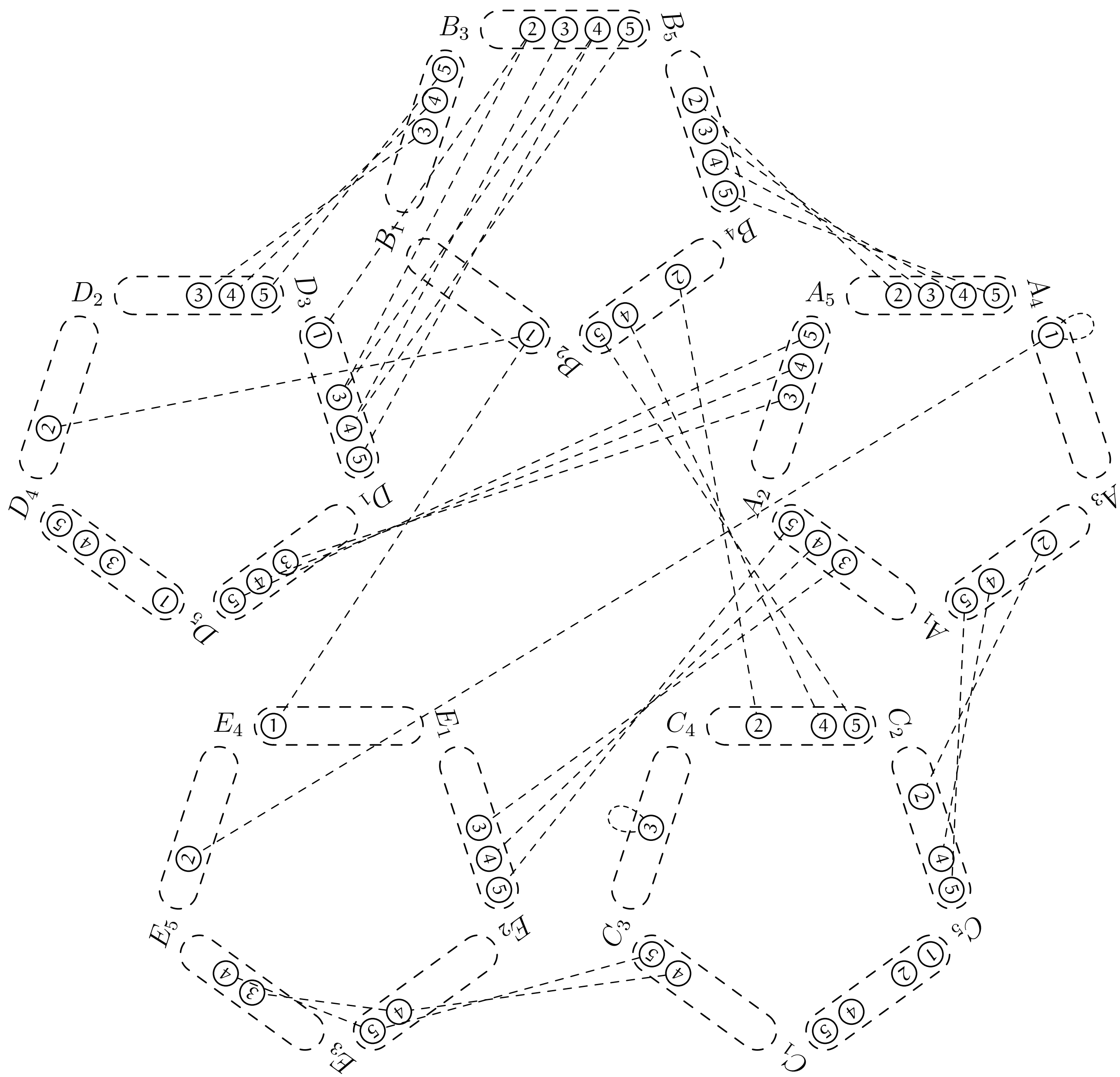
C_2 tea
C_3 milk
C_4 orange juice
C_5 Guinness
D_1 dog
D_2 snails
D_3 fox
D_4 horse
D_5 zebra
E_1 red
E_2 green
E_3 ivory
E_4 yellow
E_5 blue

After Assignment $E_4 = 1$ and Arc-Consistency.



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D_3	fox
D_4	horse
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E_1	red
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E_4	yellow
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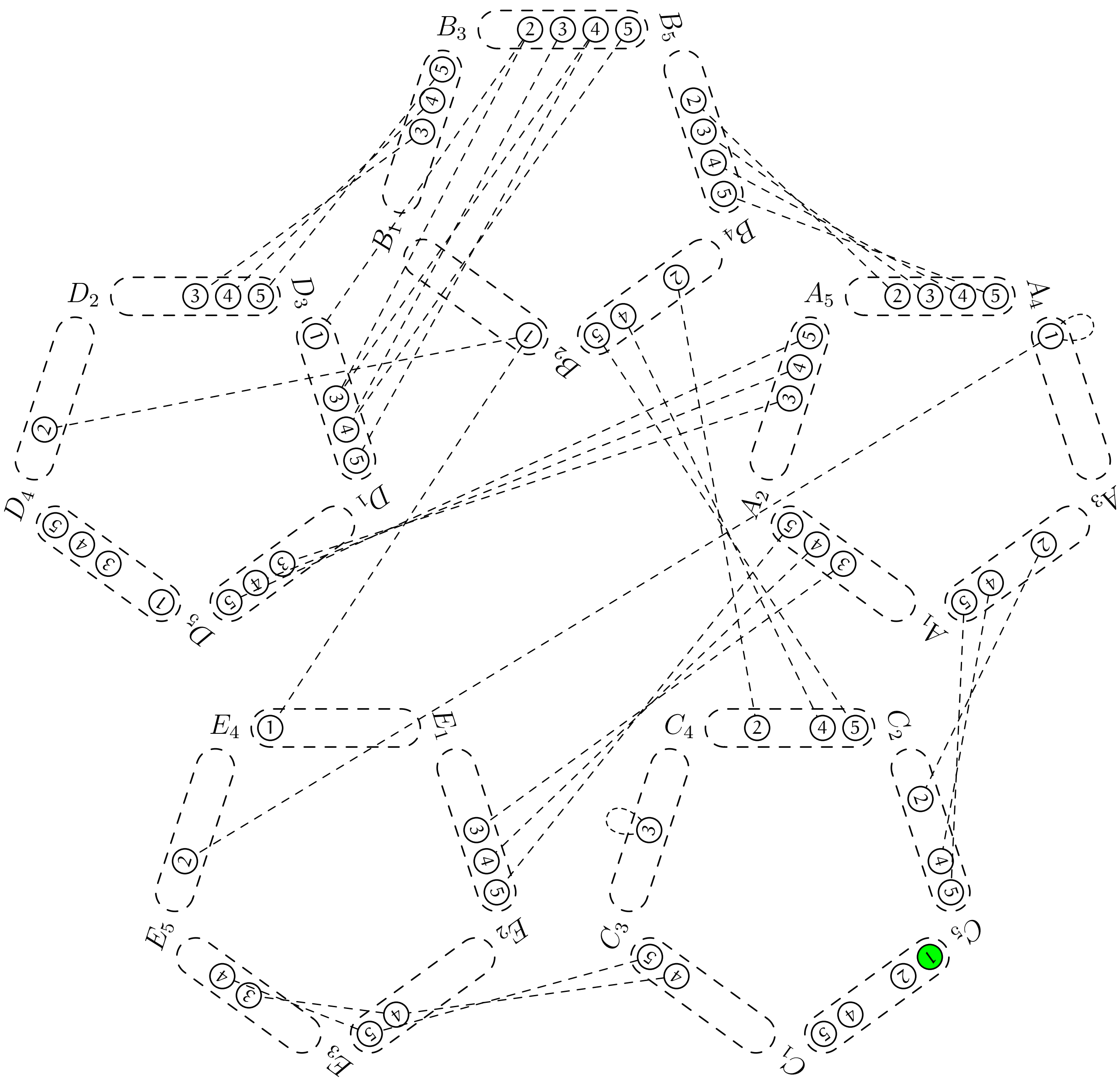
C_5's domain contains 1.



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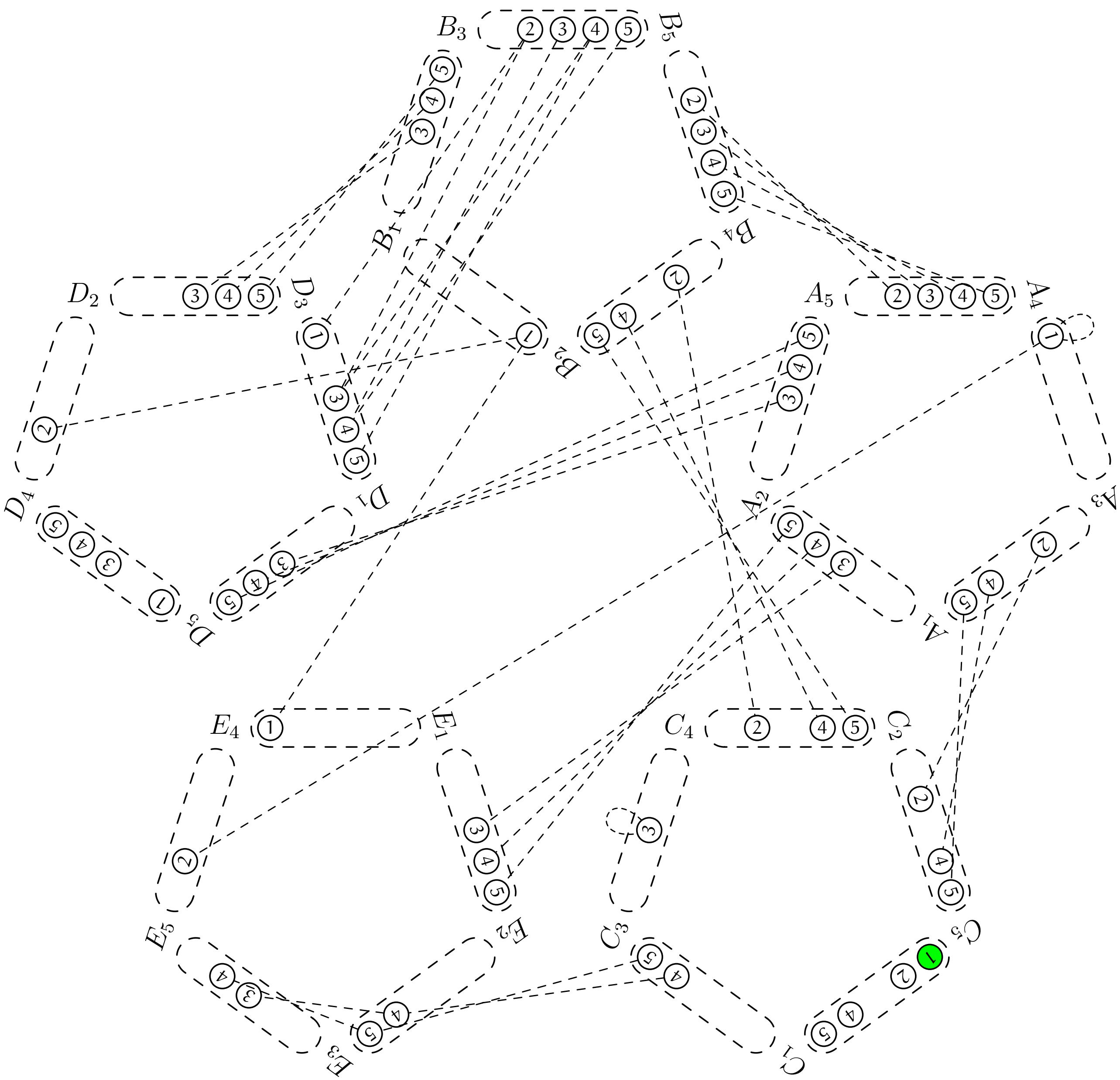
The domains of the other C_i do not contain 1.



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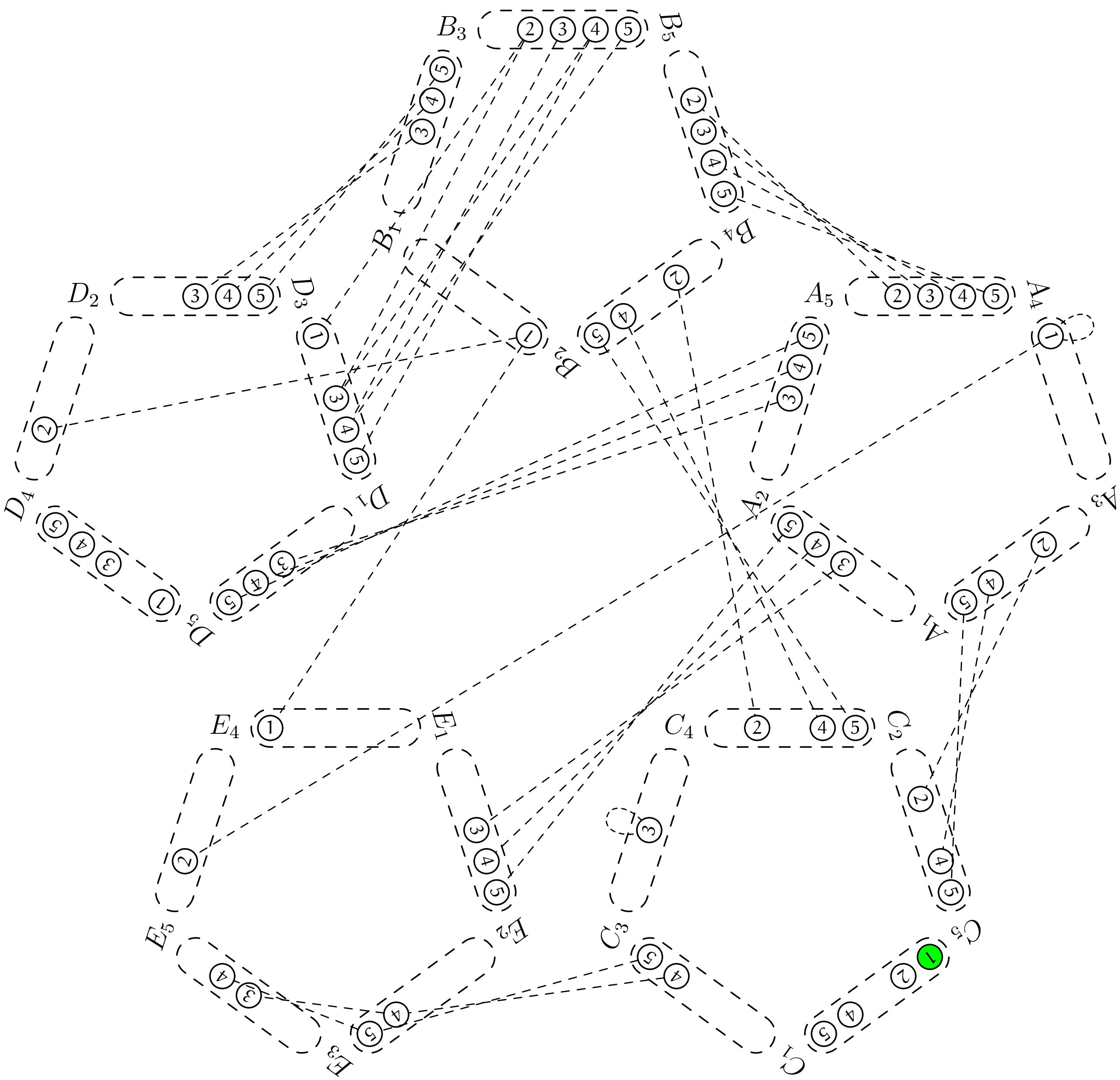
C_5 must be 1.



