Lecture 23: Logic I

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08/01/2016

Announcements

Roadmap

- Introduction
- Functions
- Data
- Mutability
- Objects
- Interpretation
- Paradigms
- Applications

Roadmap

Introduction

Functions

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Interpretation

Paradigms

Applications

- This week (Paradigms), the goals are:

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  - To study examples of paradigms that are very different from what we have seen so far

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Paradigms

Applications

- This week (Paradigms), the goals are:
  - To study examples of paradigms that are very different from what we have seen so far
  - To expand our definition of what counts as programming

Today’s Example: Map Coloring

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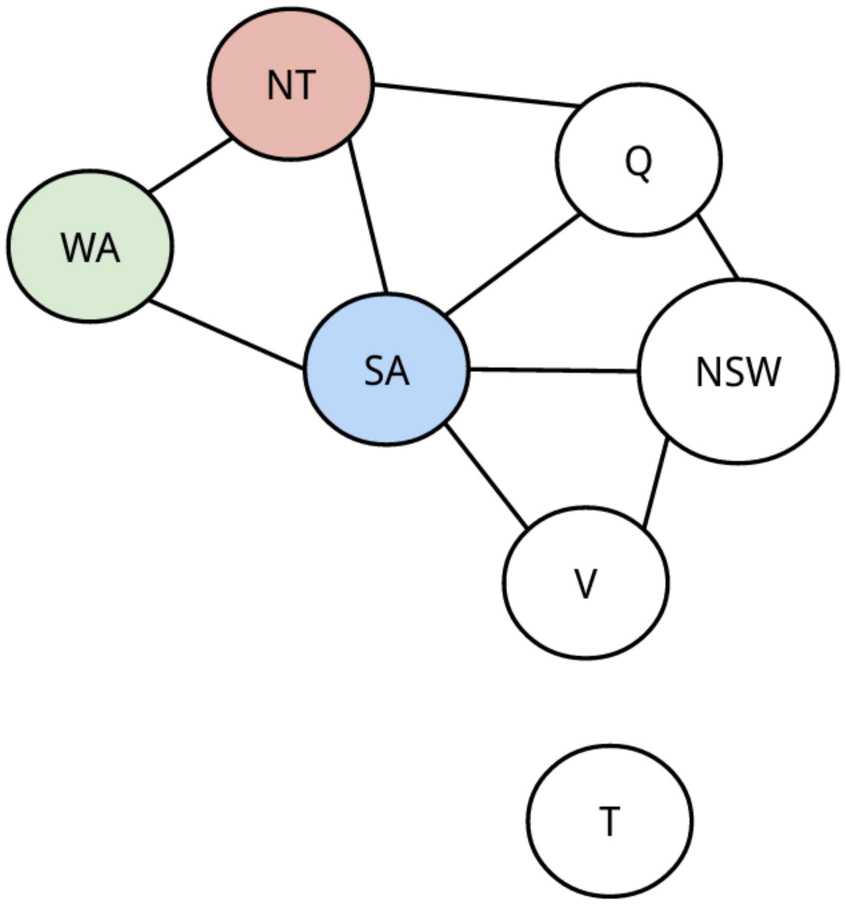

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```
# Declarative map coloring idea:
Find a solution where:
- All regions of the map are colored
- No neighboring regions have the same color
```

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Most Declarative Programming

- Solve less cool problems
- But the problems can be much bigger
- More standard approach for programmers

Logic

The programming language

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```
; declare all border relations first
logic> (fact (two-away ?r1 ?r2)
             (border ?r1 ?mid)
             (border ?mid ?r2)
             (not (border ?r1 ?r2)))
logic> (query (two-away ?r1 ?r2))
Success!
r1: nsw   r2: wa
r1: nt    r2: v
r1: q     r2: wa
r1: q     r2: v
```

An Aside

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```
logic> (query (border NSW Q))
```

An Aside

```
logic> (query (border NSW Q))
Success!
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An Aside

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logic> (query (border NSW Q))
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logic> (query (border Q NSW))
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- Relations are not *symmetric*, which is weird for borders
- We can fix this by declaring more facts for borders, but we won’t do that yet because doing so introduces *cycles*
- Handling cycles is hard (remember cyclic linked lists?), and makes the whole example a bit too complicated
  - So we will leave it out for now
- But the basic idea is that, if we have cycles, we have to keep track of what regions we have already seen, to make sure we don’t look through the same regions forever

Compound Queries

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- Compound queries contain more than one relation

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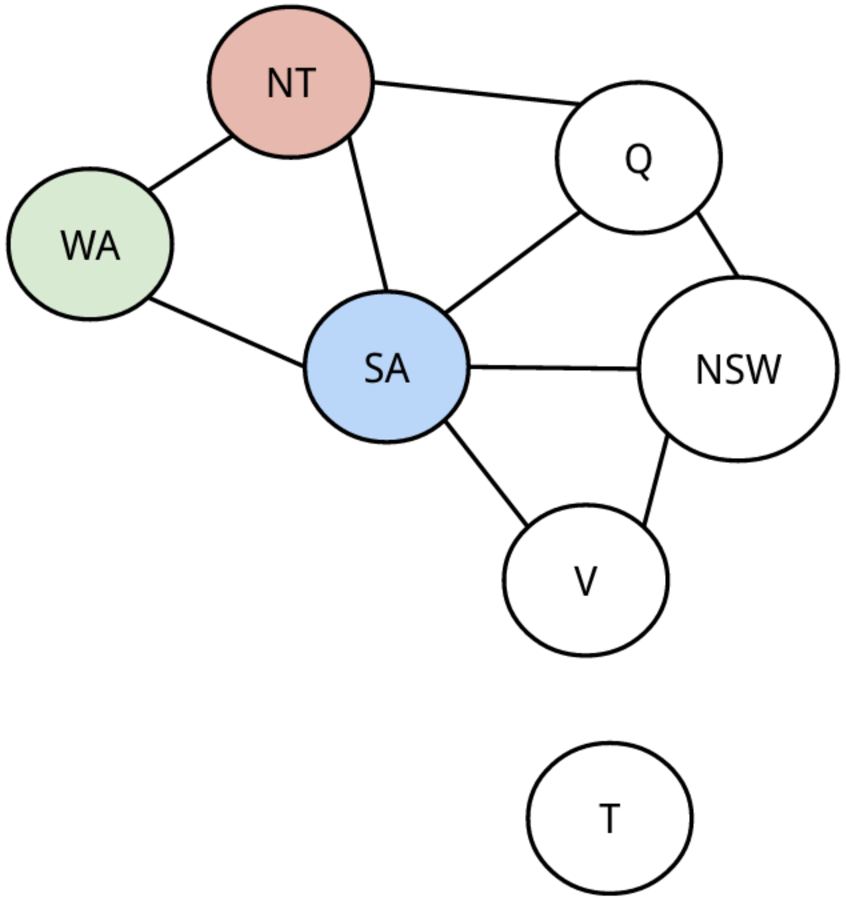

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logic> (query (two-away NSW ?region)
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```

