### IST 4: Planned Schedule - Spring 2015

<table>
<thead>
<tr>
<th>mon</th>
<th>tue</th>
<th>wed</th>
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<tbody>
<tr>
<td>30</td>
<td>M1</td>
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<td>6</td>
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<td>oh</td>
<td>M1</td>
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<td>13</td>
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<td>2M2</td>
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<td>oh</td>
<td>M2</td>
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<td>1</td>
<td>oh</td>
<td></td>
<td>5</td>
<td>oh</td>
</tr>
</tbody>
</table>

- **T** = today
- **x** = hw#x out
- **x** = hw#x due
- **oh** = office hours
- **Mx** = MQx out
- **Mx** = MQx due

---

**Midterms**

T  midterms
So far... True for any Boolean Algebra

**T0: duality principle**

**T1: Single complement per element**

- **A1. Identities:**
  \[ a + 0 = a \quad \text{and} \quad a \cdot 1 = a \]

- **A2. Complements:**
  \[ a + \overline{a} = 1 \quad \text{and} \quad a \cdot \overline{a} = 0 \]

- **A3. Commutativity:**
  \[ a + b = b + a \quad \text{and} \quad a \cdot b = b \cdot a \]

- **A4. Distributivity:**
  \[ a + (b \cdot c) = (a + b) \cdot (a + c) \quad \text{and} \quad a \cdot (b + c) = (a \cdot b) + (a \cdot c) \]

**L1: self Absorption**

\[ \overline{a} = a \]
Boolean Algebra

It is all about syntax...

Boolean ‘editing’
Absorption Theorem

Theorem 2: \[ a + a \cdot b = a \]
Absorption Theorem

Theorem 2: \[ a + a \cdot b = a \]

Can delete anything!!

\[ a + a \cdot b = a \]
Absorption Theorem

Theorem 2: \[ a + a \cdot b = a \]

Can delete anything!!
Absorption Theorem

Theorem 2: \[ a + a \cdot b = a \]

Can *insert* anything!!
Absorption Theorem

**Theorem 2:** \[ a + a \cdot b = a \]
\[ a \cdot (a + b) = a \]

**Proof:**

1. **A1. Identities:**
   \[ a + 0 = a \] and \[ a \cdot 1 = a \]

2. **A2. Complements:**
   \[ a + \bar{a} = 1 \] and \[ a \cdot \bar{a} = 0 \]

3. **A3. Commutativity:**
   \[ a + b = b + a \] and \[ a \cdot b = b \cdot a \]

4. **A4. Distributivity:**
   \[ a + (b \cdot c) = (a + b) \cdot (a + c) \] and \[ a \cdot (b + c) = (a \cdot b) + (a \cdot c) \]
Absorption Theorem

**Theorem 2:** \( a + a \cdot b = a \)

**Proof:**

\[
\begin{align*}
    a + a \cdot b &= a \cdot 1 + a \cdot b \\
    &= a \cdot (1 + b) \\
    &= a \cdot 1 \\
    &= a
\end{align*}
\]

- **A1. Identities:**
  - \( a + 0 = a \) and \( a \cdot 1 = a \)
- **A2. Complements:**
  - \( a + \bar{a} = 1 \) and \( a \cdot \bar{a} = 0 \)
- **A3. Commutativity:**
  - \( a + b = b + a \) and \( a \cdot b = b \cdot a \)
- **A4. Distributivity:**
  - \( a + (b \cdot c) = (a + b) \cdot (a + c) \) and \( a \cdot (b + c) = (a \cdot b) + (a \cdot c) \)

**Question:**

\( a = 1 \)???
Simple Absorption

A proof of a theorem can help in identifying useful lemmas

**Lemma 2:**

\[
1 + a = 1
\]

\[
0 \cdot a = 0
\]

- **A1. Identities:**
  \[a + 0 = a \quad \text{and} \quad a \cdot 1 = a\]
- **A2. Complements:**
  \[a + \bar{a} = 1 \quad \text{and} \quad a \cdot \bar{a} = 0\]
- **A3. Commutativity:**
  \[a + b = b + a \quad \text{and} \quad a \cdot b = b \cdot a\]
- **A4. Distributivity:**
  \[a + (b \cdot c) = (a + b) \cdot (a + c) \quad \text{and} \quad a \cdot (b + c) = (a \cdot b) + (a \cdot c)\]
Simple Absorption

Lemma 2: \( 1 + a = 1 \)

Proof:

\[
1 + a = (1 + a) \cdot 1 = (a + 1) \cdot (a + \overline{a}) = a + 1 \cdot \overline{a} = a + \overline{a} = 1
\]

- A1. Identities: \( a + 0 = a \) and \( a \cdot 1 = a \)
- A2. Complements: \( a + \overline{a} = 1 \) and \( a \cdot \overline{a} = 0 \)
- A3. Commutativity: \( a + b = b + a \) and \( a \cdot b = b \cdot a \)
- A4. Distributivity: \( a + (b \cdot c) = (a + b) \cdot (a + c) \) and \( a \cdot (b + c) = (a \cdot b) + (a \cdot c) \)
Absorption Theorem

A proof of a theorem can help in identifying useful lemmas

Theorem 2: \[ a + a \cdot b = a \]
\[ a \cdot (a + b) = a \]
\[ 1 + a = 1 \]

Proof:

\[ a + a \cdot b = a \cdot 1 + a \cdot b \]
\[ = a \cdot (1 + b) \]
\[ = a \cdot 1 \]
\[ = a \]

- A1. Identities:
  \[ a + 0 = a \text{ and } a \cdot 1 = a \]
- A2. Complements:
  \[ a + \bar{a} = 1 \text{ and } a \cdot \bar{a} = 0 \]
- A3. Commutativity:
  \[ a + b = b + a \text{ and } a \cdot b = b \cdot a \]
- A4. Distributivity:
  \[ a + (b \cdot c) = (a + b) \cdot (a + c) \text{ and } a \cdot (b + c) = (a \cdot b) + (a \cdot c) \]
Proofs are FUN...