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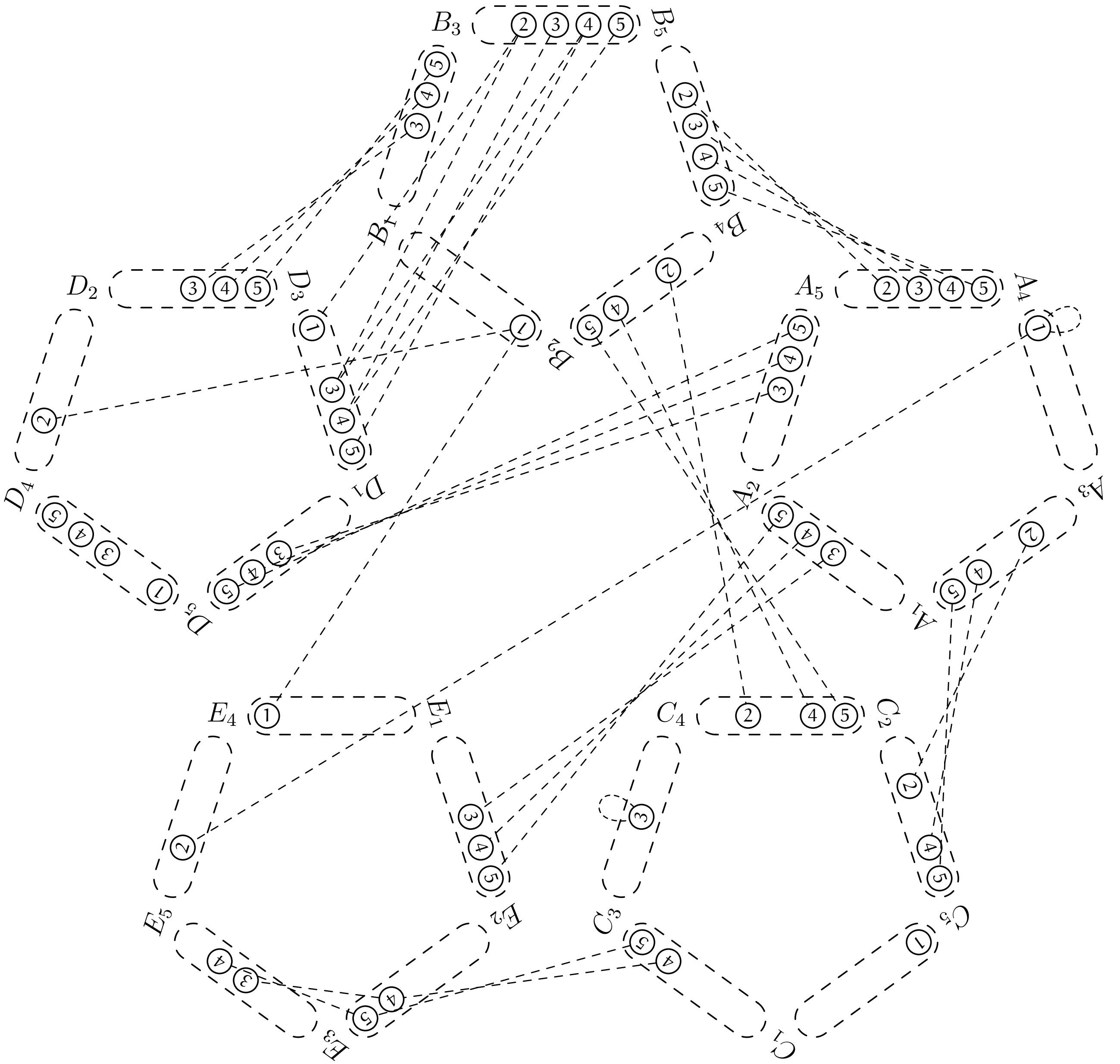
After Assignment $C_5 = 1$ and Arc-Consistency.



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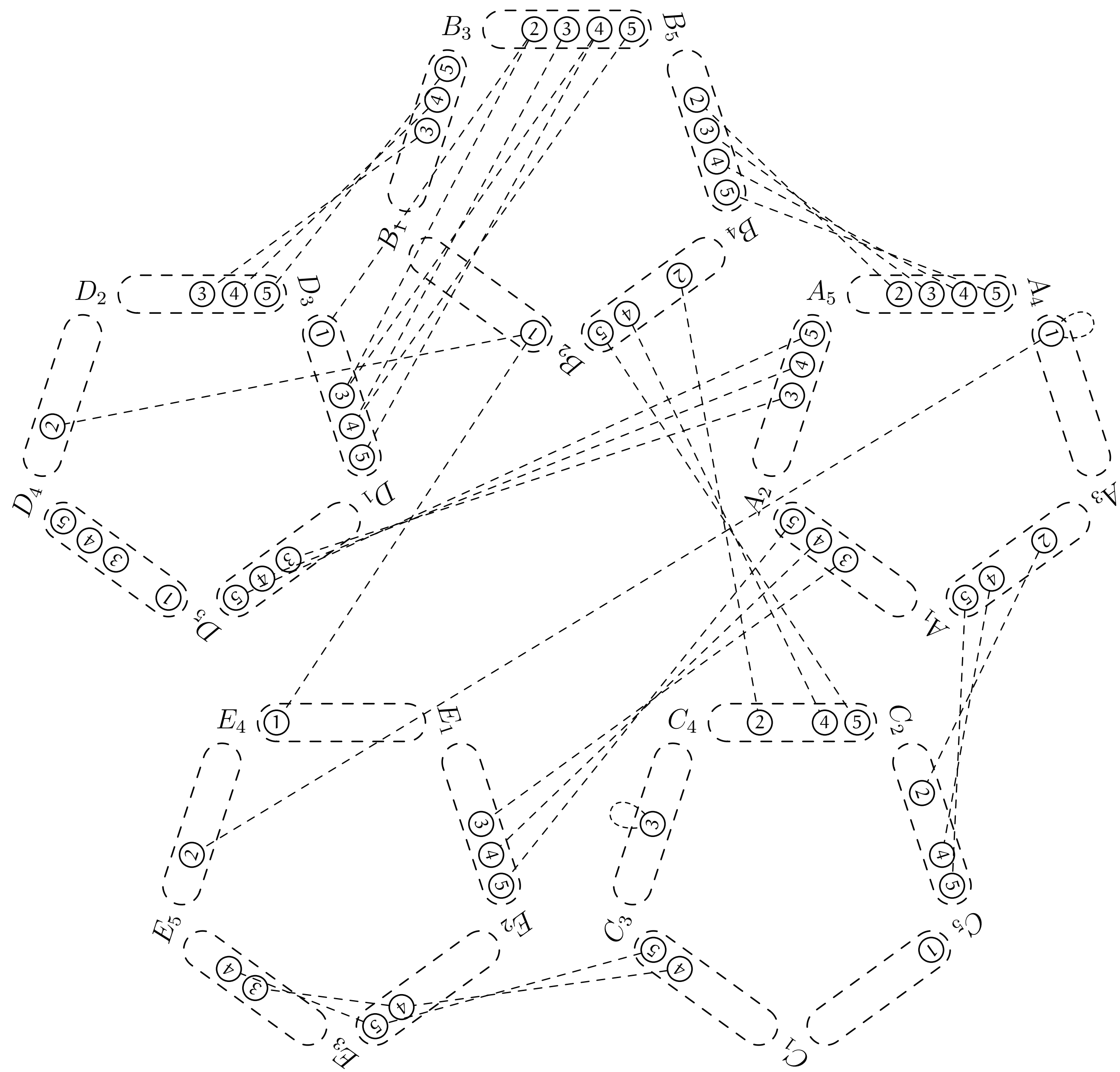
Start MAC-Search (Maintain Arc-Consistency).



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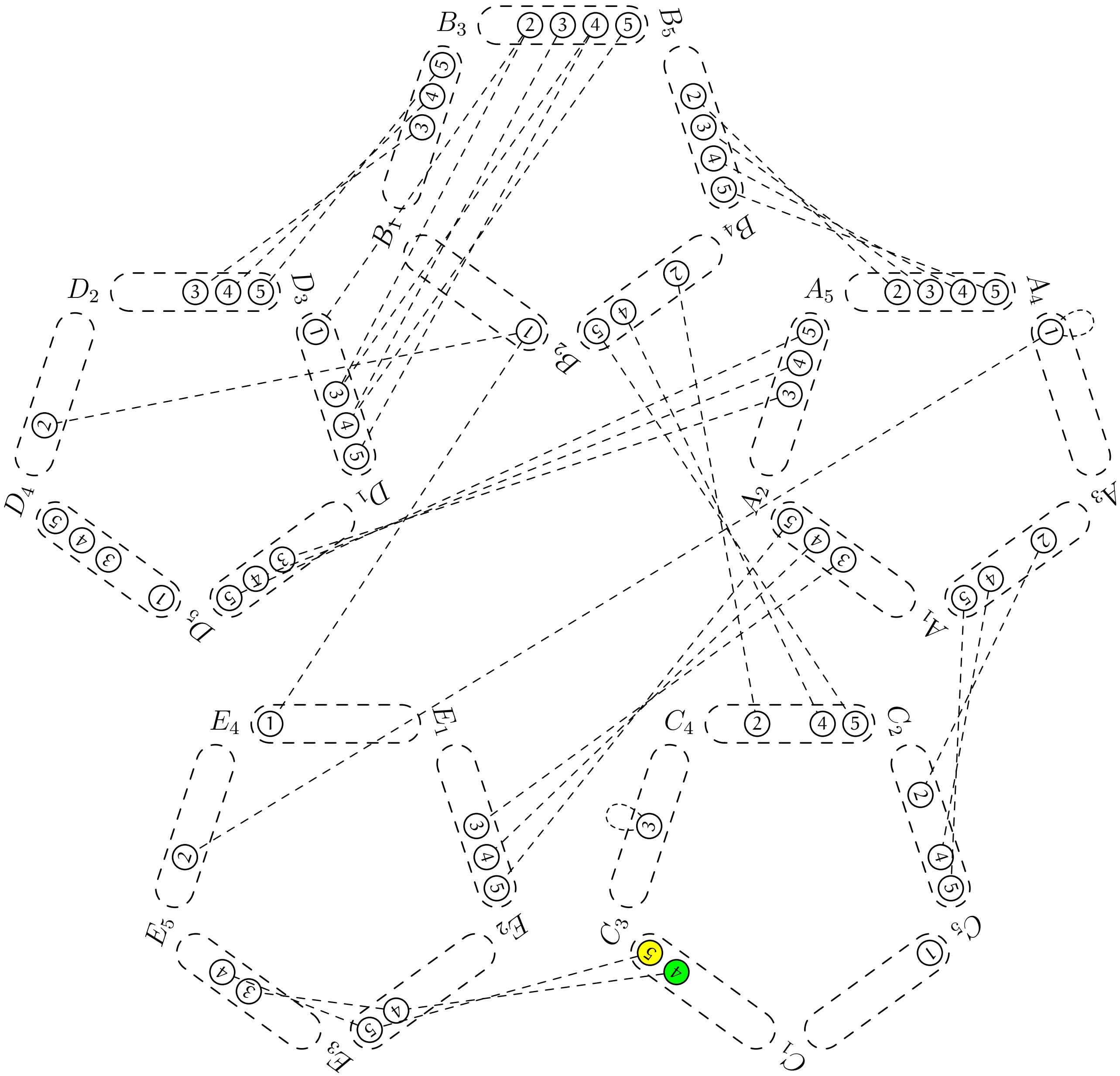
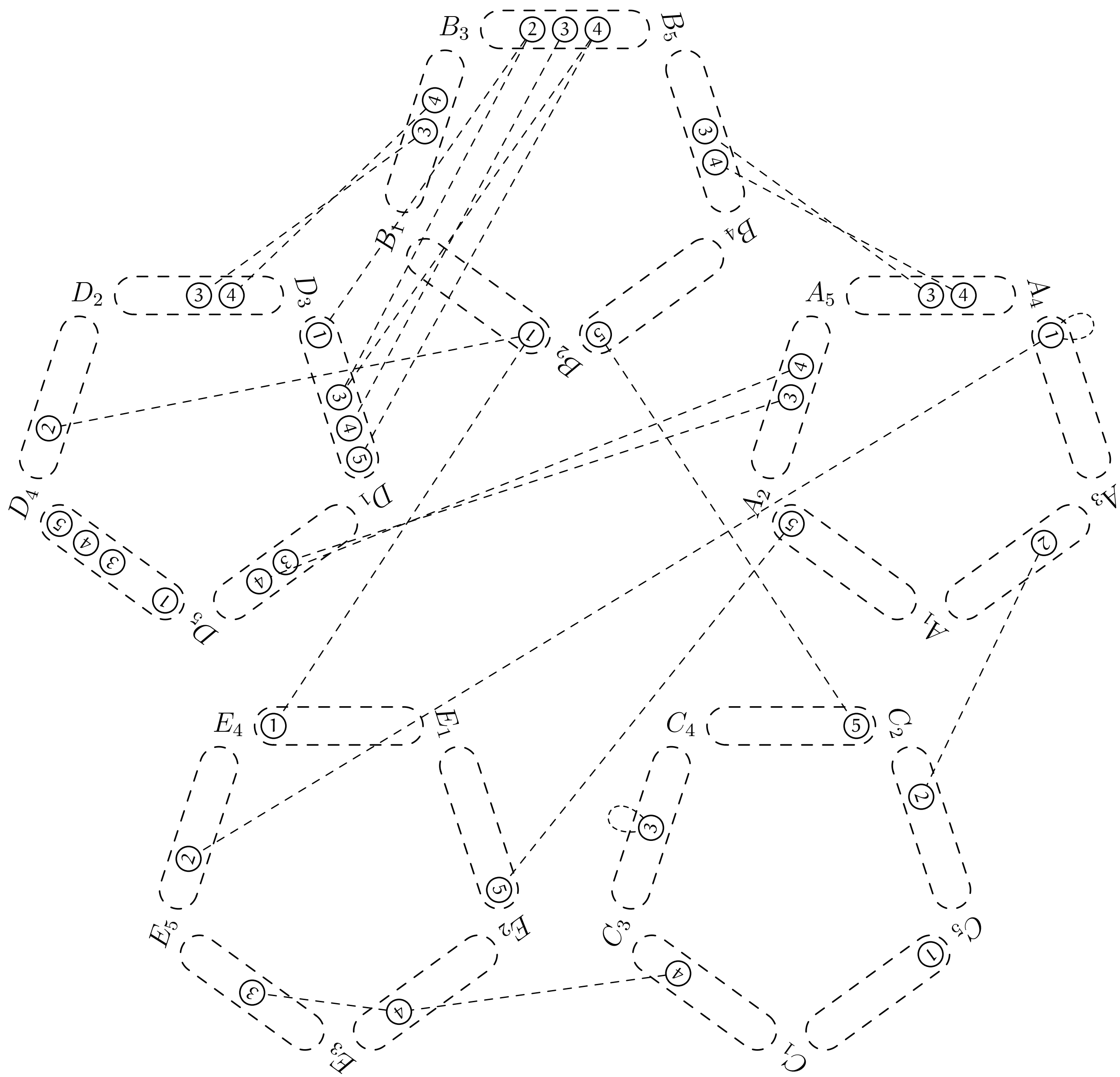
A_2	Spaniard
A_3	Irishman
A_4	Nigerian
A_5	Japanese
B_1	go
B_2	cricket
B_3	judo
B_4	poker
B_5	polo
C_1	coffee
C_2	tea
C_3	milk
C_4	orange juice
C_5	Guinness
D_1	dog
D_2	snails
D_3	fox
D_4	horse
D_5	zebra
E_1	red
E_2	green
E_3	ivory
E_4	yellow
E_5	blue

Select C_1 as Current Variable.



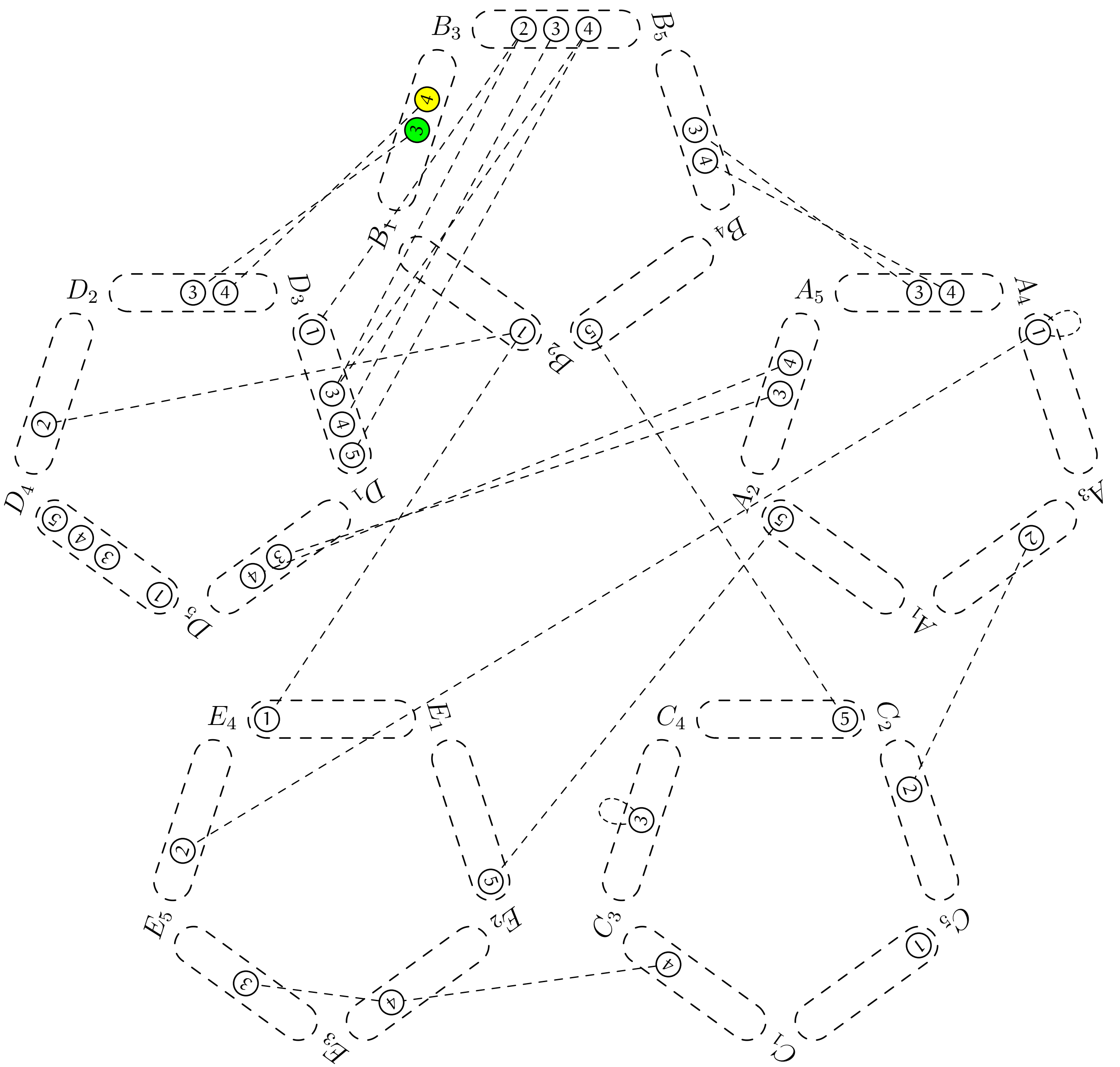
A_1	Englishman
A_2	Spaniard
A_3	Irishman
A_4	Nigerian
A_5	Japanese
B_1	go
B_2	cricket
B_3	judo
B_4	poker
B_5	polo
C_1	coffee
C_2	tea
C_3	milk
C_4	orange juice
C_5	Guinness
D_1	dog
D_2	snails
D_3	fox
D_4	horse
D_5	zebra
E_1	red
E_2	green
E_3	ivory
E_4	yellow
E_5	blue

After Assignment $C_1 = 4$ and Arc-Consistency.