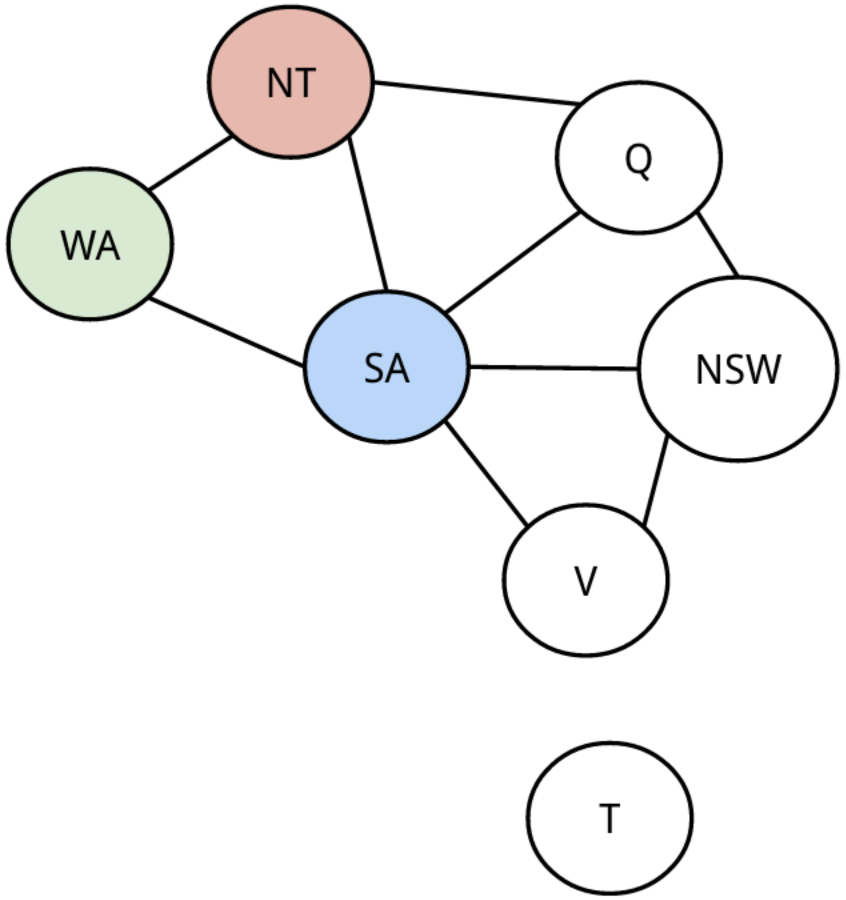

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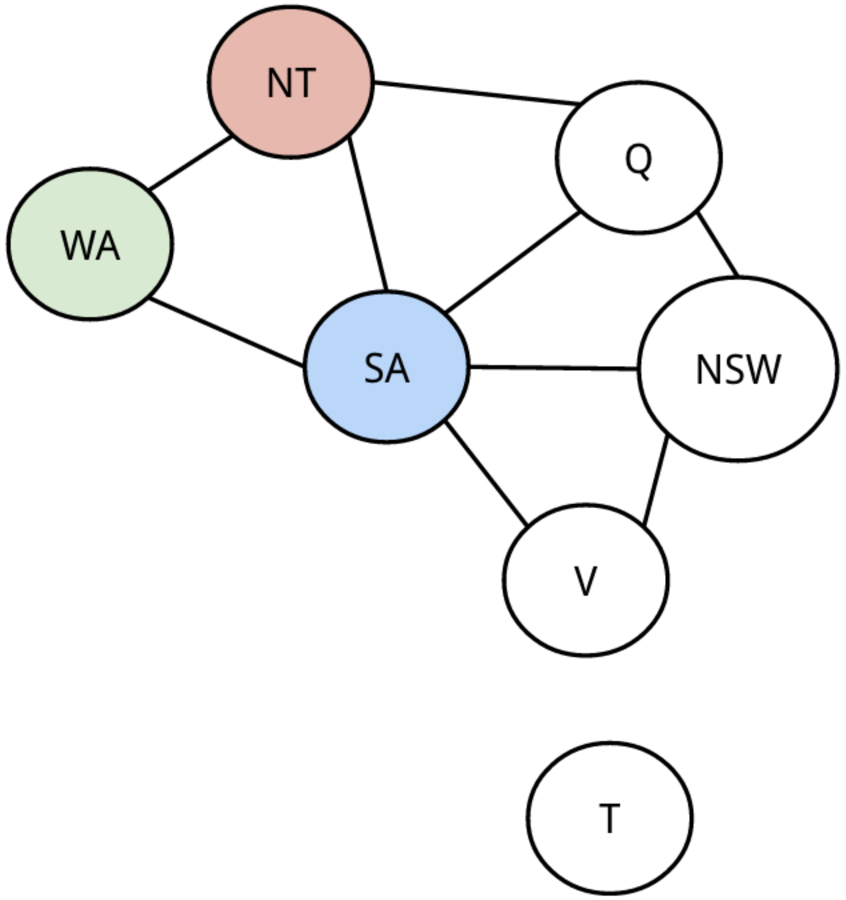
```



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logic> (query (two-away NSW ?region)
              (two-away Q ?region))
Success!
region: wa
```

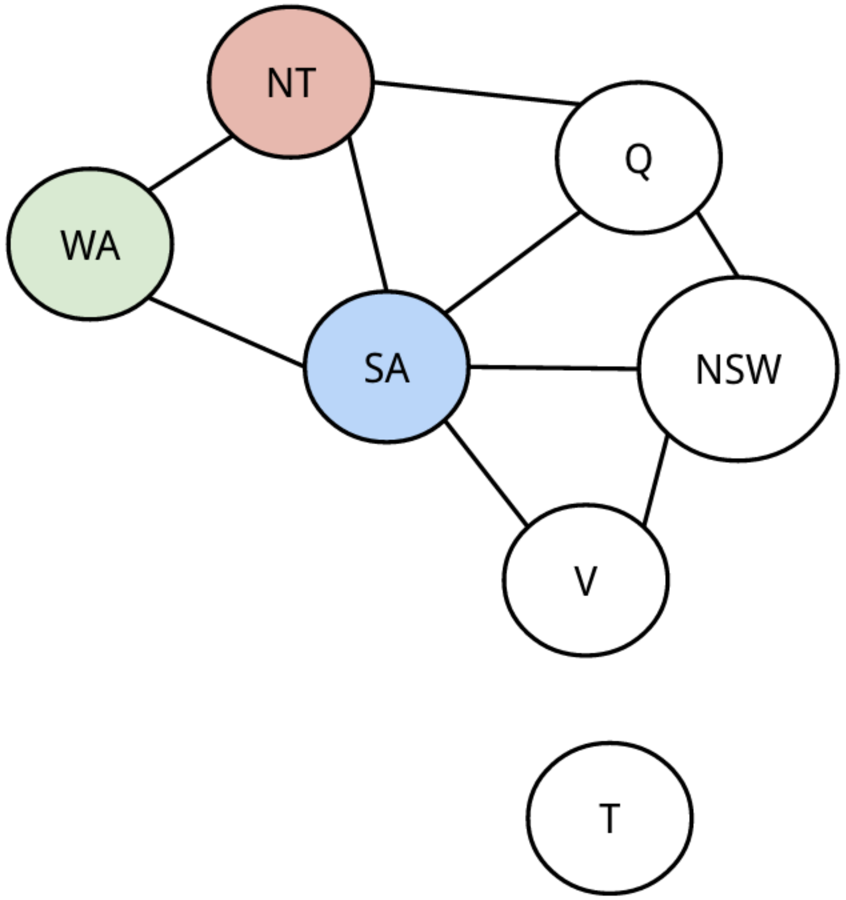

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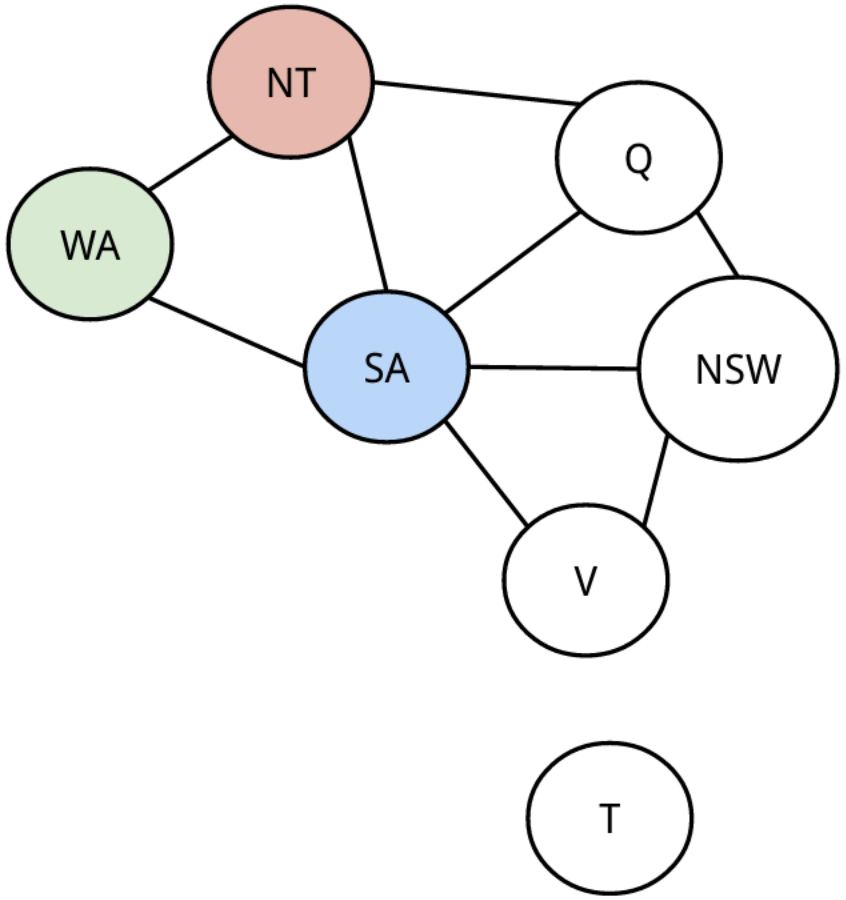
```
logic> (query (two-away NSW ?region)
              (two-away Q ?region))
Success!
region: wa
logic> (query (two-away ?r1 ?r2)
              (border NT ?r2))
```



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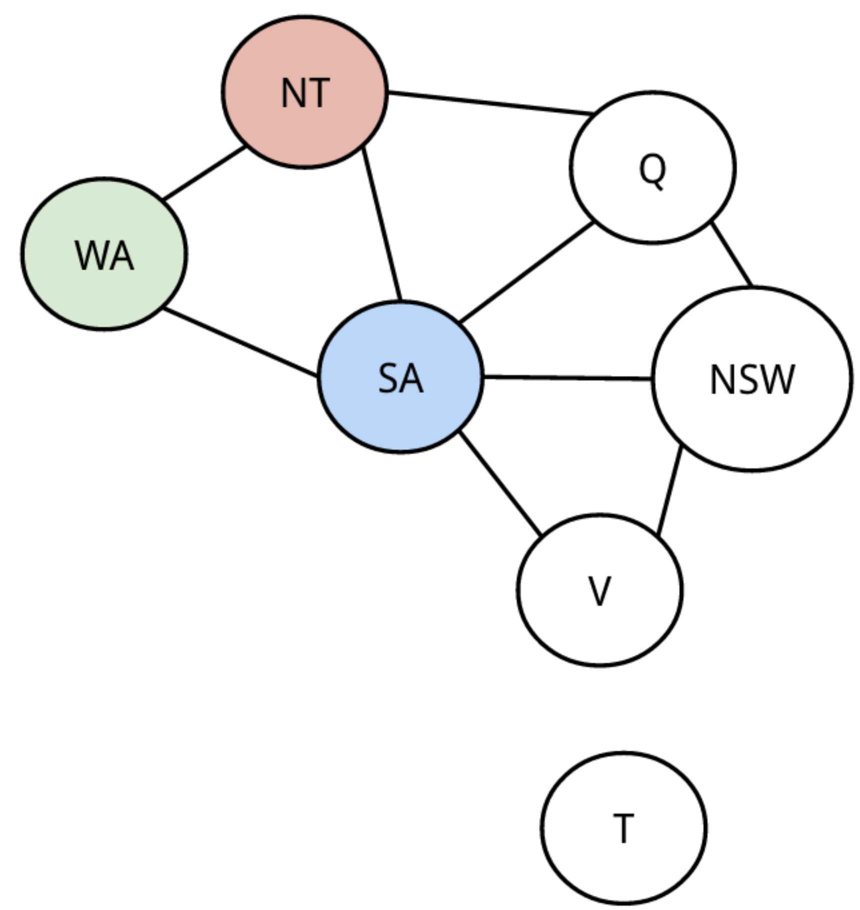
```



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Success!
region: wa
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              (border NT ?r2))
Success!
r1: nsw   r2: wa
```

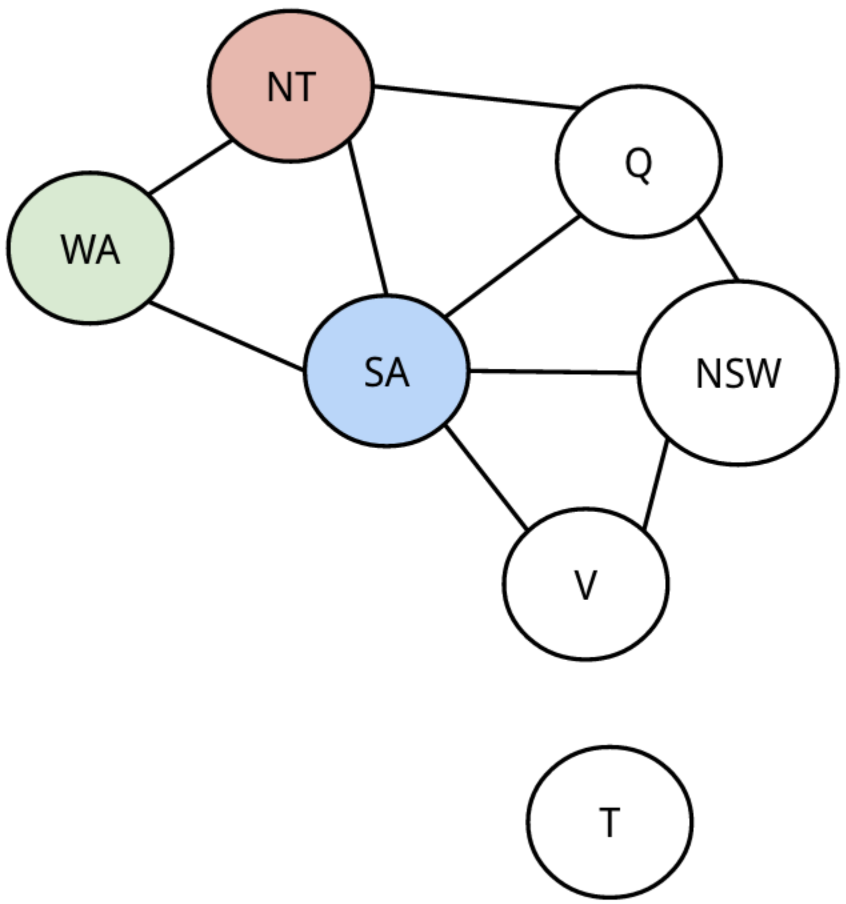

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logic> (query (two-away NSW ?region)
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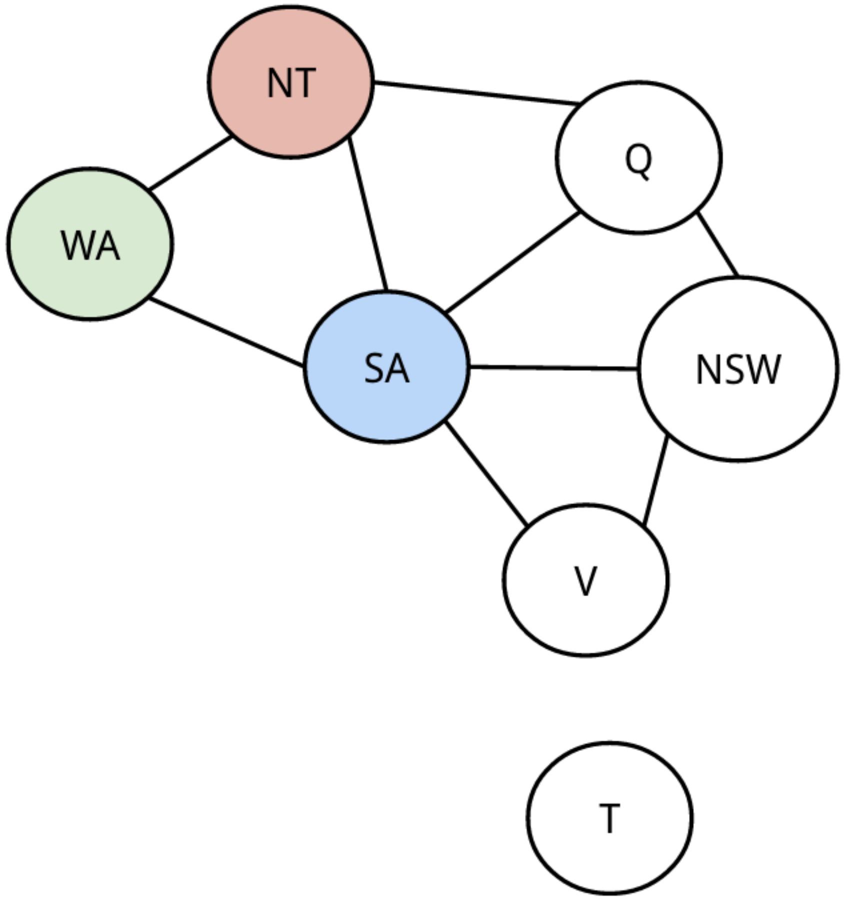
Success!
region: wa
logic> (query (two-away ?r1 ?r2)
              (border NT ?r2))
Success!
r1: nsw   r2: wa
r1: q     r2: wa
```



Recursive facts

Also, hierarchical facts

Recursive Facts

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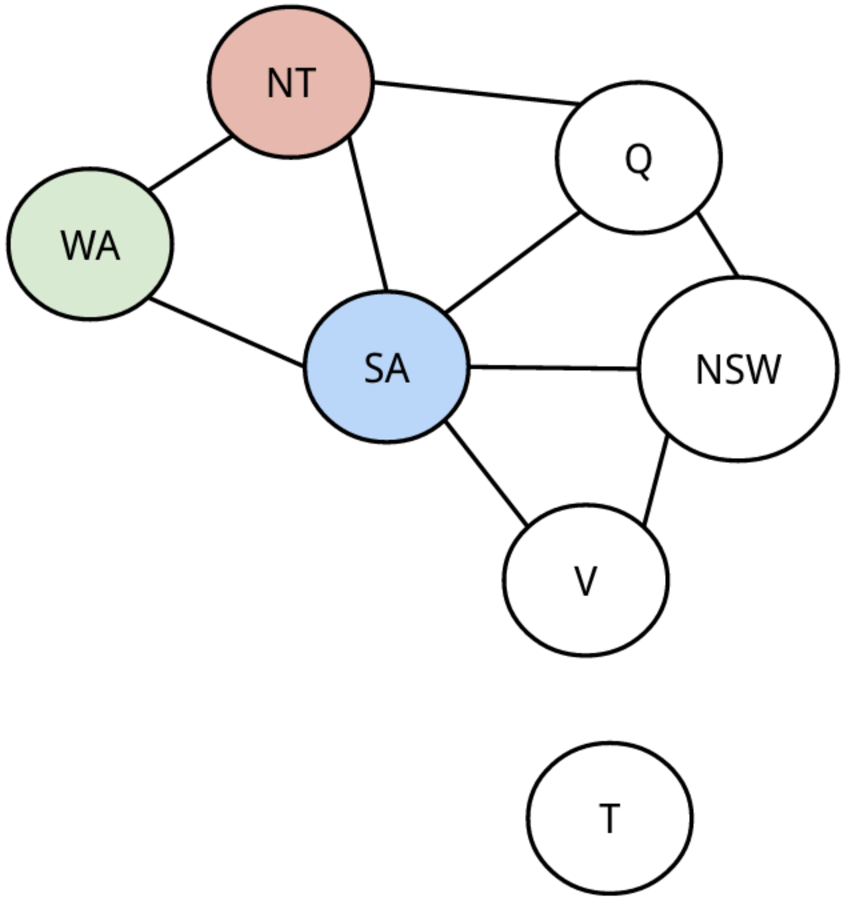

Recursive Facts (demo)

- A *recursive fact* uses the same relation in the conclusion and one or more hypotheses
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```
logic> (fact (connected ?r1 ?r2)
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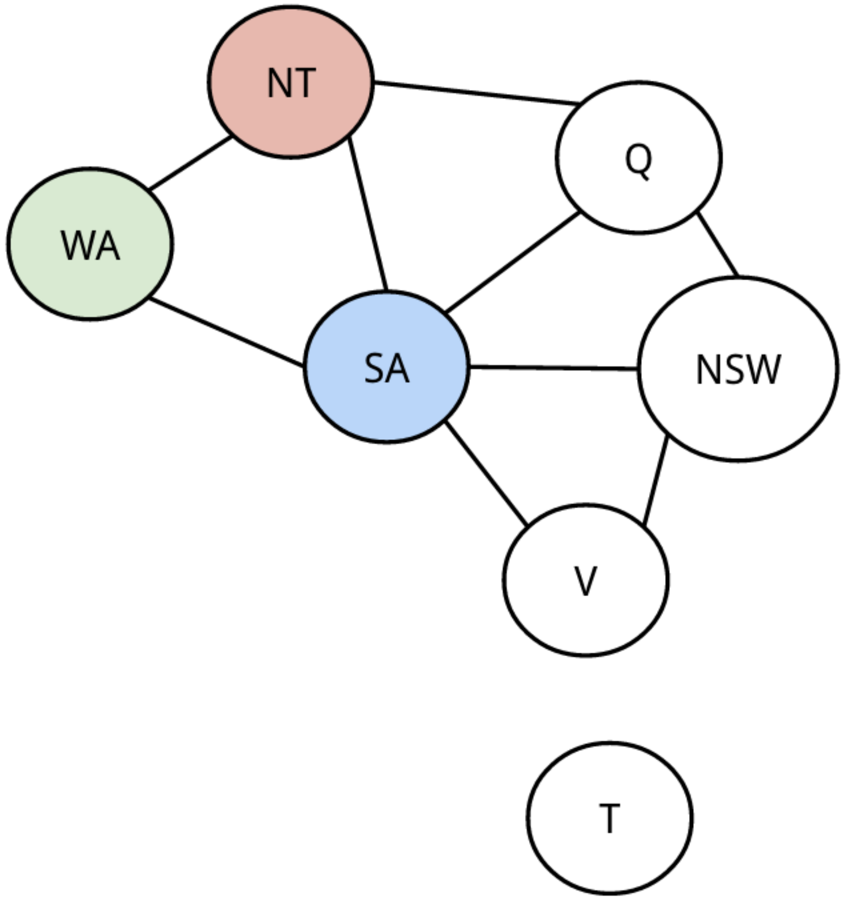
logic> (fact (connected ?r1 ?r2)
             (border ?r1 ?next)
             (connected ?next ?r2))
```