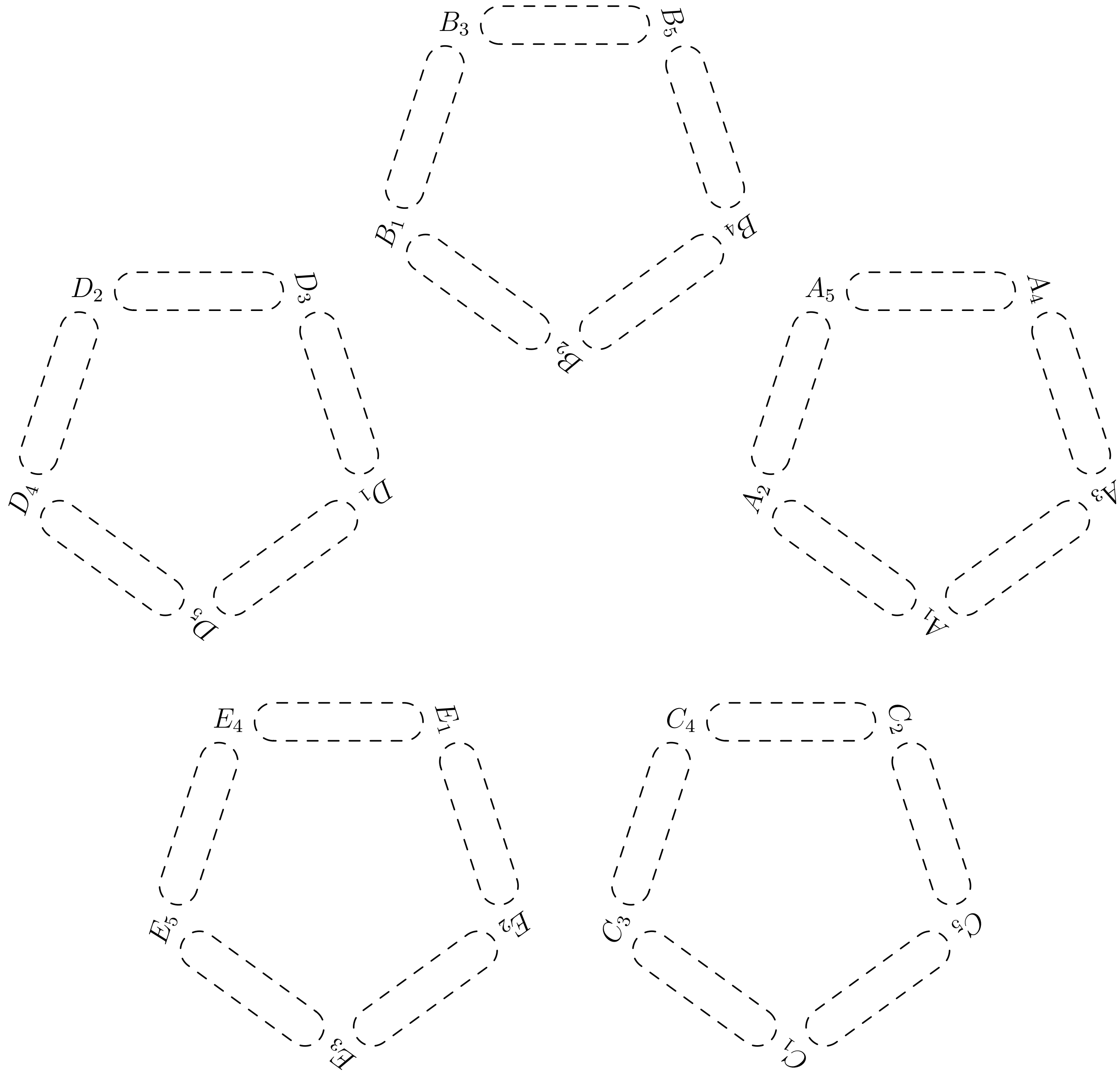
A_1	Englishman
A_2	Spaniard
A_3	Irishman
A_4	Nigerian
A_5	Japanese
B_1	go
B_2	cricket
B_3	judo
B_4	poker
B_5	polo
C_1	coffee
C_2	tea
C_3	milk
C_4	orange juice
C_5	Guinness
D_1	dog
D_2	snails
D_3	fox
D_4	horse
D_5	zebra
E_1	red
E_2	green
E_3	ivory
E_4	yellow
E_5	blue

Select B_1 as Current Variable.



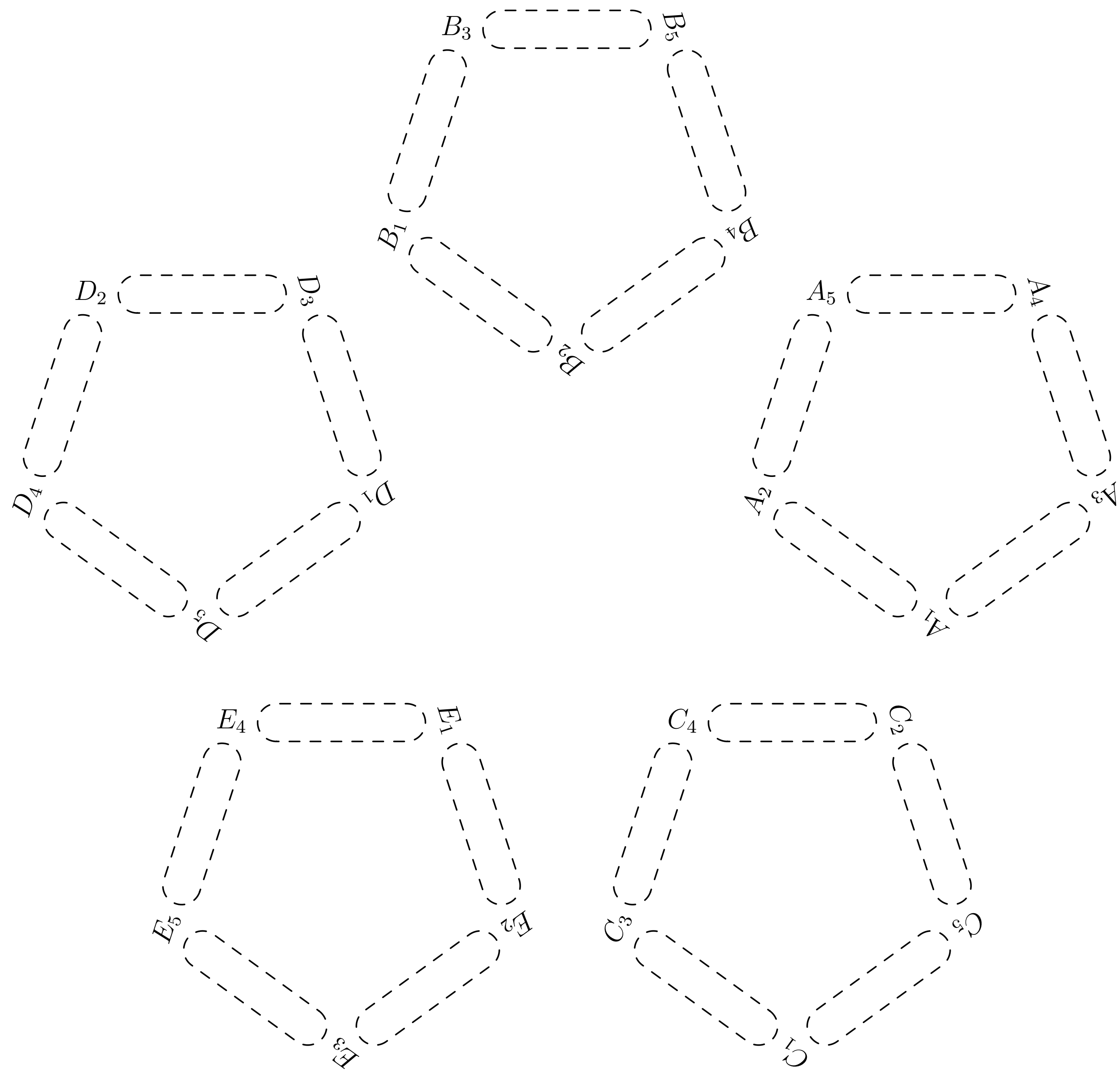
A_1	Englishman
A_2	Spaniard
A_3	Irishman
A_4	Nigerian
A_5	Japanese
B_1	go
B_2	cricket
B_3	judo
B_4	poker
B_5	polo
C_1	coffee
C_2	tea
C_3	milk
C_4	orange juice
C_5	Guinness
D_1	dog
D_2	snails
D_3	fox
D_4	horse
D_5	zebra
E_1	red
E_2	green
E_3	ivory
E_4	yellow
E_5	blue

After Assignment $B_1 = 3$ and Arc-Consistency.



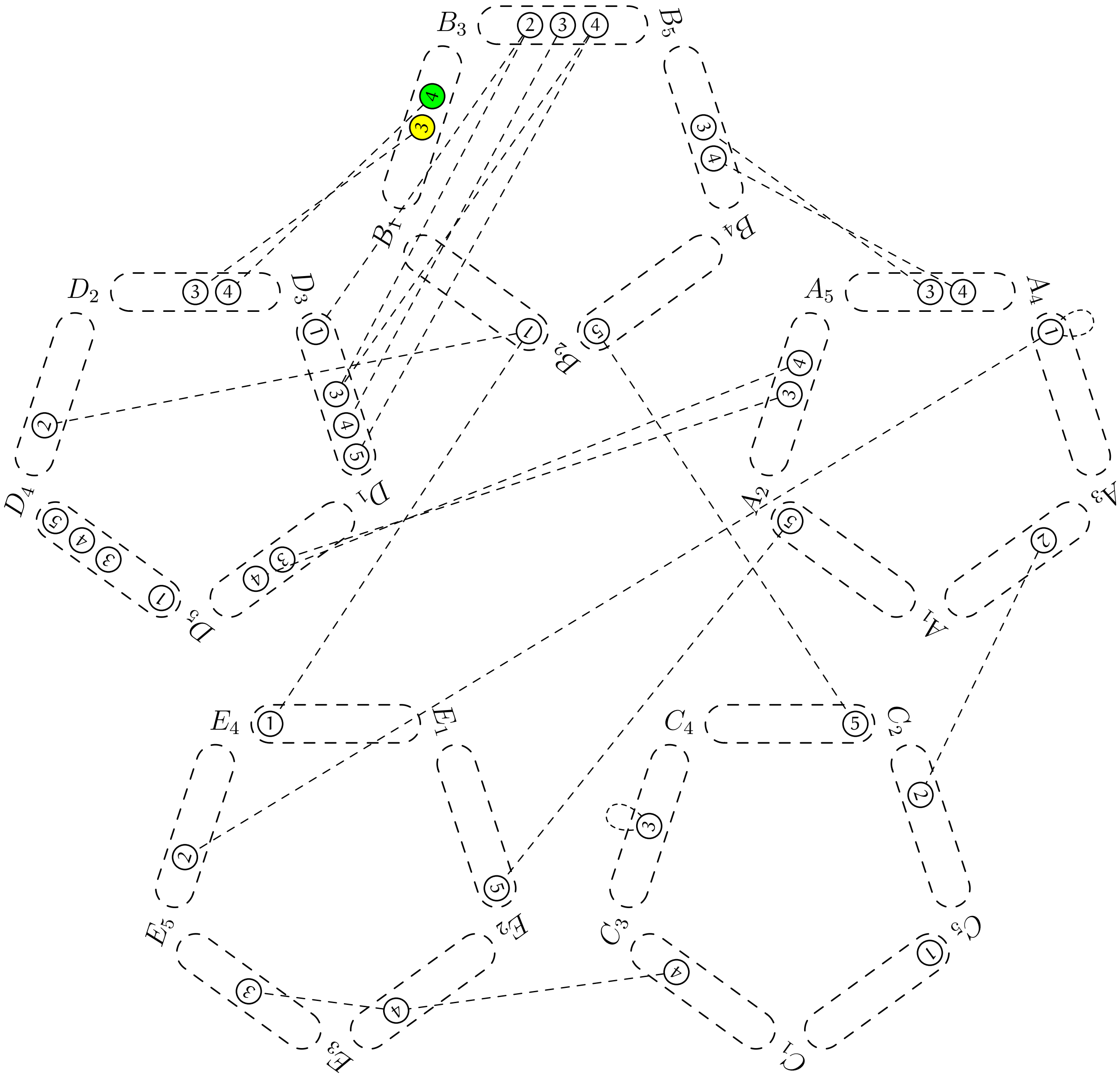
A_1	Englishman
A_2	Spaniard
A_3	Irishman
A_4	Nigerian
A_5	Japanese
B_1	go
B_2	cricket
B_3	judo
B_4	poker
B_5	polo
C_1	coffee
C_2	tea
C_3	milk
C_4	orange juice
C_5	Guinness
D_1	dog
D_2	snails
D_3	fox
D_4	horse
D_5	zebra
E_1	red
E_2	green
E_3	ivory
E_4	yellow
E_5	blue

All domains are empty. We must backtrack on B_1.



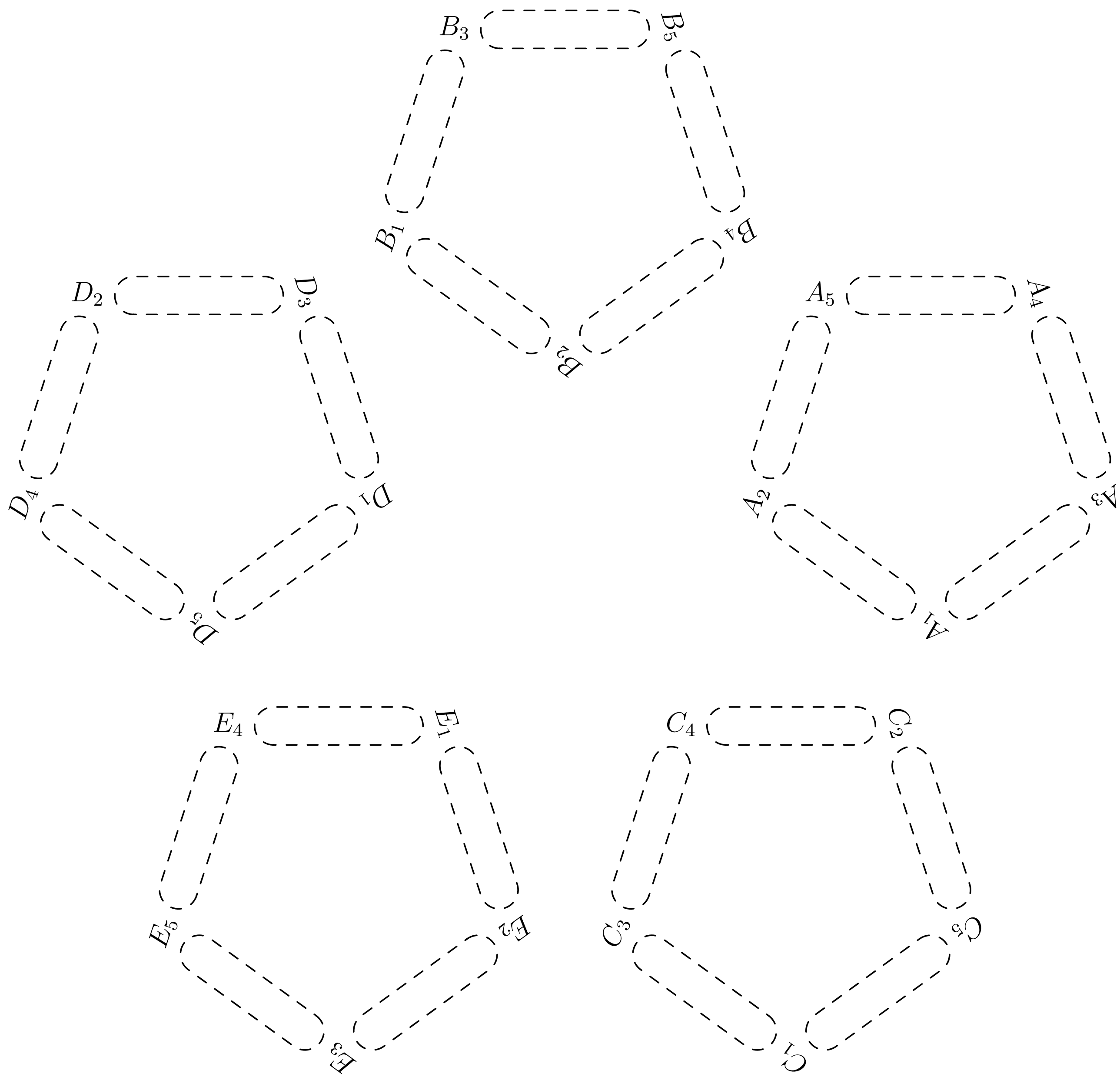
A_1	Englishman
A_2	Spaniard
A_3	Irishman
A_4	Nigerian
A_5	Japanese
B_1	go
B_2	cricket
B_3	judo
B_4	poker
B_5	polo
C_1	coffee
C_2	tea
C_3	milk
C_4	orange juice
C_5	Guinness
D_1	dog
D_2	snails
D_3	fox
D_4	horse
D_5	zebra
E_1	red
E_2	green
E_3	ivory
E_4	yellow
E_5	blue

Next Assignment to B_1.