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logic> (fact (connected ?r1 ?r2)
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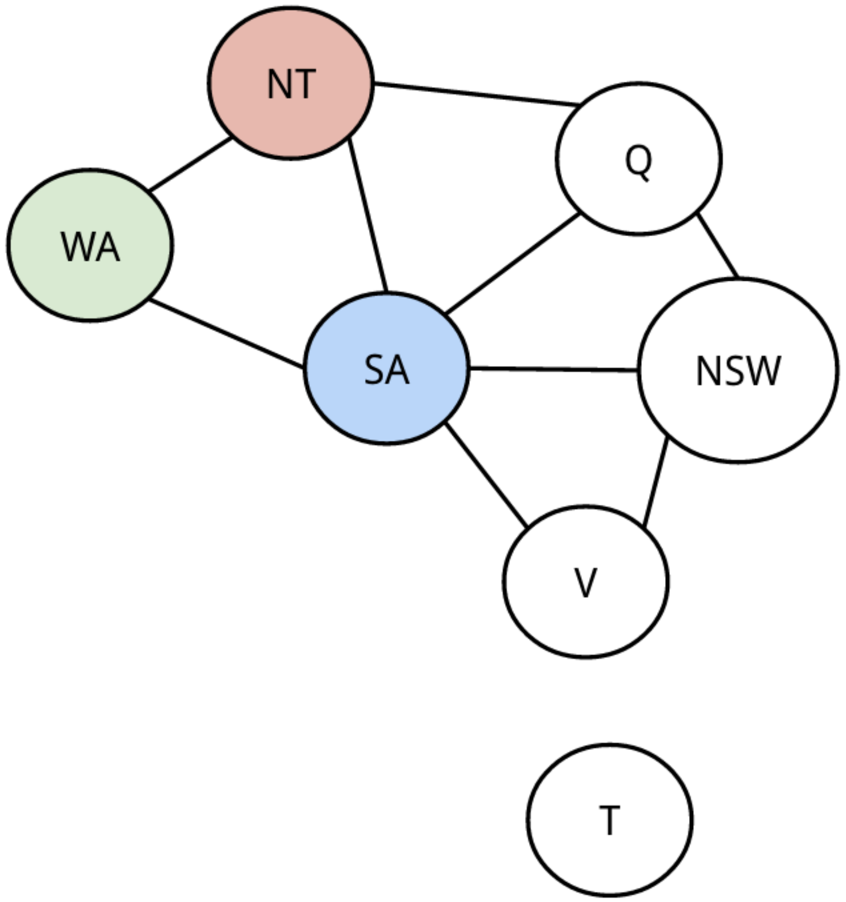

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logic> (fact (connected ?r1 ?r2)
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```

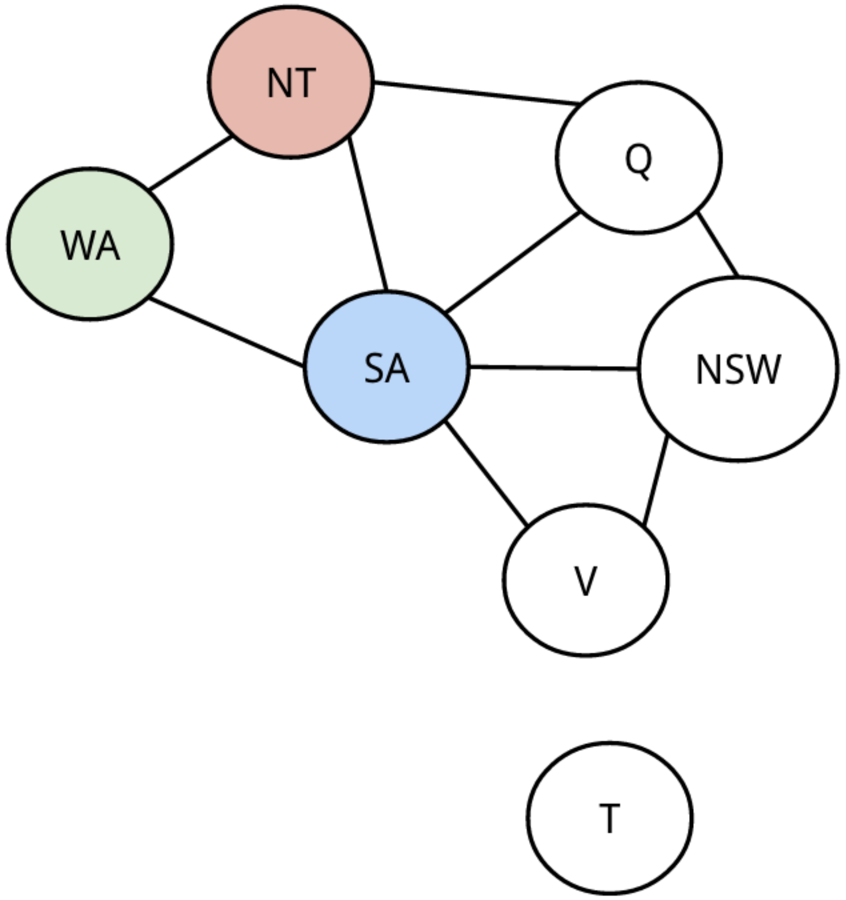

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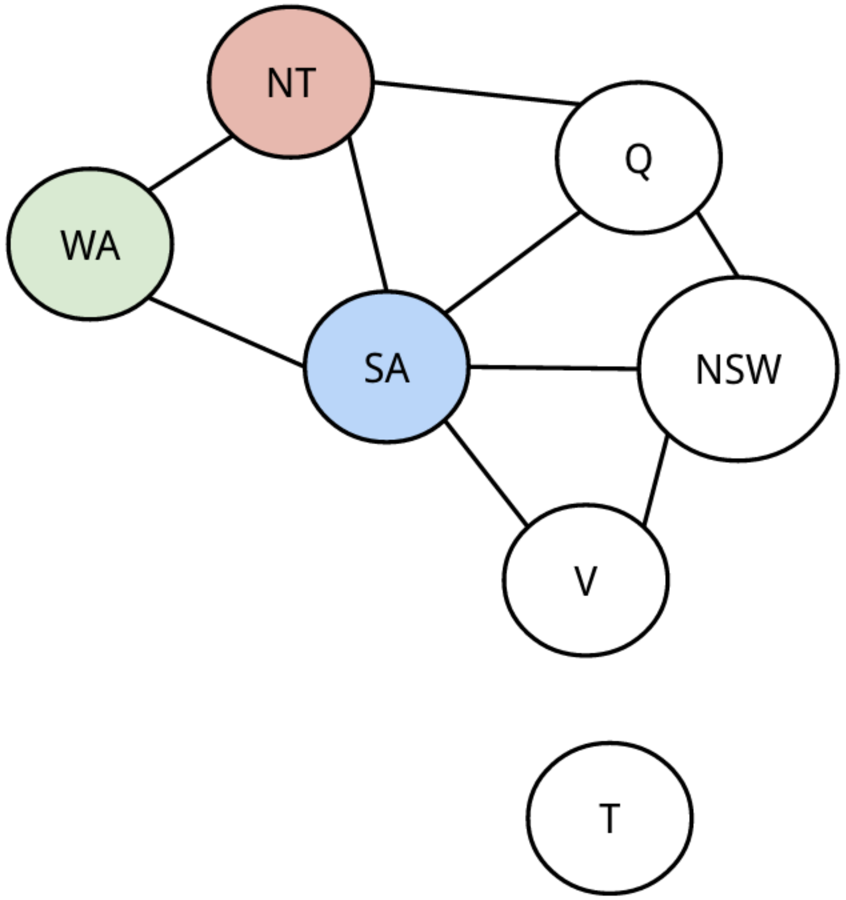

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logic> (fact (connected ?r1 ?r2)
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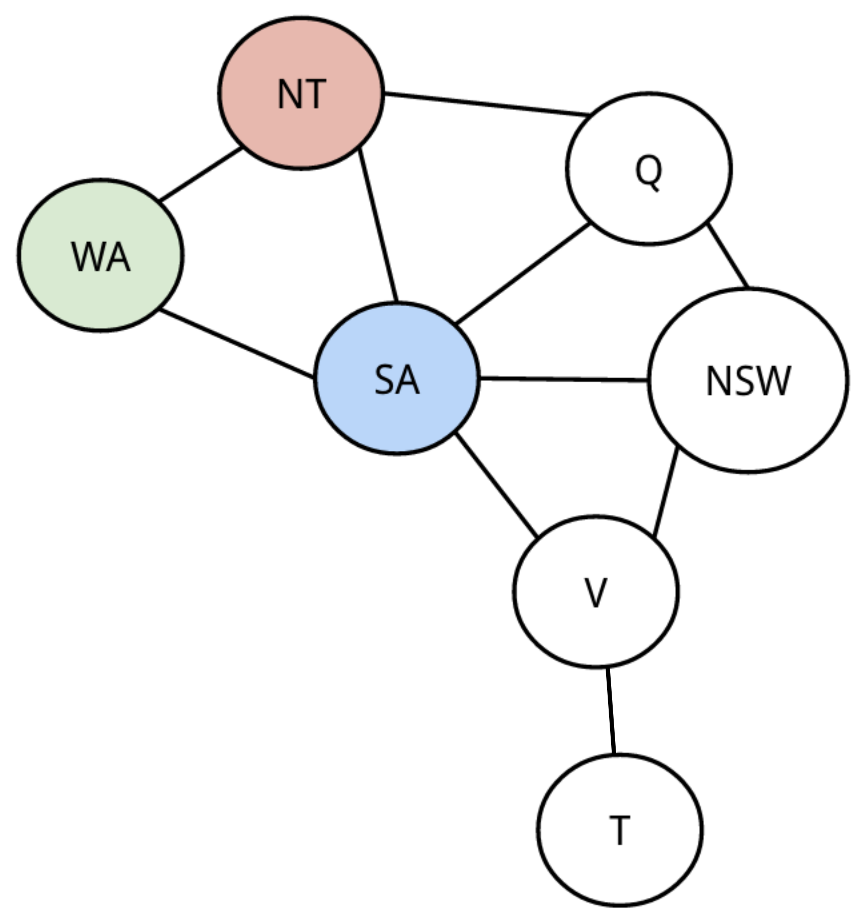
logic> (fact (connected ?r1 ?r2)
             (border ?r1 ?next)
             (connected ?next ?r2))

logic> (fact (border V T))
```



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logic> (fact (connected ?r1 ?r2)
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             (border ?r1 ?next)
             (connected ?next ?r2))

logic> (fact (border V T))
logic> (query (two-away NT T))
```

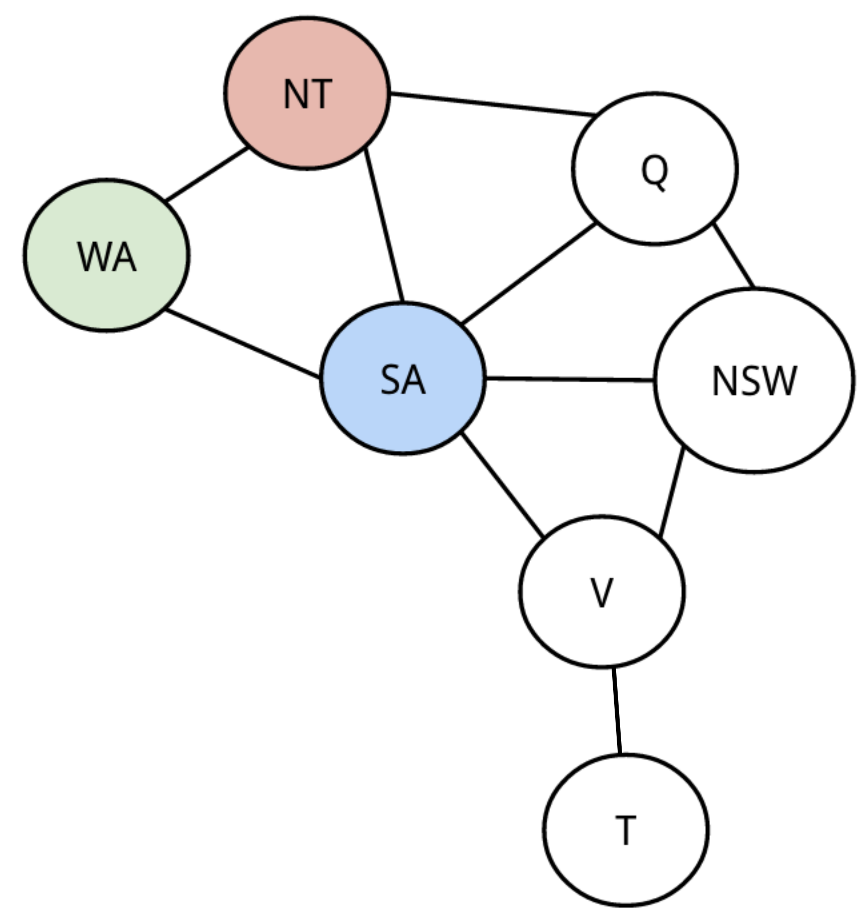

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logic> (fact (connected ?r1 ?r2)
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logic> (fact (connected ?r1 ?r2)
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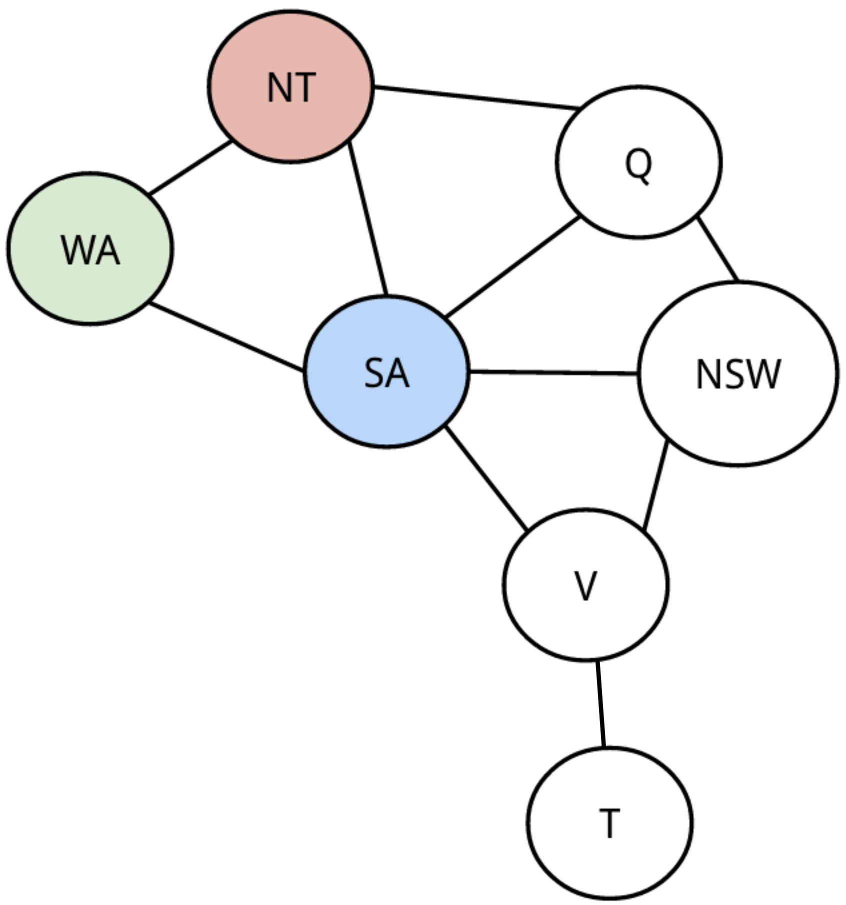
             (connected ?next ?r2))

logic> (fact (border V T))
logic> (query (two-away NT T))
Failed.
```



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logic> (fact (connected ?r1 ?r2)
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             (border ?r1 ?next)
             (connected ?next ?r2))

logic> (fact (border V T))
logic> (query (two-away NT T))
Failed.
logic> (query (connected NT T))
```