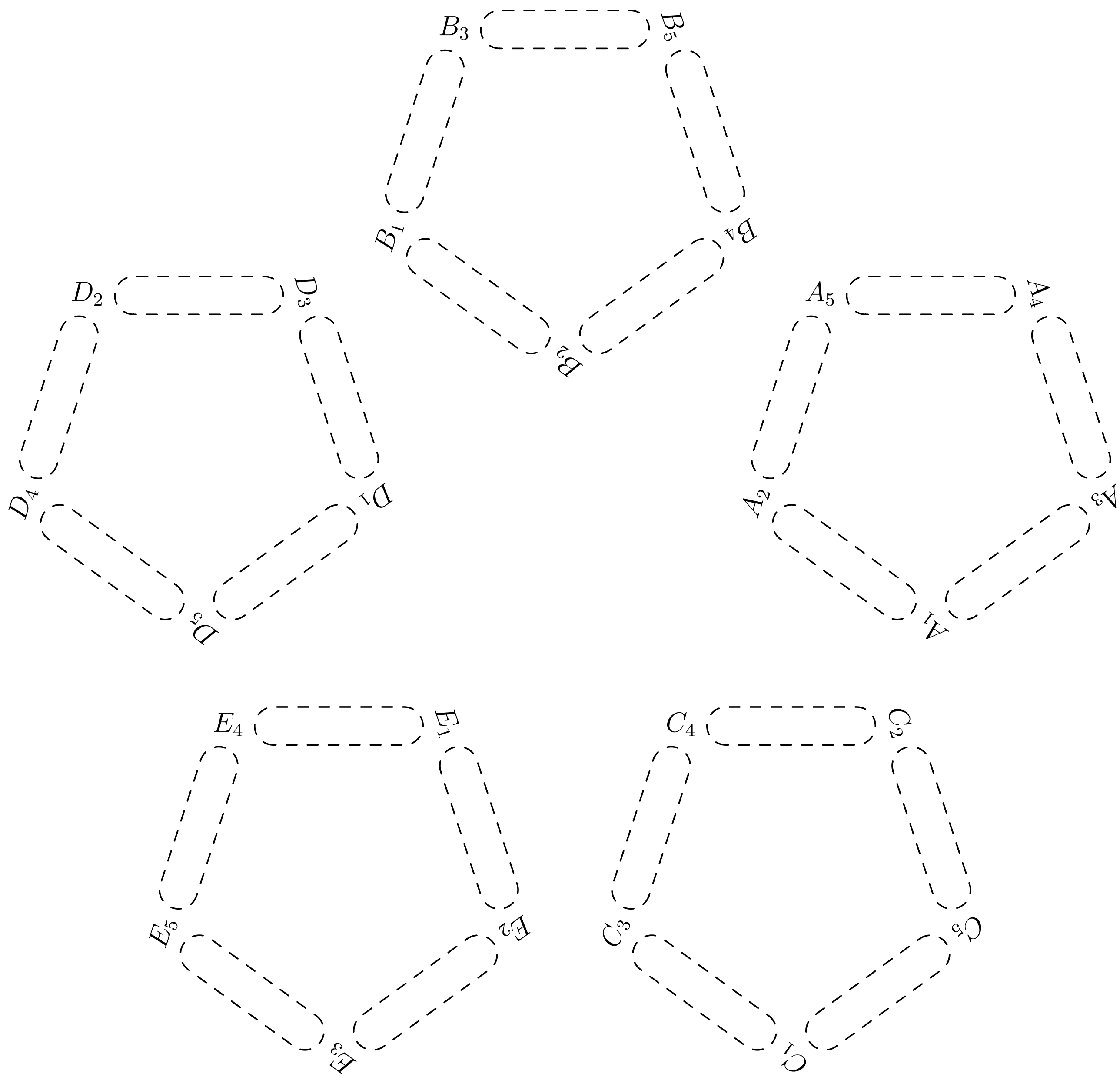
A_1 Englishman
A_2 Spaniard
A_3 Irishman
A_4 Nigerian
A_5 Japanese
B_1 go
B_2 cricket
B_3 judo
B_4 poker
B_5 polo
C_1 coffee
C_2 tea
C_3 milk
C_4 orange juice
C_5 Guinness
D_1 dog
D_2 snails
D_3 fox
D_4 horse
D_5 zebra
E_1 red
E_2 green
E_3 ivory
E_4 yellow
E_5 blue

After Assignment $B_1 = 4$ and Arc-Consistency.



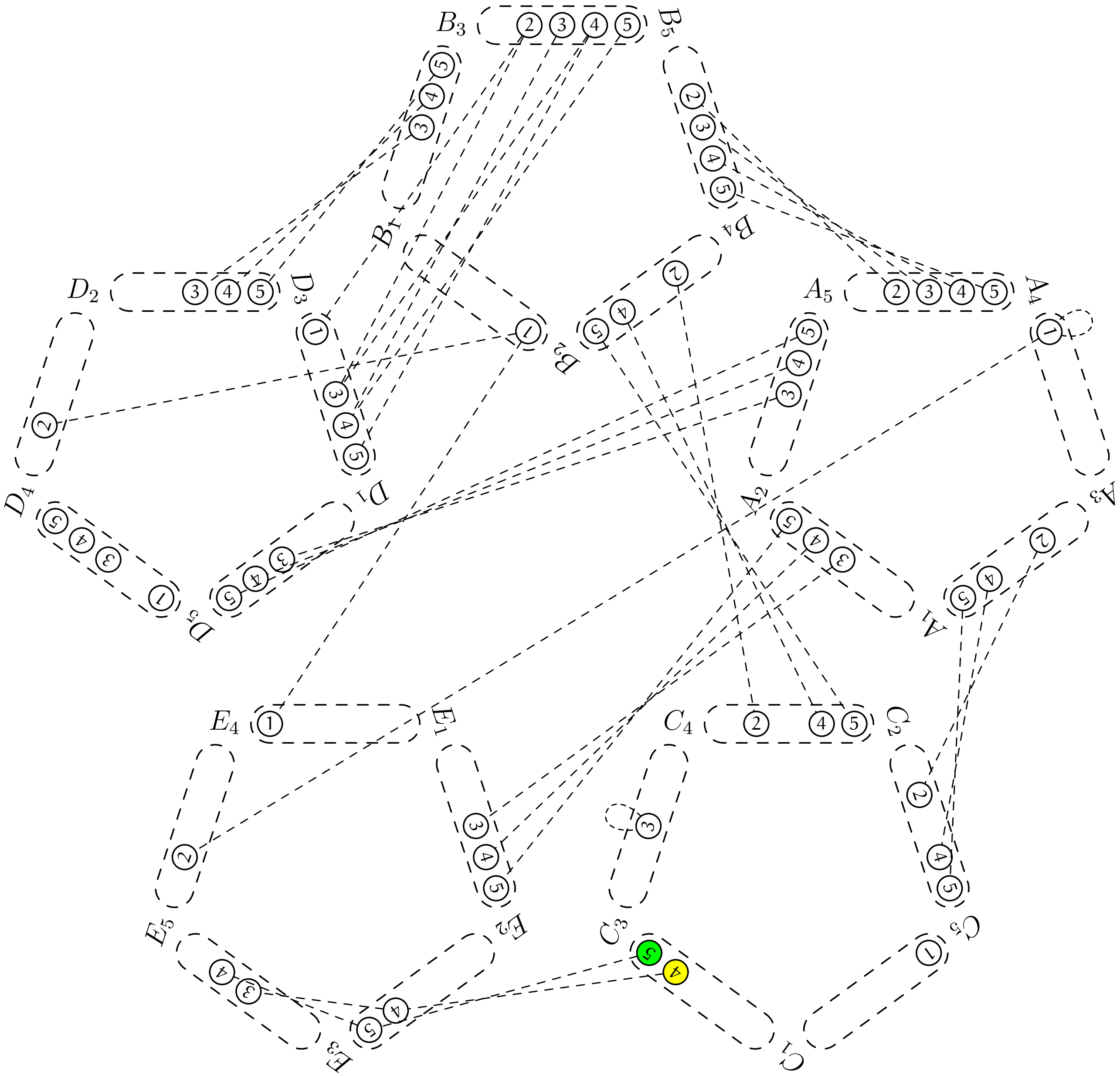
A_1	Englishman
A_2	Spaniard
A_3	Irishman
A_4	Nigerian
A_5	Japanese
B_1	go
B_2	cricket
B_3	judo
B_4	poker
B_5	polo
C_1	coffee
C_2	tea
C_3	milk
C_4	orange juice
C_5	Guinness
D_1	dog
D_2	snails
D_3	fox
D_4	horse
D_5	zebra
E_1	red
E_2	green
E_3	ivory
E_4	yellow
E_5	blue

We must backtrack on C_1.



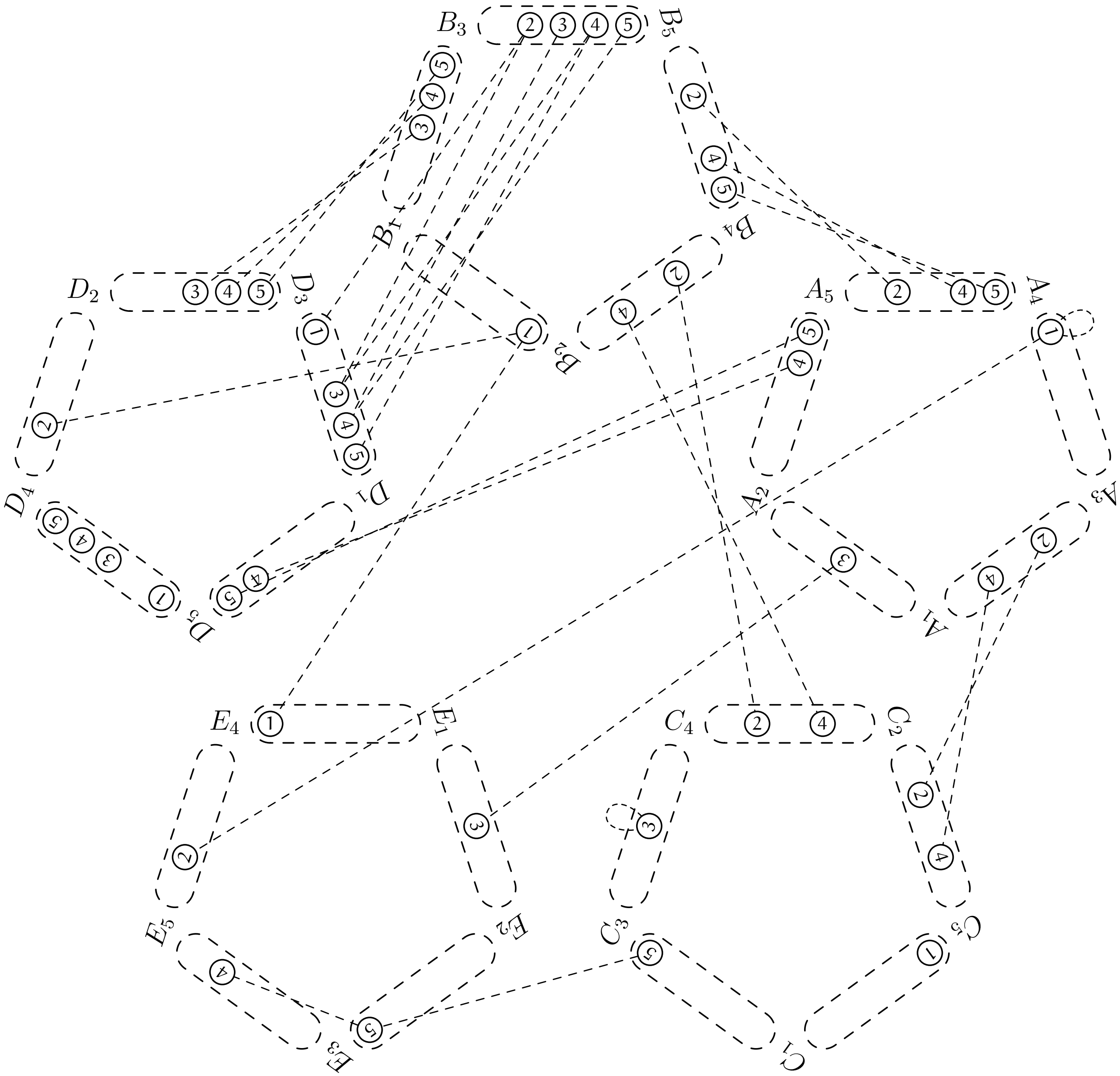
A_1	Englishman
A_2	Spaniard
A_3	Irishman
A_4	Nigerian
A_5	Japanese
B_1	go
B_2	cricket
B_3	judo
B_4	poker
B_5	polo
C_1	coffee
C_2	tea
C_3	milk
C_4	orange juice
C_5	Guinness
D_1	dog
D_2	snails
D_3	fox
D_4	horse
D_5	zebra
E_1	red
E_2	green
E_3	ivory
E_4	yellow
E_5	blue

Next Assignment to C_1.