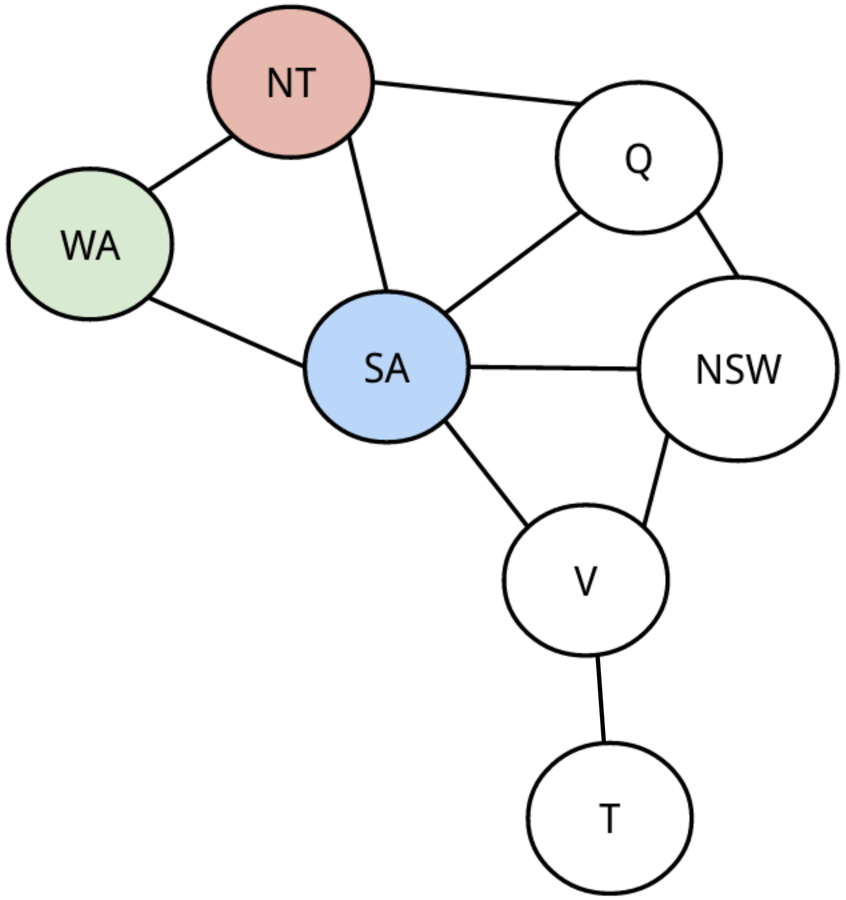

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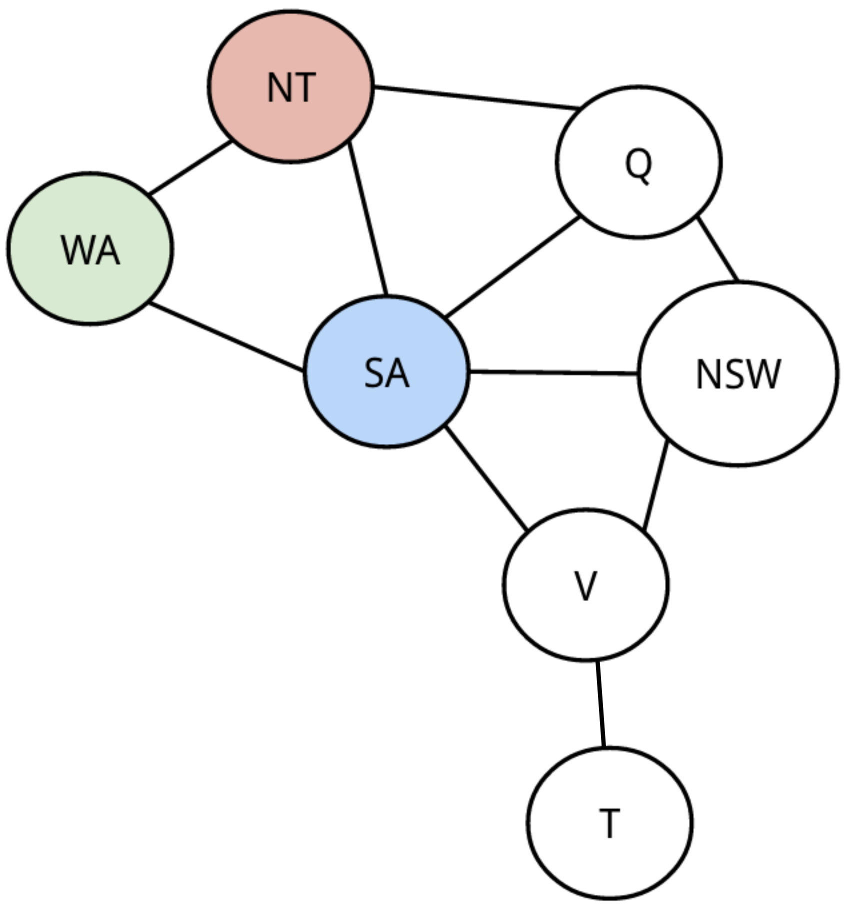
             (connected ?next ?r2))

logic> (fact (border V T))
logic> (query (two-away NT T))
Failed.
logic> (query (connected NT T))
Success!
```



Recursive Facts

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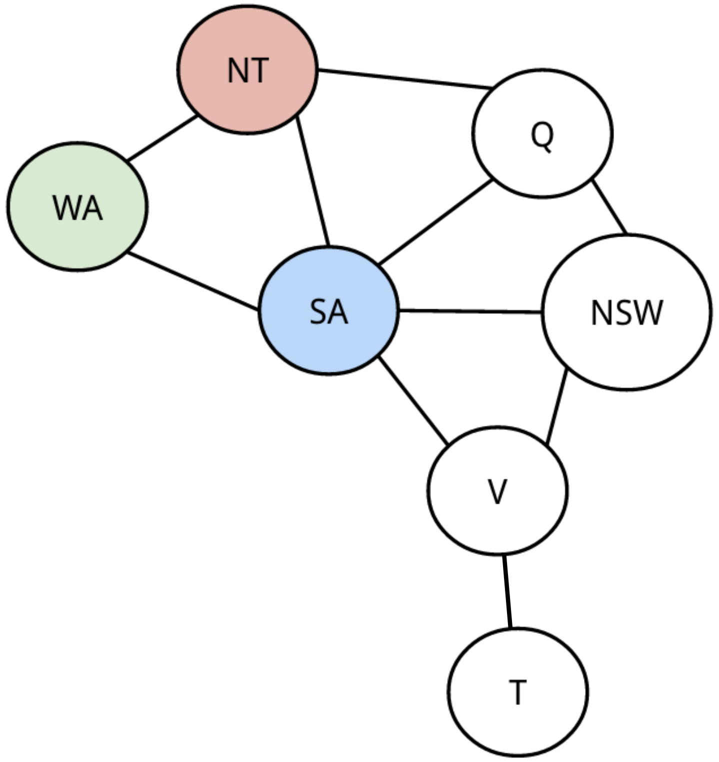

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logic> (fact (connected ?r1 ?r2)
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             (connected ?next ?r2))
```

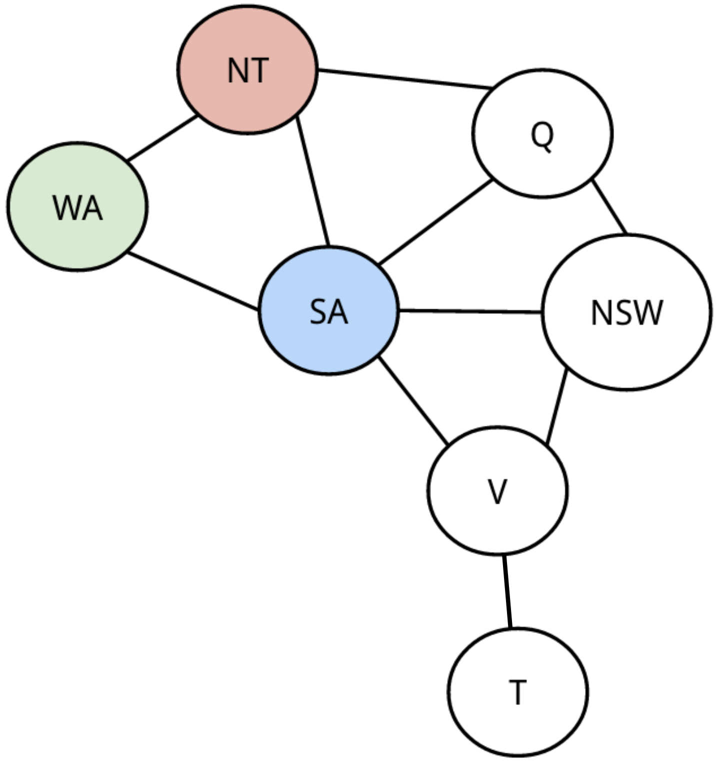

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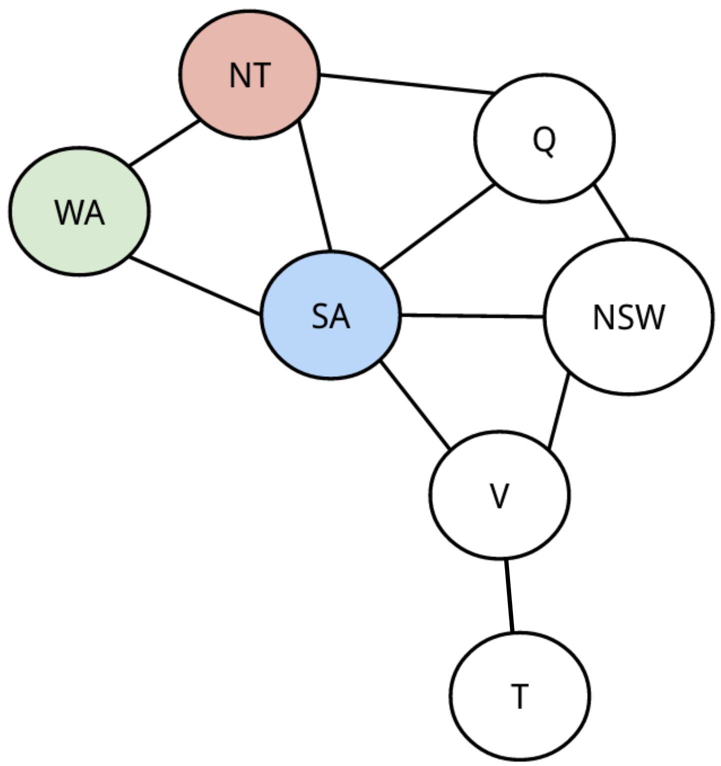
logic> (fact (connected ?r1 ?r2)
             (border ?r1 ?next)
             (connected ?next ?r2))
logic> (query (connected NT T))
Success!
```



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             (connected ?next ?r2))
logic> (query (connected NT T))
Success!
```

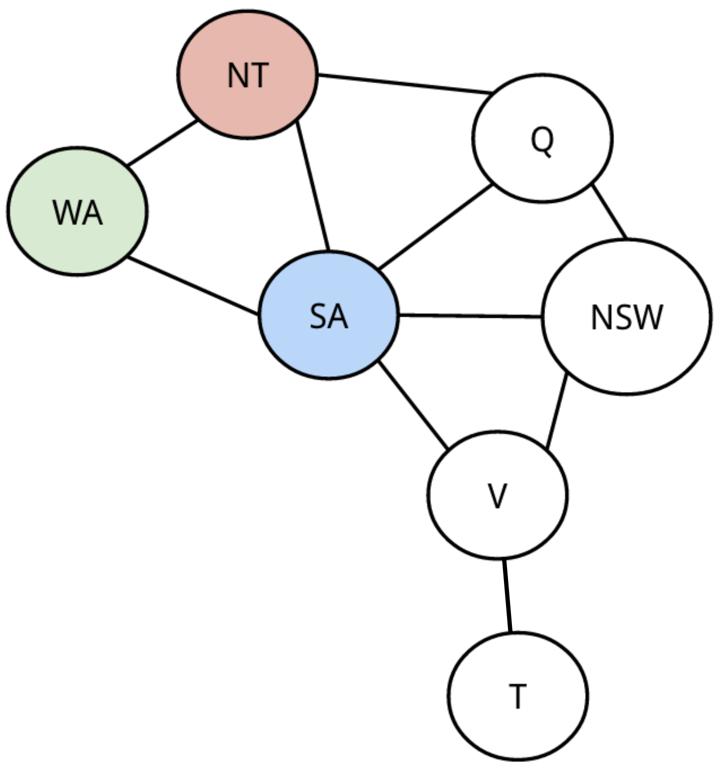

(border NT SA)

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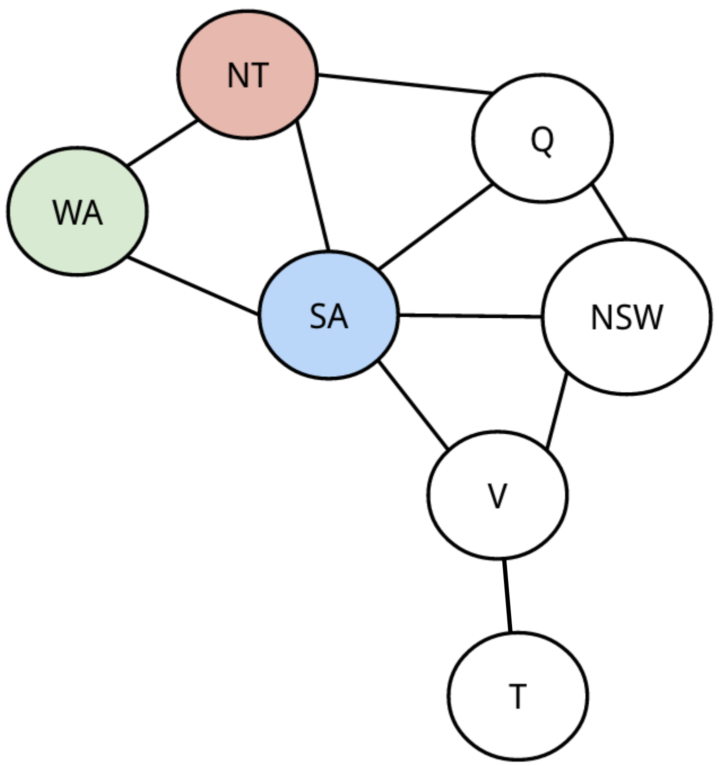
```
logic> (fact (connected ?r1 ?r2)
             (border ?r1 ?r2))
logic> (fact (connected ?r1 ?r2)
             (border ?r1 ?next)
             (connected ?next ?r2))
logic> (query (connected NT T))
Success!
```




```
(border NT SA)
(border SA V)
```

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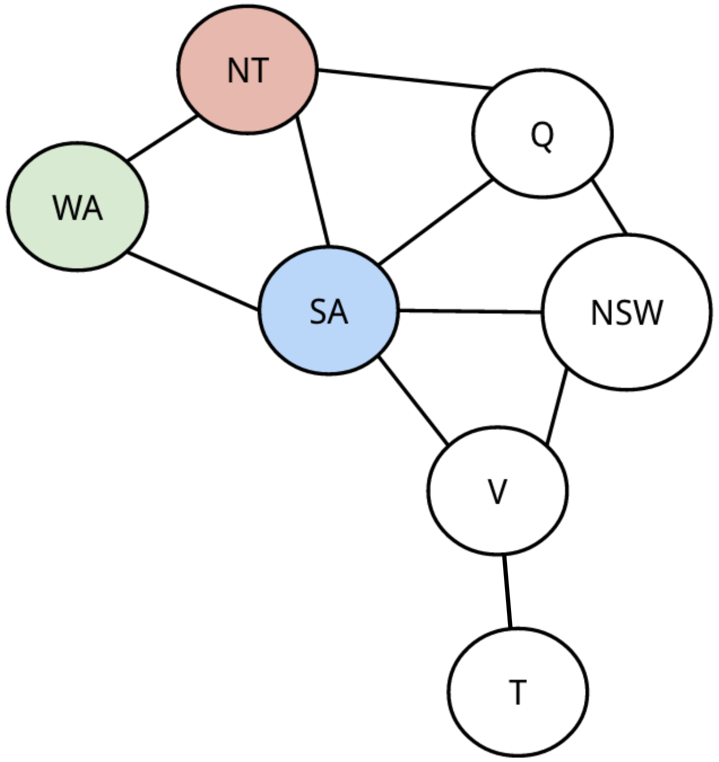
             (connected ?next ?r2))
logic> (query (connected NT T))
Success!
```




```
                                     (border NT SA)
                  (border SA V)
(border V T)
```

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logic> (fact (connected ?r1 ?r2)
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             (connected ?next ?r2))
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Success!
```