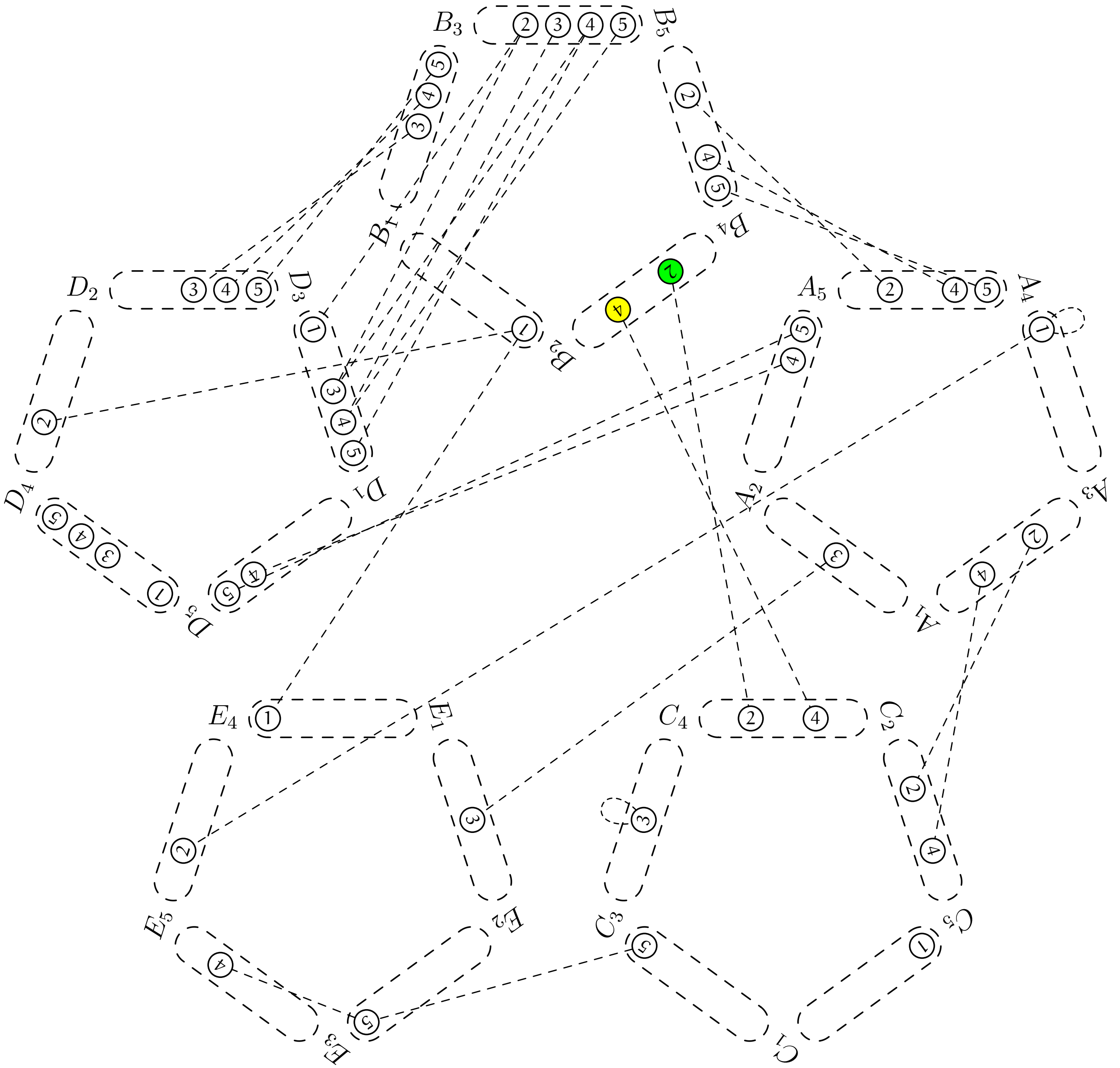
A_1	Englishman
A_2	Spaniard
A_3	Irishman
A_4	Nigerian
A_5	Japanese
B_1	go
B_2	cricket
B_3	judo
B_4	poker
B_5	polo
C_1	coffee
C_2	tea
C_3	milk
C_4	orange juice
C_5	Guinness
D_1	dog
D_2	snails
D_3	fox
D_4	horse
D_5	zebra
E_1	red
E_2	green
E_3	ivory
E_4	yellow
E_5	blue

After Assignment $C_1 = 5$ and Arc-Consistency.



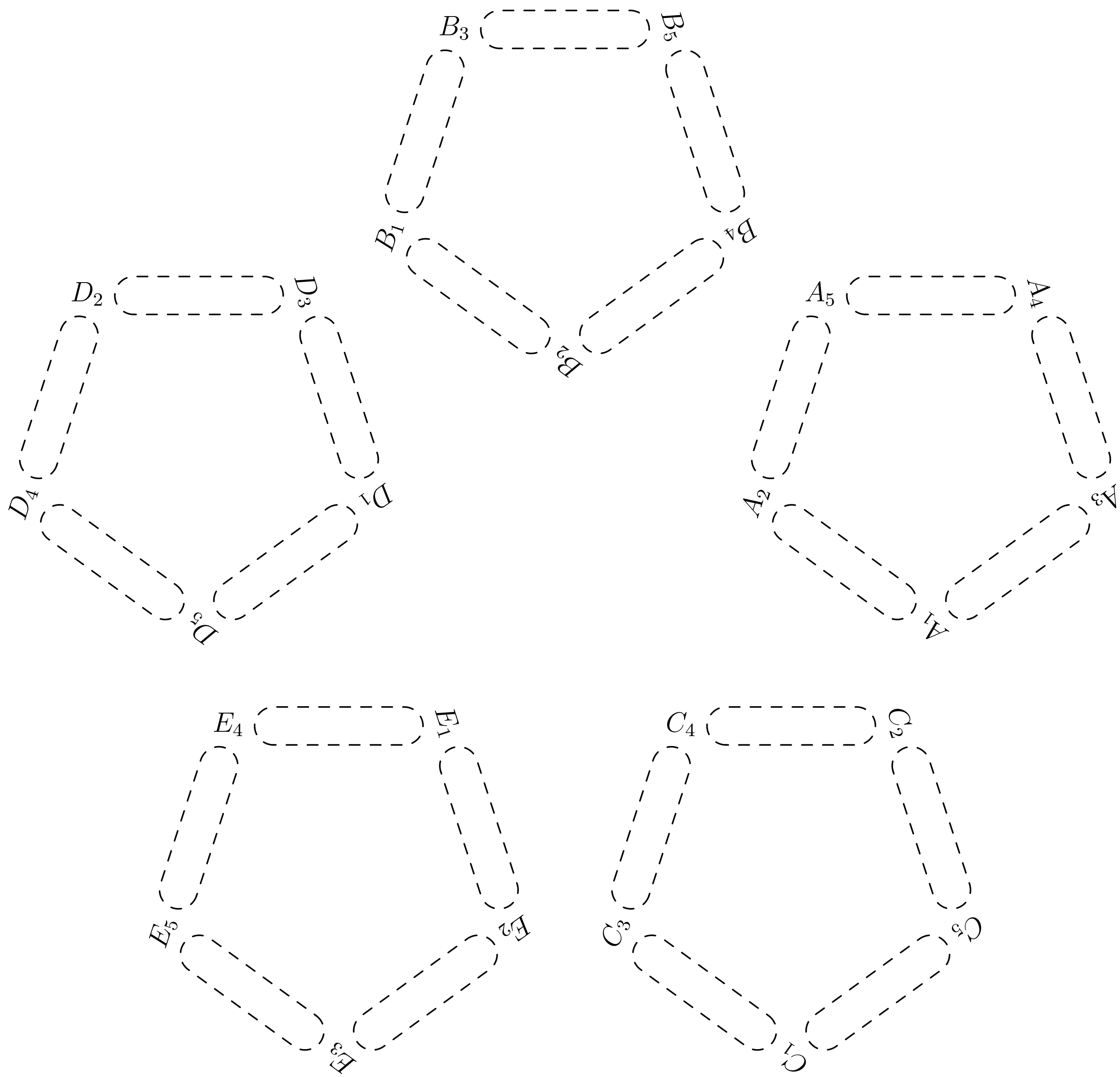
A_1	Englishman
A_2	Spaniard
A_3	Irishman
A_4	Nigerian
A_5	Japanese
B_1	go
B_2	cricket
B_3	judo
B_4	poker
B_5	polo
C_1	coffee
C_2	tea
C_3	milk
C_4	orange juice
C_5	Guinness
D_1	dog
D_2	snails
D_3	fox
D_4	horse
D_5	zebra
E_1	red
E_2	green
E_3	ivory
E_4	yellow
E_5	blue

Select B_4 as Current Variable.



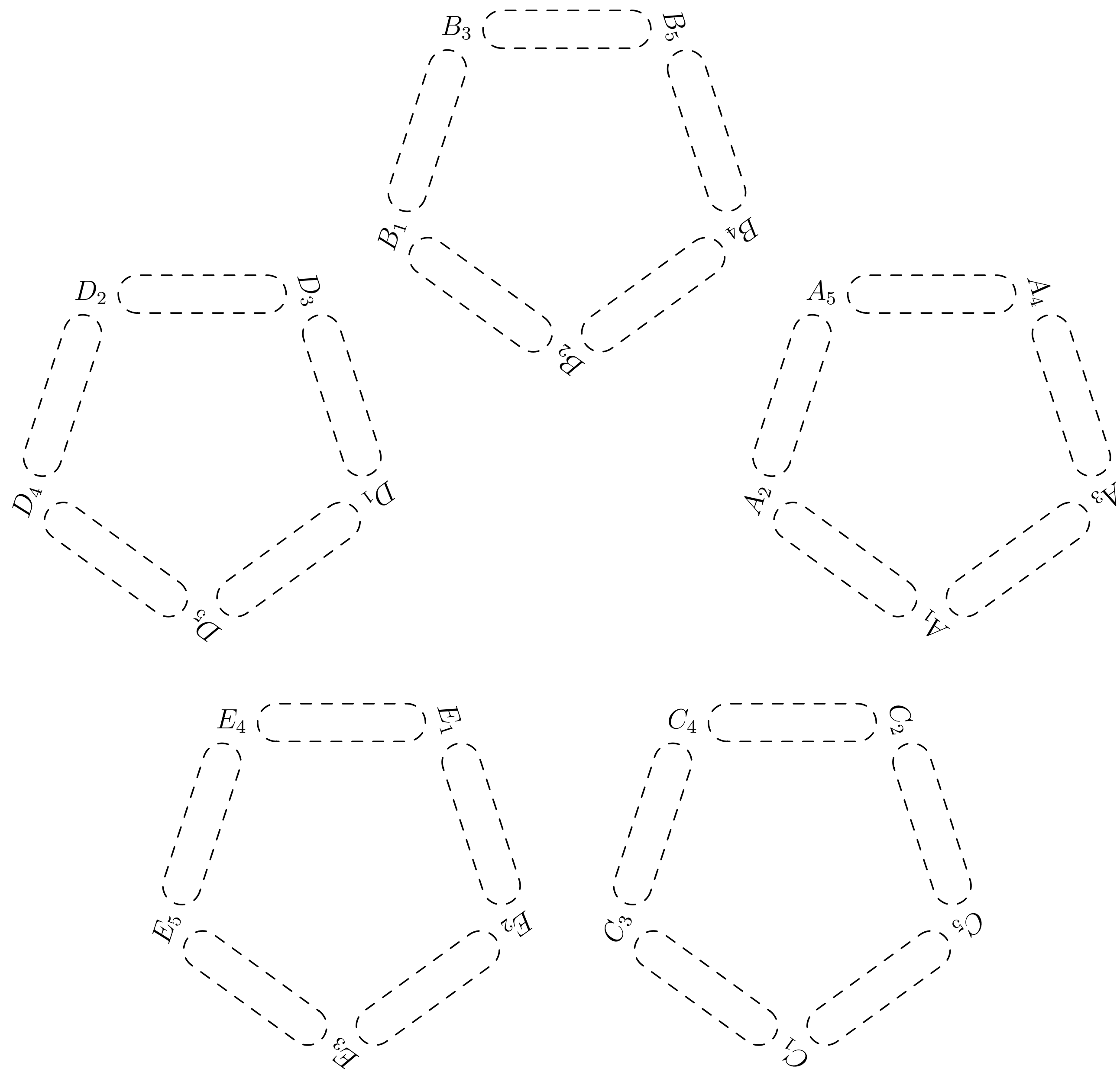
A_1	Englishman
A_2	Spaniard
A_3	Irishman
A_4	Nigerian
A_5	Japanese
B_1	go
B_2	cricket
B_3	judo
B_4	poker
B_5	polo
C_1	coffee
C_2	tea
C_3	milk
C_4	orange juice
C_5	Guinness
D_1	dog
D_2	snails
D_3	fox
D_4	horse
D_5	zebra
E_1	red
E_2	green
E_3	ivory
E_4	yellow
E_5	blue

After Assignment $B_4 = 2$ and Arc-Consistency.



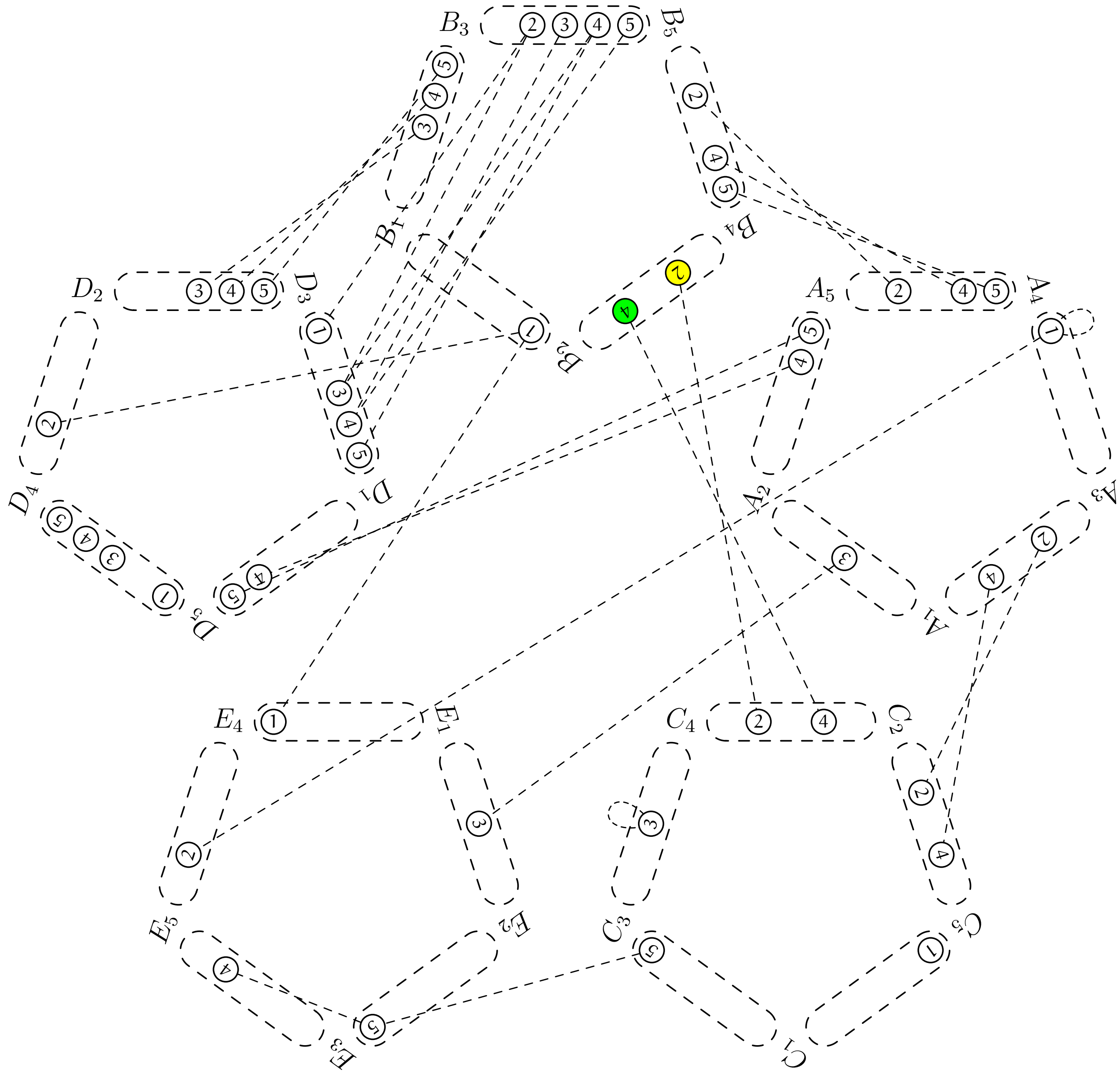
A_1	Englishman
A_2	Spaniard
A_3	Irishman
A_4	Nigerian
A_5	Japanese
B_1	go
B_2	cricket
B_3	judo
B_4	poker
B_5	polo
C_1	coffee
C_2	tea
C_3	milk
C_4	orange juice
C_5	Guinness
D_1	dog
D_2	snails
D_3	fox
D_4	horse
D_5	zebra
E_1	red
E_2	green
E_3	ivory
E_4	yellow
E_5	blue

Backtrack on B_4.



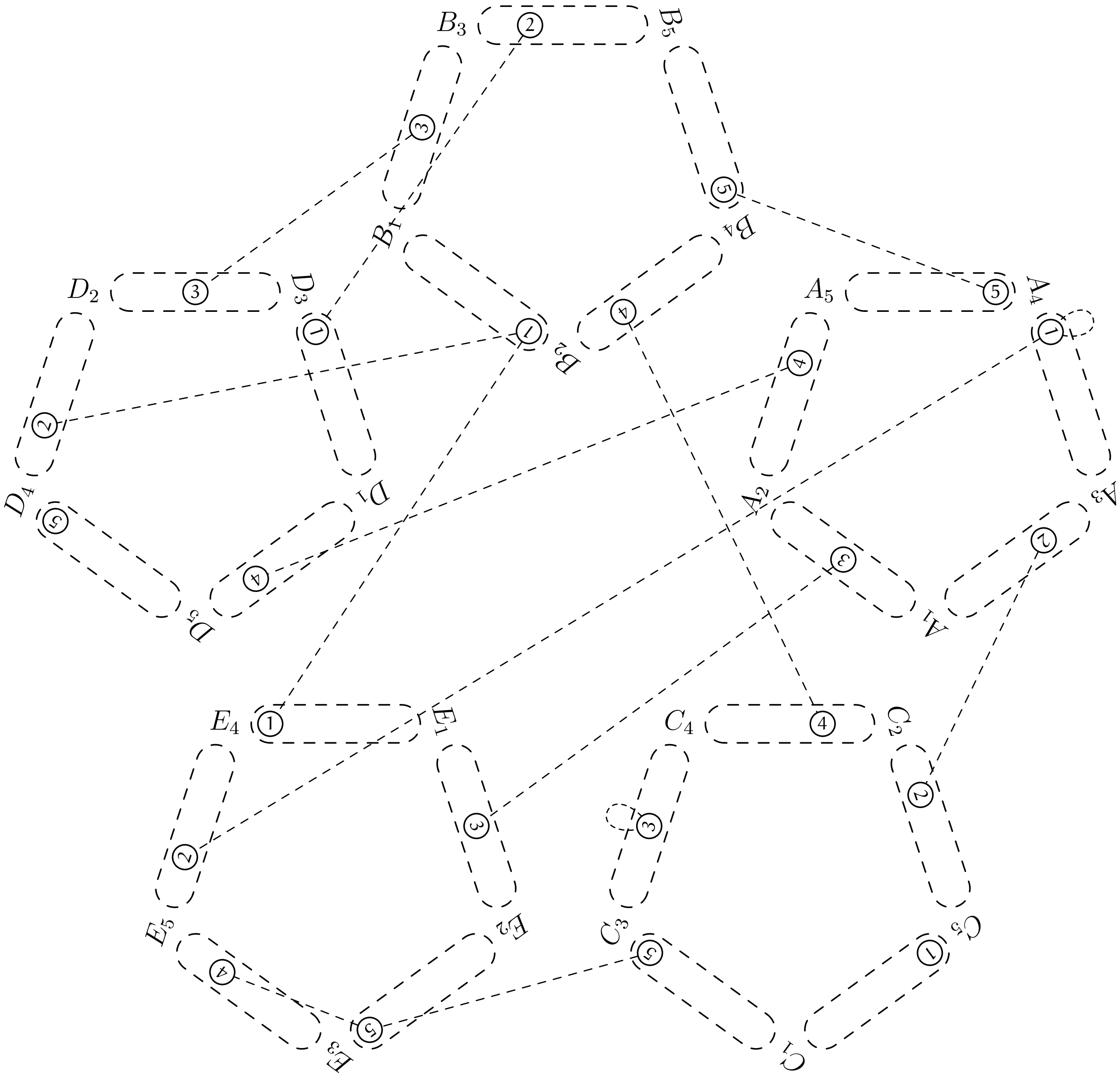
A_1	Englishman
A_2	Spaniard
A_3	Irishman
A_4	Nigerian
A_5	Japanese
B_1	go
B_2	cricket
B_3	judo
B_4	poker
B_5	polo
C_1	coffee
C_2	tea
C_3	milk
C_4	orange juice
C_5	Guinness
D_1	dog
D_2	snails
D_3	fox
D_4	horse
D_5	zebra
E_1	red
E_2	green
E_3	ivory
E_4	yellow
E_5	blue

Next Assignment to B_4.



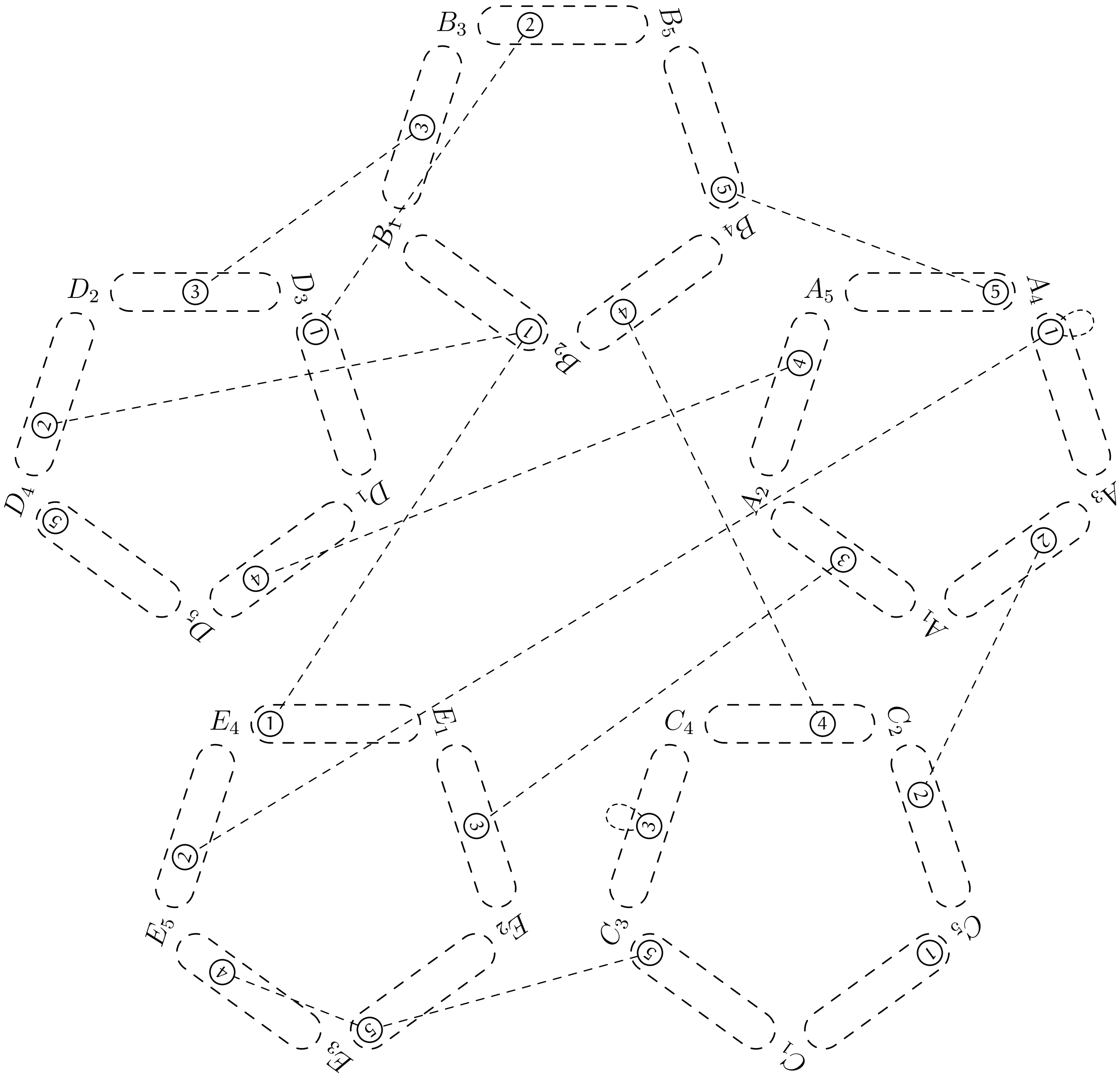
A_1	Englishman
A_2	Spaniard
A_3	Irishman
A_4	Nigerian
A_5	Japanese
B_1	go
B_2	cricket
B_3	judo
B_4	poker
B_5	polo
C_1	coffee
C_2	tea
C_3	milk
C_4	orange juice
C_5	Guinness
D_1	dog
D_2	snails
D_3	fox
D_4	horse
D_5	zebra
E_1	red
E_2	green
E_3	ivory
E_4	yellow
E_5	blue

After Assignment $B_4 = 4$ and Arc-Consistency.



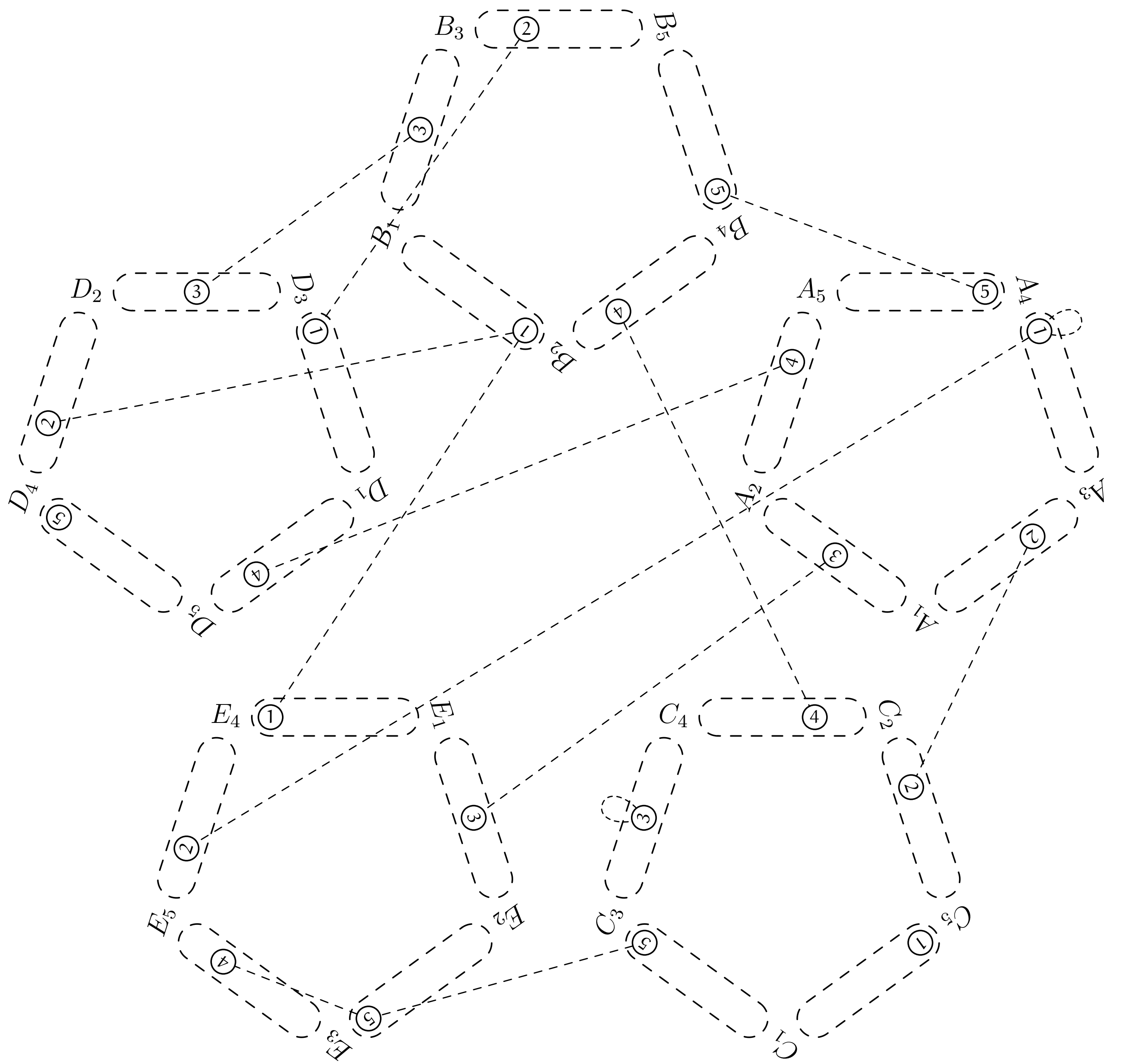
A_1	Englishman
A_2	Spaniard
A_3	Irishman
A_4	Nigerian
A_5	Japanese
B_1	go
B_2	cricket
B_3	judo
B_4	poker
B_5	polo
C_1	coffee
C_2	tea
C_3	milk
C_4	orange juice
C_5	Guinness
D_1	dog
D_2	snails
D_3	fox
D_4	horse
D_5	zebra
E_1	red
E_2	green
E_3	ivory
E_4	yellow
E_5	blue

All domains are singletons.



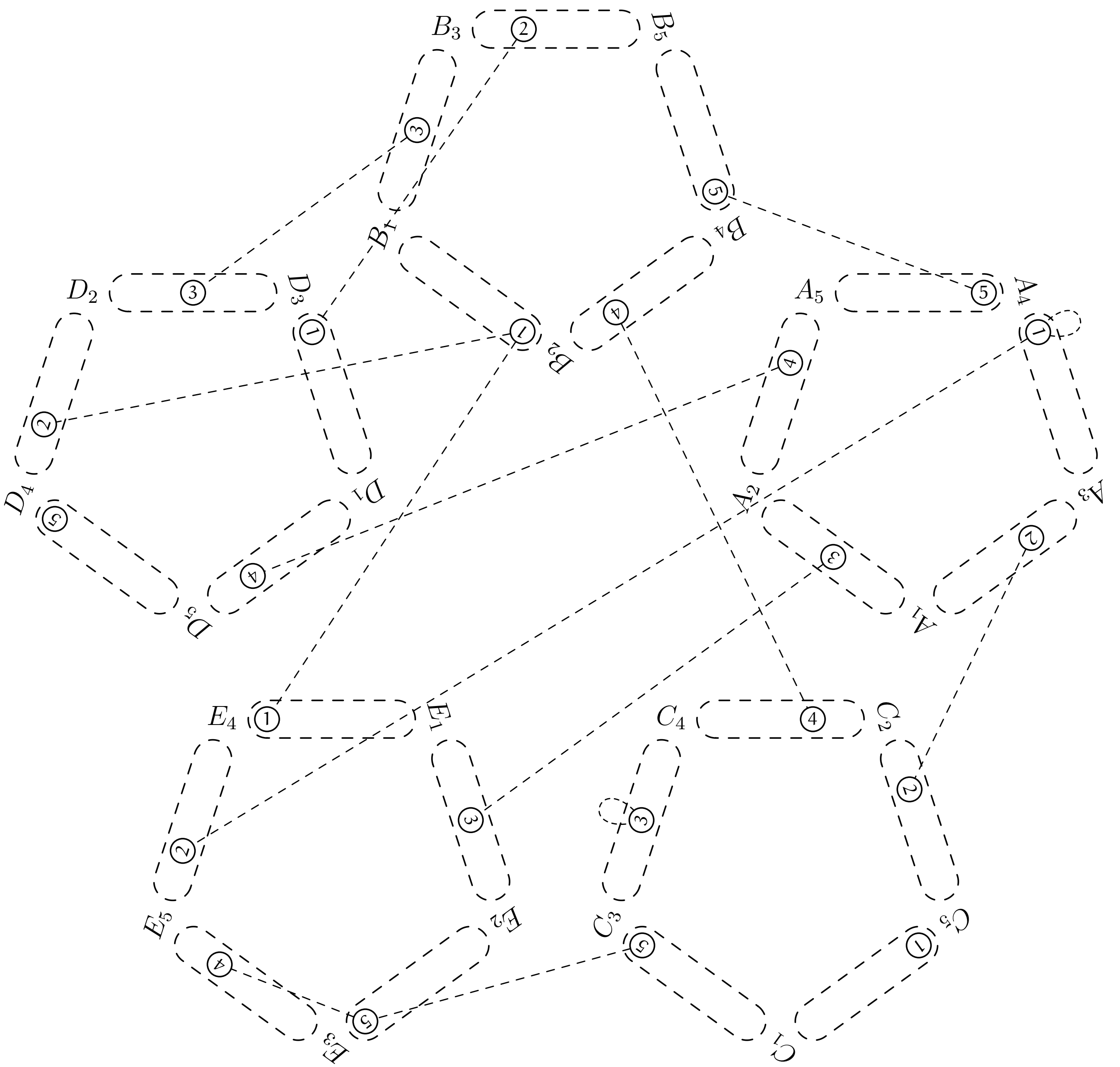
A_1	Englishman
A_2	Spaniard
A_3	Irishman
A_4	Nigerian
A_5	Japanese
B_1	go
B_2	cricket
B_3	judo
B_4	poker
B_5	polo
C_1	coffee
C_2	tea
C_3	milk
C_4	orange juice
C_5	Guinness
D_1	dog
D_2	snails
D_3	fox
D_4	horse
D_5	zebra
E_1	red
E_2	green
E_3	ivory
E_4	yellow
E_5	blue

All constraints are satisfied.