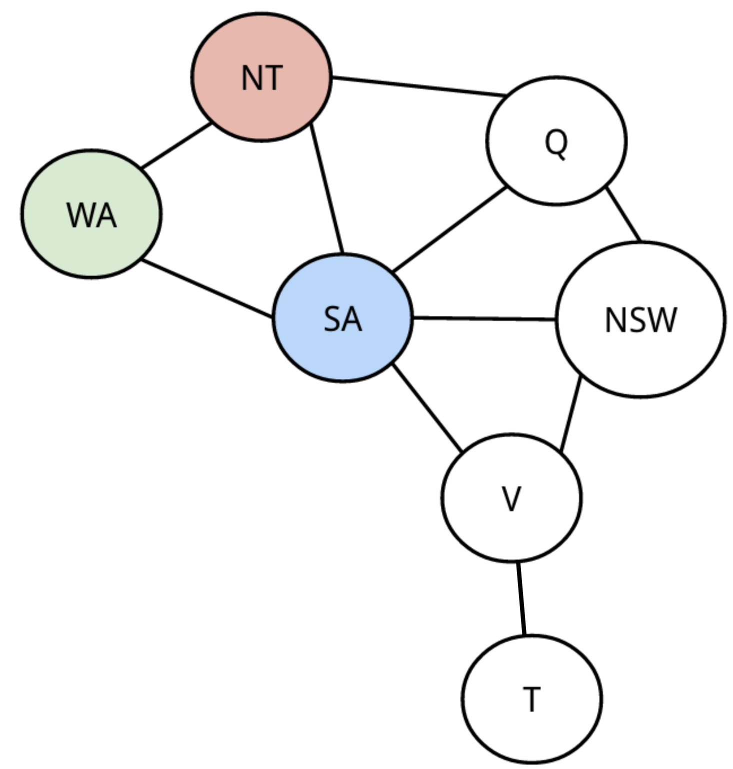


```
                                    (border NT SA)
            (border SA V)
(border V T) ⟹ (connected V T)
```

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             (border ?r1 ?r2))
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             (connected ?next ?r2))
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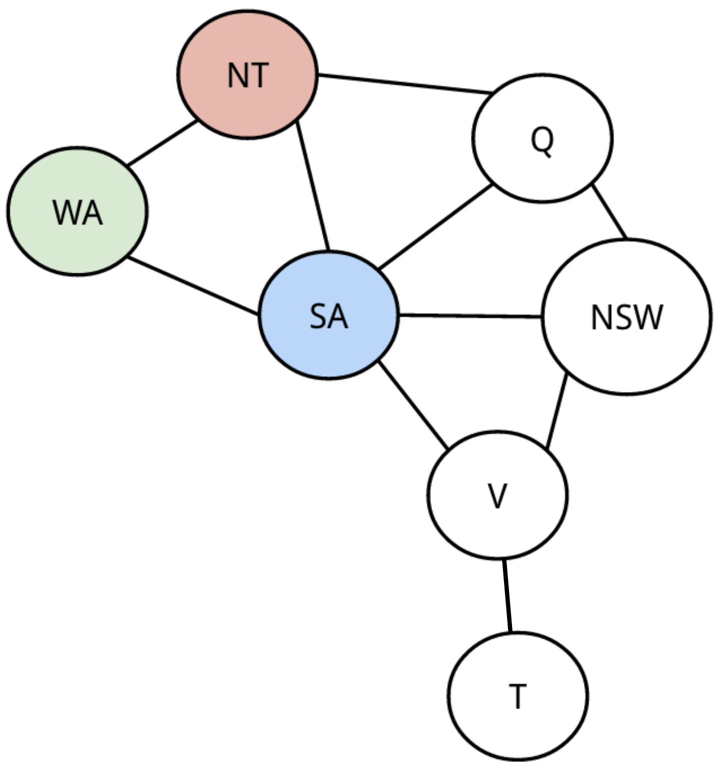
Success!
```



(border NT SA)

(border SA V)

(border V T) $\Rightarrow$ (connected V T) $\Rightarrow$ (connected SA T)

Recursive Facts

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logic> (fact (connected ?r1 ?r2)
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             (connected ?next ?r2))
logic> (query (connected NT T))
Success!
```

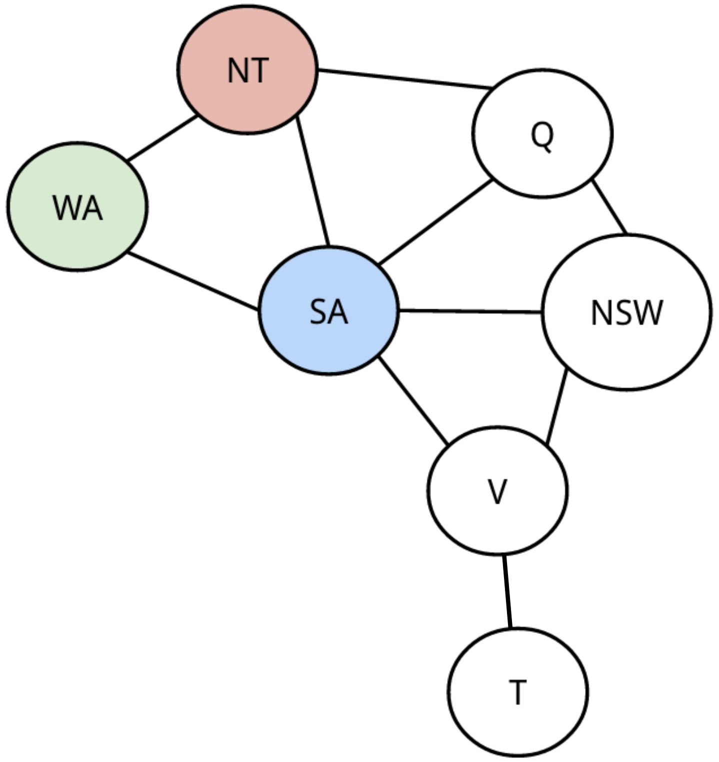


```
                                        (border NT SA)
                 (border SA V)                               ⇒ (connected NT T)
                                   ⇒    (connected SA T)
(border V T) ⇒  (connected V T)
```

Hierarchical Facts

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- Relations can also contain lists in addition to symbols

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```
(fact (australia (NSW NT Q SA T WA V)))
```

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```
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symbol

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list of symbols

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symbol   list of symbols

- The fancy name for this is *hierarchy*, but it’s not a fancy or complex idea

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symbol — list of symbols

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```
logic> (query (australia ?regions))
```

Hierarchical Facts

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list of symbols

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```

$$\texttt{(fact (}\underbrace{\texttt{australia}}_{\text{symbol}}\ \texttt{(}\underbrace{\texttt{NSW NT Q SA T WA V}}_{\text{list of symbols}}\texttt{)))}$$

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```
logic> (query (australia ?regions))
Success!
regions: (nsw nt q sa t wa v)
```

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symbol — list of symbols

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```
logic> (query (australia ?regions))
Success!
regions: (nsw nt q sa t wa v)
logic> (query (australia (?first . ?rest)))
```

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```
logic> (query (australia ?regions))
Success!
regions: (nsw nt q sa t wa v)
logic> (query (australia (?first . ?rest)))
Success!
first: nsw   rest: (nt q sa t wa v)
```

Hierarchical Facts

- Relations can also contain lists in addition to symbols

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(fact (australia (NSW NT Q SA T WA V)))
```

symbol — list of symbols

- The fancy name for this is *hierarchy*, but it's not a fancy or complex idea
- Variables can refer to either symbols or lists of symbols

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logic> (query (australia ?regions))
Success!
regions: (nsw nt q sa t wa v)
logic> (query (australia (?first . ?rest)))
Success!
first: nsw   rest: (nt q sa t wa v)
```

- Why the dot? Because we are using Scheme lists, `(nsw nt q sa t wa v)` is the same as `(nsw . (nt q sa t wa v))`

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Failed.
logic> (query (in ?x (1 2 3 4)))
Success!
x: 1
x: 2
x: 3
x: 4
```

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logic> (fact (append () ?lst ?lst))
logic> (fact (append (?first . ?rest) ?lst (?first . ?rest+lst))
             (append ?rest ?lst ?rest+lst))
logic> (query (append (1 2) (3 4) (1 2 3 4)))
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             (append ?rest ?lst ?rest+lst))
logic> (query (append (1 2) (3 4) (1 2 3 4)))
Success!
logic> (query (append (1 2) (3 4 5) (1 2 3 4)))
Failed.
logic> (query (append ?lst1 ?lst2 (1 2 3 4)))
Success!
lst1: ()          lst2: (1 2 3 4)
lst1: (1)         lst2: (2 3 4)
lst1: (1 2)       lst2: (3 4)
lst1: (1 2 3)     lst2: (4)
lst1: (1 2 3 4)   lst2: ()
```

Let’s Color Australia

In two different ways

Map Coloring Way #1

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# Declarative map coloring idea:
Find a solution where:
- All regions of the map are colored
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              (in ?T   (red green blue))
              (in ?V   (red green blue))
              (in ?WA  (red green blue))
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- This is very different idea, so you’ll have to practice!