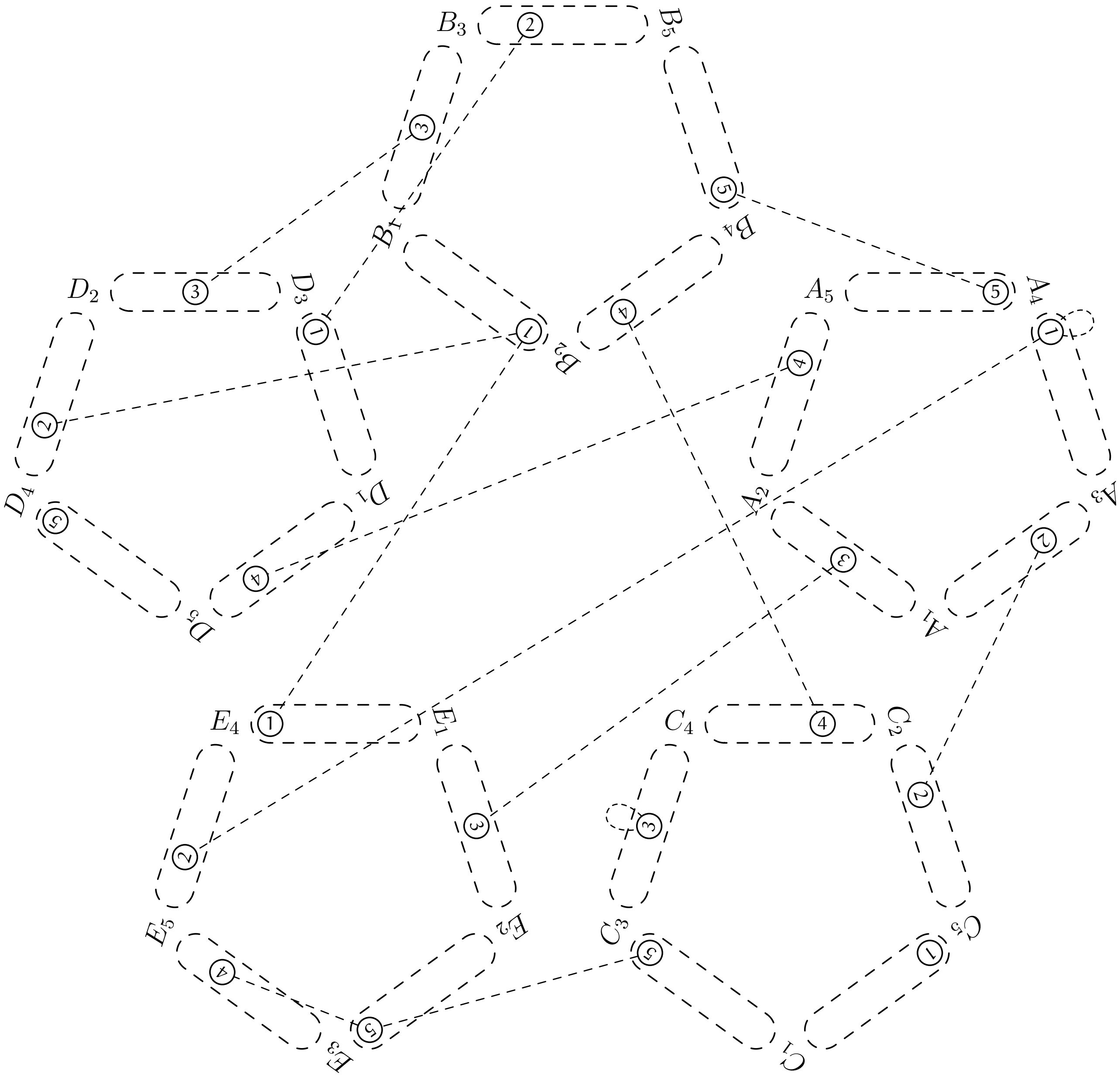
A_1	Englishman
A_2	Spaniard
A_3	Irishman
A_4	Nigerian
A_5	Japanese
B_1	go
B_2	cricket
B_3	judo
B_4	poker
B_5	polo
C_1	coffee
C_2	tea
C_3	milk
C_4	orange juice
C_5	Guinness
D_1	dog
D_2	snails
D_3	fox
D_4	horse
D_5	zebra
E_1	red
E_2	green
E_3	ivory
E_4	yellow
E_5	blue

We have solved the problem.



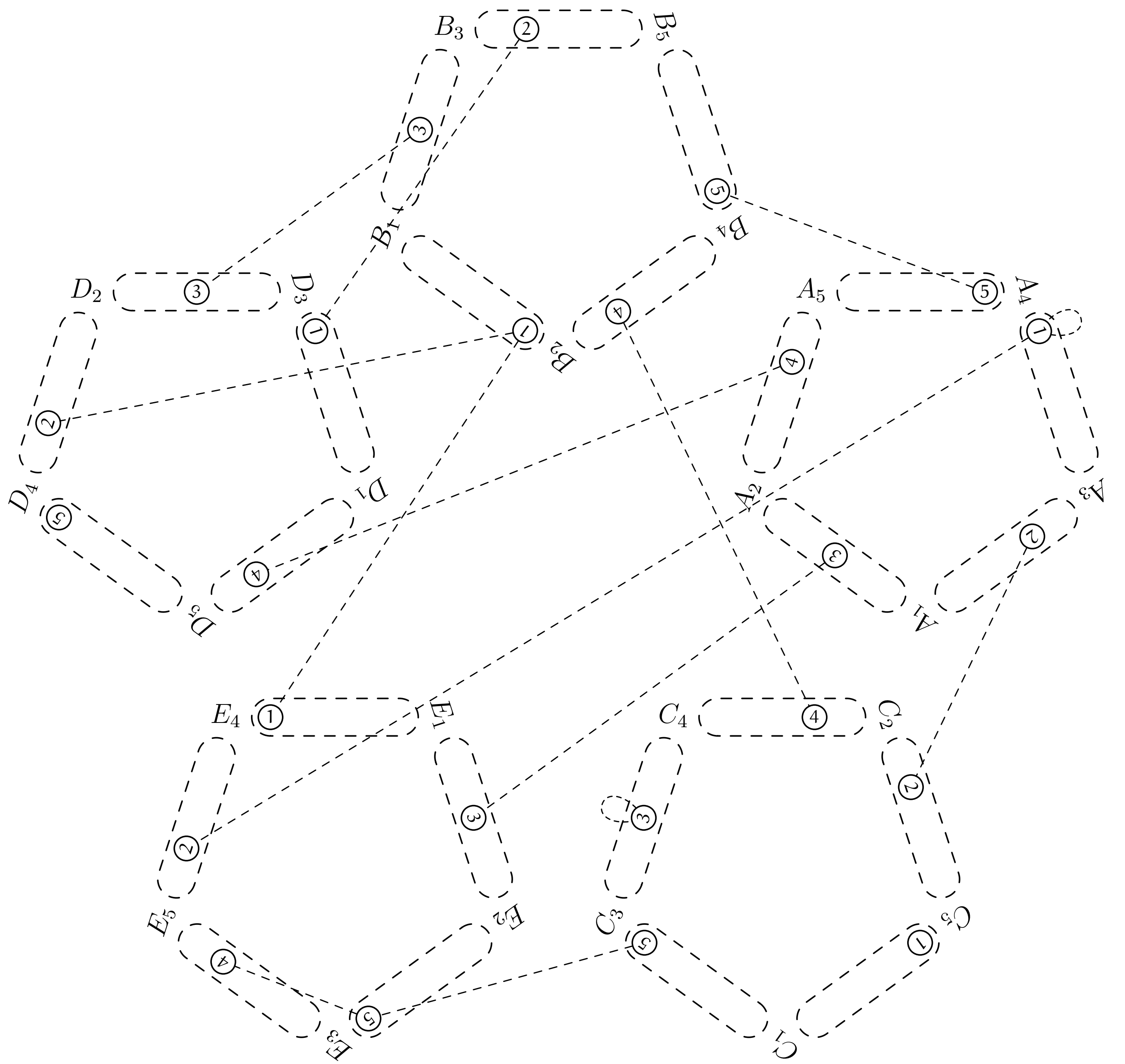
A_1	Englishman
A_2	Spaniard
A_3	Irishman
A_4	Nigerian
A_5	Japanese
B_1	go
B_2	cricket
B_3	judo
B_4	poker
B_5	polo
C_1	coffee
C_2	tea
C_3	milk
C_4	orange juice
C_5	Guinness
D_1	dog
D_2	snails
D_3	fox
D_4	horse
D_5	zebra
E_1	red
E_2	green
E_3	ivory
E_4	yellow
E_5	blue

$D_5 = 5$ (the zebra).



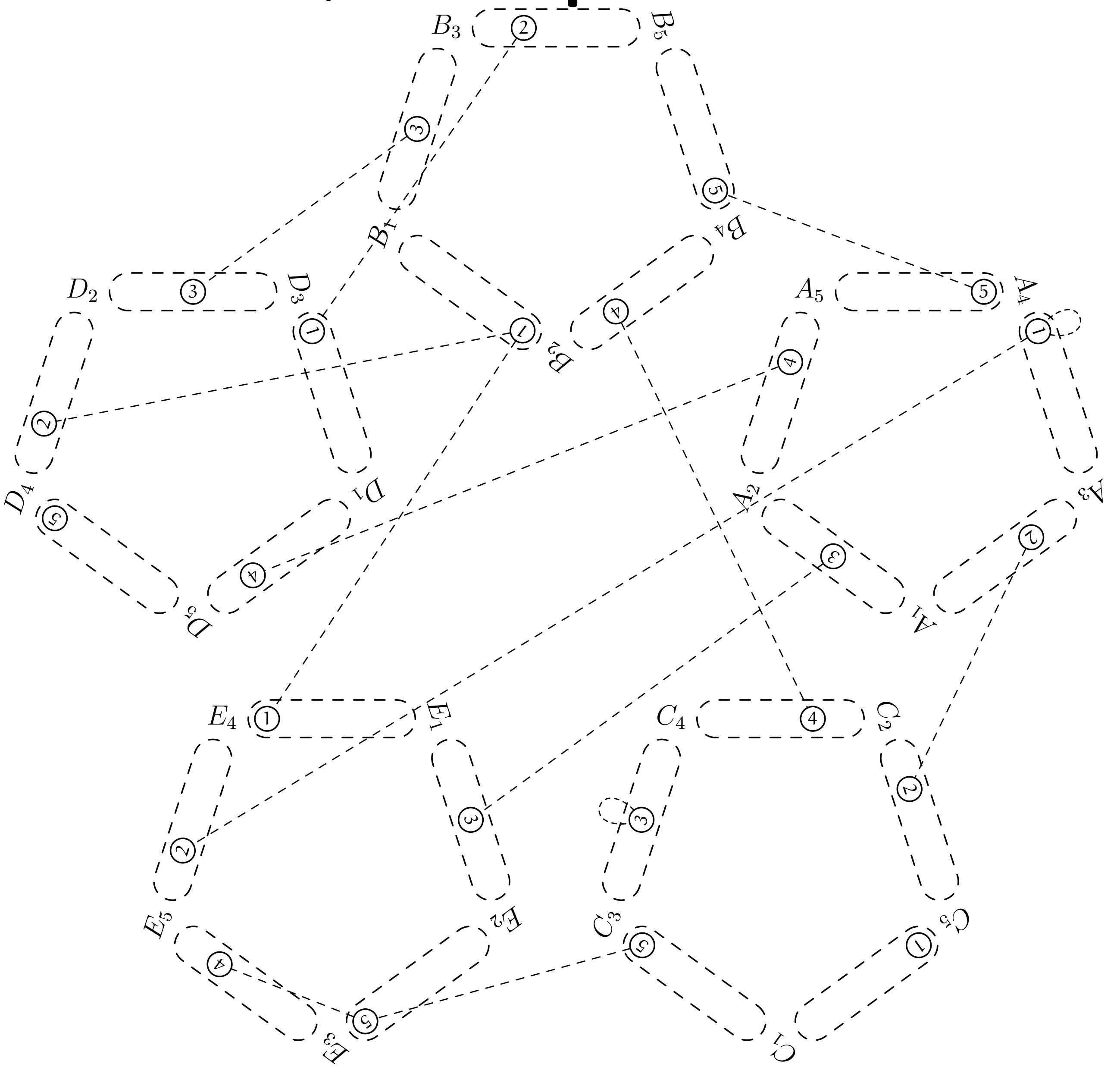
A_1	Englishman
A_2	Spaniard
A_3	Irishman
A_4	Nigerian
A_5	Japanese
B_1	go
B_2	cricket
B_3	judo
B_4	poker
B_5	polo
C_1	coffee
C_2	tea
C_3	milk
C_4	orange juice
C_5	Guinness
D_1	dog
D_2	snails
D_3	fox
D_4	horse
D_5	zebra
E_1	red
E_2	green
E_3	ivory
E_4	yellow
E_5	blue

$D_5 = 5$ (the zebra). $A_5 = 5$ (the Japanese).



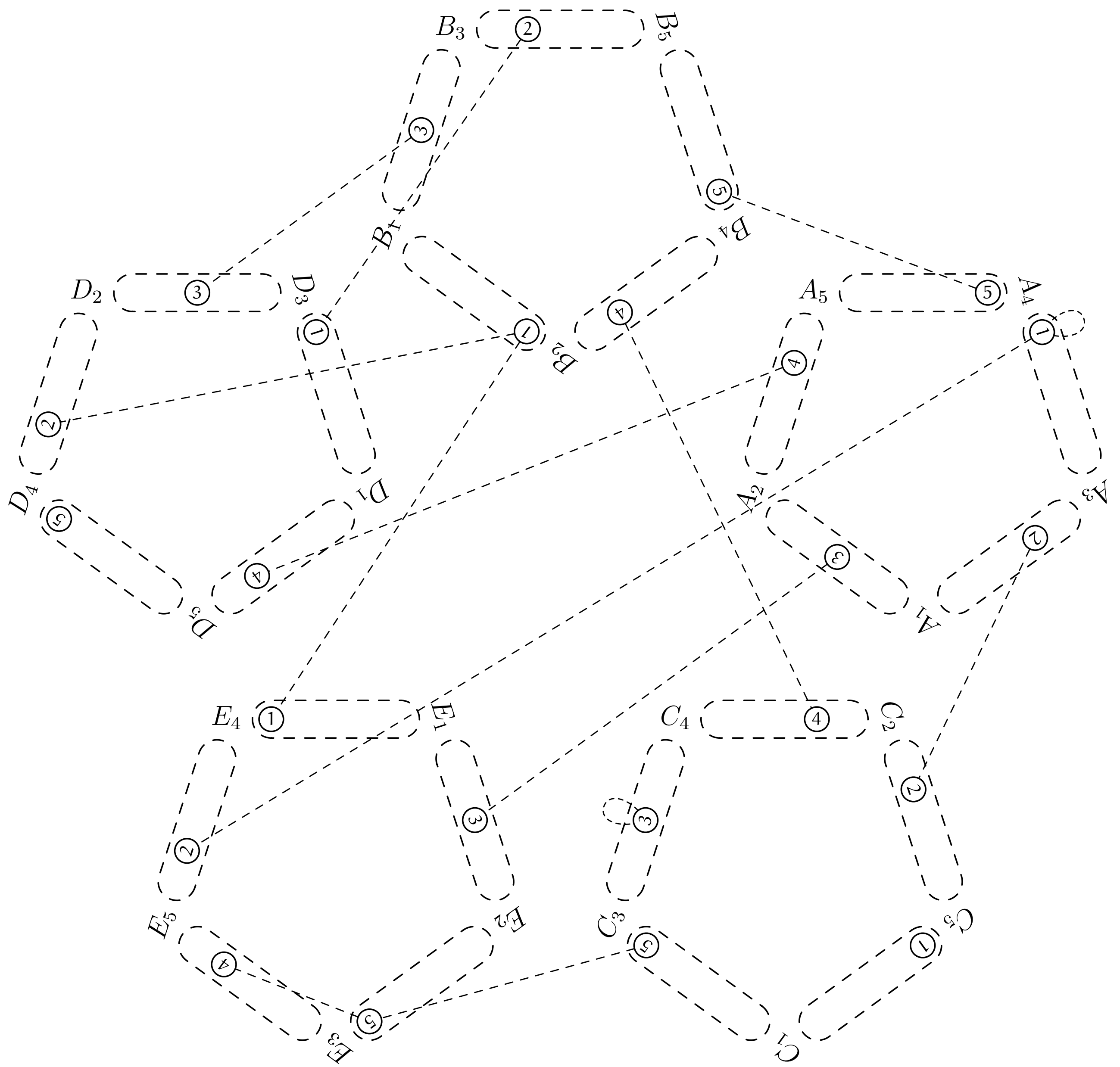
A_1	Englishman
A_2	Spaniard
A_3	Irishman
A_4	Nigerian
A_5	Japanese
B_1	go
B_2	cricket
B_3	judo
B_4	poker
B_5	polo
C_1	coffee
C_2	tea
C_3	milk
C_4	orange juice
C_5	Guinness
D_1	dog
D_2	snails
D_3	fox
D_4	horse
D_5	zebra
E_1	red
E_2	green
E_3	ivory
E_4	yellow
E_5	blue

$D_5 = 5$ (the zebra). $A_5 = 5$ (the Japanese). Therefore, the Japanese owns the zebra.



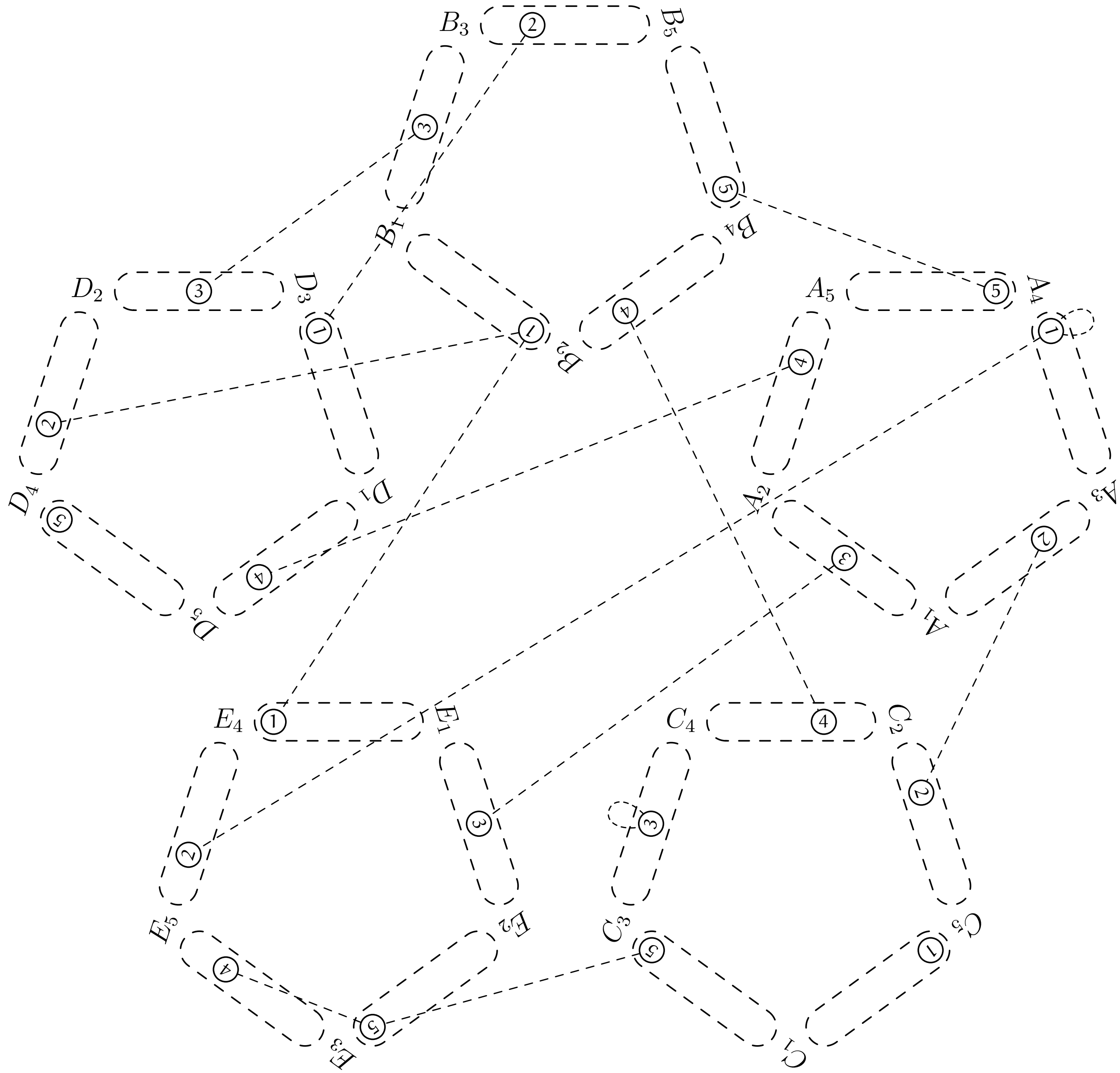
A_1	Englishman
A_2	Spaniard
A_3	Irishman
A_4	Nigerian
A_5	Japanese
B_1	go
B_2	cricket
B_3	judo
B_4	poker
B_5	polo
C_1	coffee
C_2	tea
C_3	milk
C_4	orange juice
C_5	Guinness
D_1	dog
D_2	snails
D_3	fox
D_4	horse
D_5	zebra
E_1	red
E_2	green
E_3	ivory
E_4	yellow
E_5	blue

To some this may have come as a complete surprise.



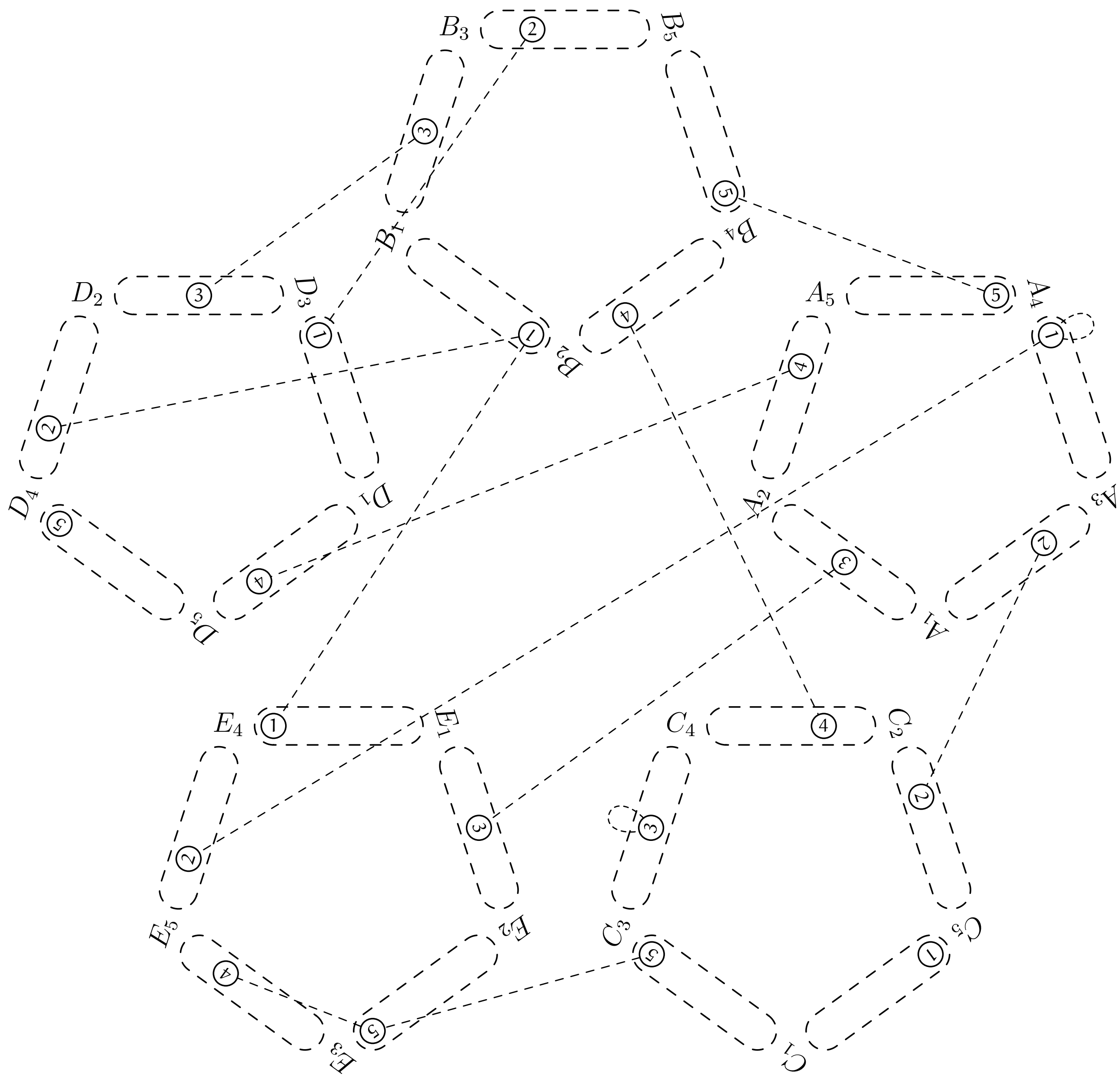
A_1	Englishman
A_2	Spaniard
A_3	Irishman
A_4	Nigerian
A_5	Japanese
B_1	go
B_2	cricket
B_3	judo
B_4	poker
B_5	polo
C_1	coffee
C_2	tea
C_3	milk
C_4	orange juice
C_5	Guinness
D_1	dog
D_2	snails
D_3	fox
D_4	horse
D_5	zebra
E_1	red
E_2	green
E_3	ivory
E_4	yellow
E_5	blue

$C_5 = 1$ (Guinness).



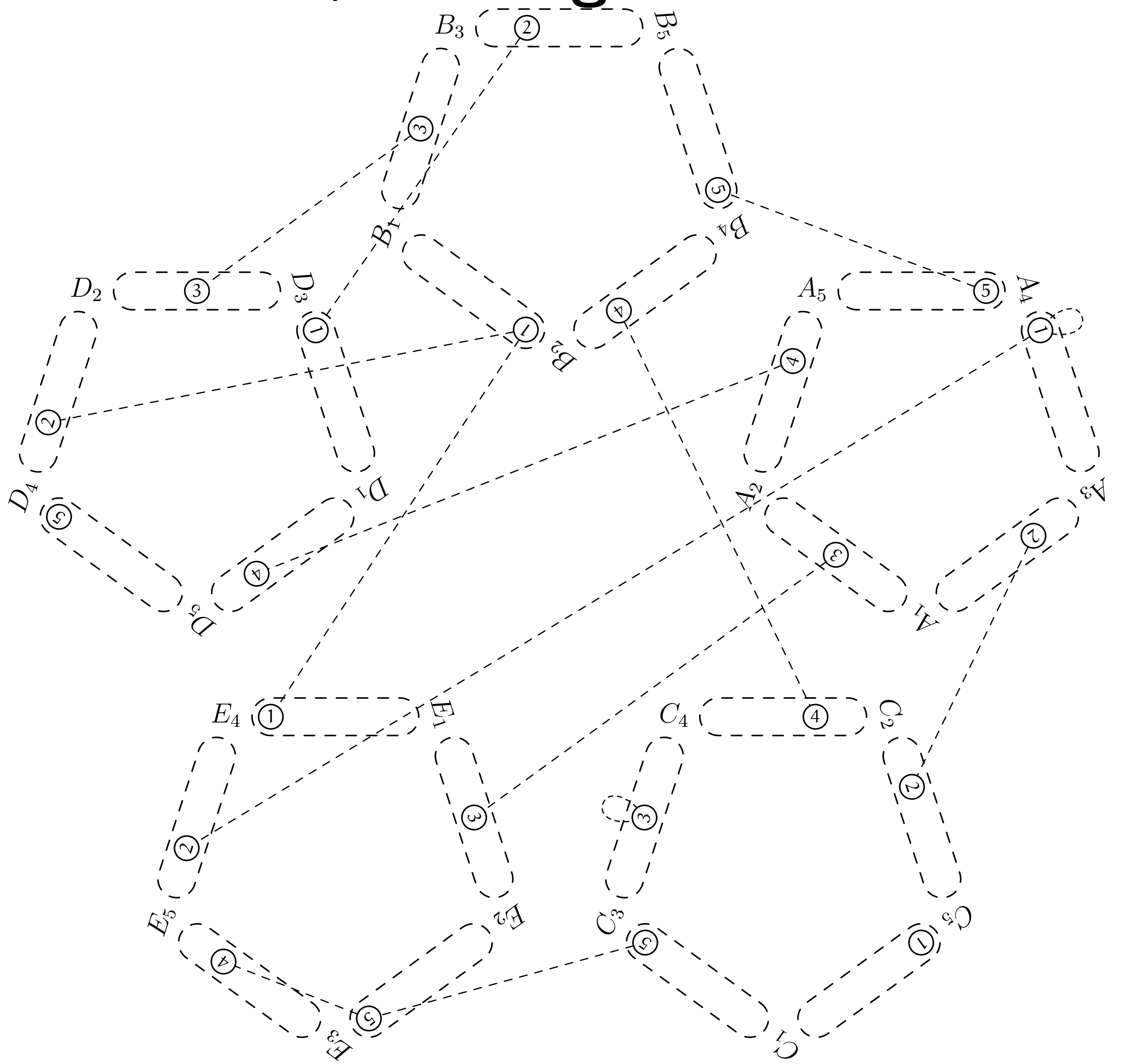
A_1 Englishman
A_2 Spaniard
A_3 Irishman
A_4 Nigerian
A_5 Japanese
B_1 go
B_2 cricket
B_3 judo
B_4 poker
B_5 polo
C_1 coffee
C_2 tea
C_3 milk
C_4 orange juice
C_5 Guinness
D_1 dog
D_2 snails
D_3 fox
D_4 horse
D_5 zebra
E_1 red
E_2 green
E_3 ivory
E_4 yellow
E_5 blue

$C_5 = 1$ (Guinness). $A_4 = 1$ (the Nigerian).



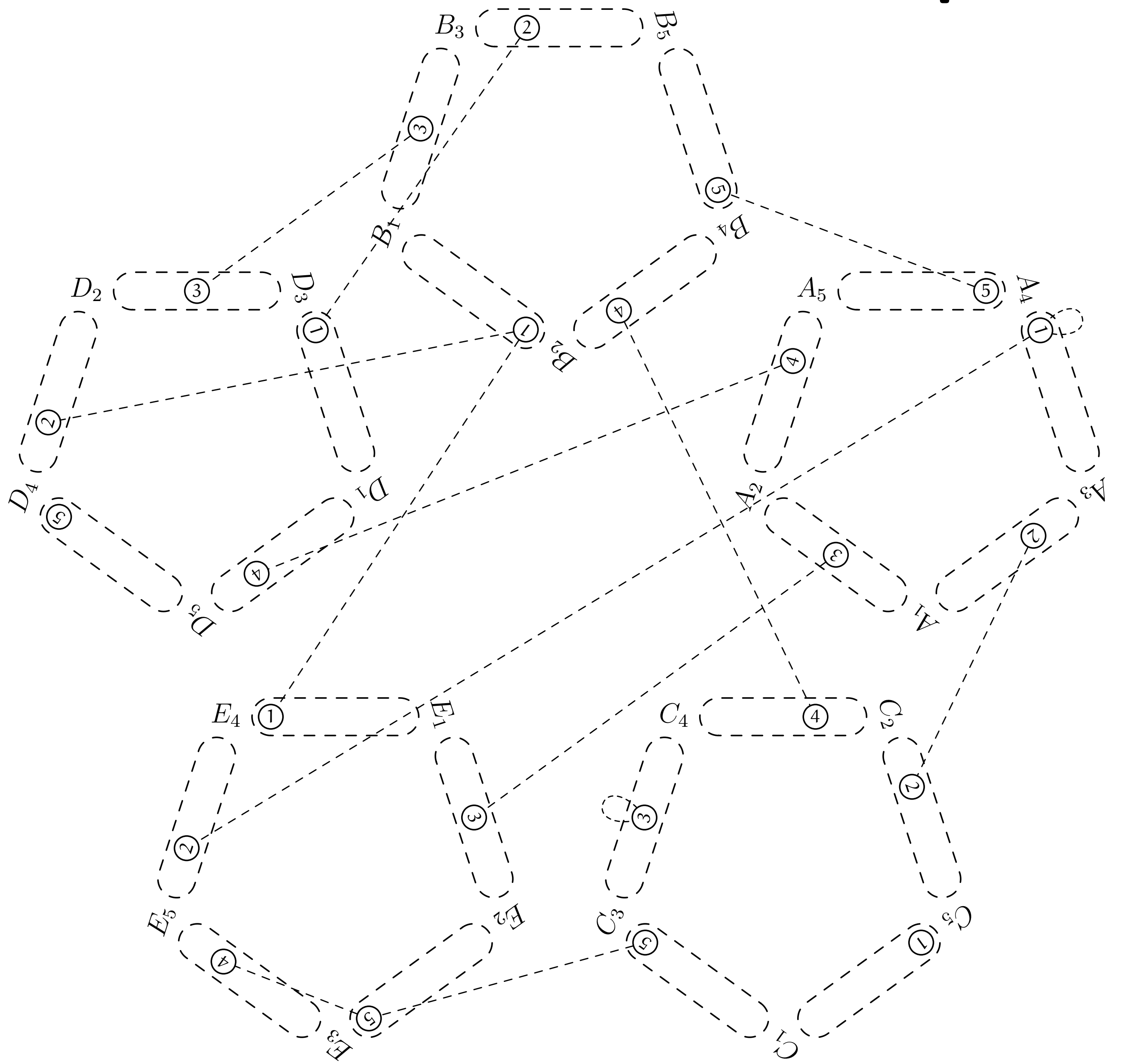
A_1	Englishman
A_2	Spaniard
A_3	Irishman
A_4	Nigerian
A_5	Japanese
B_1	go
B_2	cricket
B_3	judo
B_4	poker
B_5	polo
C_1	coffee
C_2	tea
C_3	milk
C_4	orange juice
C_5	Guinness
D_1	dog
D_2	snails
D_3	fox
D_4	horse
D_5	zebra
E_1	red
E_2	green
E_3	ivory
E_4	yellow
E_5	blue

$C_5 = 1$ (Guinness). $A_4 = 1$ (the Nigerian). Therefore, the Nigerian drinks Guinness.



A_1	Englishman
A_2	Spaniard
A_3	Irishman
A_4	Nigerian
A_5	Japanese
B_1	go
B_2	cricket
B_3	judo
B_4	poker
B_5	polo
C_1	coffee
C_2	tea
C_3	milk
C_4	orange juice
C_5	Guinness
D_1	dog
D_2	snails
D_3	fox
D_4	horse
D_5	zebra
E_1	red
E_2	green
E_3	ivory
E_4	yellow
E_5	blue

Given that Lagos has a large Guinness brewery, this should not have come as a complete surprise.



A_1	Englishman
A_2	Spaniard
A_3	Irishman
A_4	Nigerian
A_5	Japanese
B_1	go
B_2	cricket
B_3	judo
B_4	poker
B_5	polo
C_1	coffee
C_2	tea
C_3	milk
C_4	orange juice
C_5	Guinness
D_1	dog
D_2	snails
D_3	fox
D_4	horse
D_5	zebra
E_1	red
E_2	green
E_3	ivory
E_4	yellow
E_5	blue