Not every proof...
My Ranking of Proofs

Correct and short

Wrong and fun

Correct but painful

Wrong and long
Proofs are FUN...
Proofs are FUN...
Proofs are FUN...
Proofs are FUN...
Proofs are FUN...
Proofs are FUN...
Proofs are FUN...
Proofs are FUN...
My Dear Children,

A young monkey named Genius picked a green walnut, and bit, through a bitter rind, down into a hard shell. He then threw the walnut away, saying: “How stupid people are! They told me walnuts are good to eat.”

His grandmother, whose name was Wisdom, picked up the walnut—peeled off the rind with her fingers, cracked the shell, and shared the kernel with her grandson, saying: “Those get on best in life who do not trust to first impressions.”

Proofs are fun: Be patient and crack it!
Boolean Algebra

Now it is your turn
The Positive Win:

- **A1. Identities:**
  \[ a + 0 = a \text{ and } a \cdot 1 = a \]

- **A2. Complements:**
  \[ a + \bar{a} = 1 \text{ and } a \cdot \bar{a} = 0 \]

- **A3. Commutativity:**
  \[ a + b = b + a \text{ and } a \cdot b = b \cdot a \]

- **A4. Distributivity:**
  \[ a + (b \cdot c) = (a + b) \cdot (a + c) \text{ and } a \cdot (b + c) = (a \cdot b) + (a \cdot c) \]

\[ a + \bar{a} \cdot b = a + b \]
The Positive Win:

\[ a + \overline{a} \cdot b = a + b \]

**Proof:**
\[
\begin{align*}
    a + \overline{a} \cdot b &= (a + \overline{a}) \cdot (a + b) & \text{(A4)} \\
    &= 1 \cdot (a + b) & \text{(A2)} \\
    &= (a + b) \cdot 1 & \text{(A3)} \\
    &= a + b & \text{(A1)}
\end{align*}
\]
Boolean Algebra

One more...
Derive the answer?

\[ (a + b) \cdot (\bar{a} + b) = (b + a) \cdot (b + \bar{a}) \quad \text{(A3)} \]

\[ = b + a \cdot \bar{a} \quad \text{(A4)} \]

\[ = b + 0 \quad \text{(A2)} \]

\[ = b \quad \text{(A1)} \]
B wins: \[(a + b) \cdot (\bar{a} + b) = b\]

The positive win: \[a + \bar{a} \cdot b = a + b\]

Absorption: \[a + ab = a\]
Current state

- **A1. Identities:**
  \[ a + 0 = a \quad \text{and} \quad a \cdot 1 = a \]

- **A2. Complements:**
  \[ a + \bar{a} = 1 \quad \text{and} \quad a \cdot \bar{a} = 0 \]

- **A3. Commutativity:**
  \[ a + b = b + a \quad \text{and} \quad a \cdot b = b \cdot a \]

- **A4. Distributivity:**
  \[ a + (b \cdot c) = (a + b) \cdot (a + c) \quad \text{and} \quad a \cdot (b + c) = (a \cdot b) + (a \cdot c) \]

- **L1. Self Absorption:**
  \[ a + a = a \quad \text{and} \quad a \cdot a = a \]

- **L2. Simple Absorption:**
  \[ a + 1 = 1 \quad \text{and} \quad a \cdot 0 = 0 \]

- **T0. Duality:**
  Correctness is maintained when interchange + and \( \cdot \), as well as 0 and 1.

- **T1. Distinct Complement:**
  Every element has another element that is its unique complement.

- **T2. Absorption:**
  \[ a + ab = a \quad \text{and} \quad a \cdot (a + b) = a \]
Boolean Algebra

associativity does not need to be an axiom
Associativity Theorem

Theorem 3:

\[(a + b) + c = a + (b + c)\]
\[(a \cdot b) \cdot c = a \cdot (b \cdot c)\]

Proof: (ideas)

We will prove the other one follows by duality
Associativity Theorem

Theorem 3: \[(a + b) + c = a + (b + c)\]
\[(a \cdot b) \cdot c = a \cdot (b \cdot c)\]

Proof: (ideas)

So far we have seen 'linear proofs'

Arrows are axioms, lemmas, theorems....
Associativity Theorem

Theorem 3:  

\[(a + b) + c = a + (b + c)\]

\[(a \cdot b) \cdot c = a \cdot (b \cdot c)\]

Proof: (ideas)

A ‘nonlinear proof’ - has an architecture
**Associativity Theorem**

**Theorem 3:**

\[(a + b) + c = a + (b + c)\]

\[(a \cdot b) \cdot c = a \cdot (b \cdot c)\]

**Proof: (ideas)**

A 'nonlinear proof' - has an **architecture**

Prove 1

\[(a + a \cdot (b \cdot c)) \quad \parallel \quad 1 \parallel (a + (a \cdot b) \cdot c)\]
Associativity Theorem

Theorem 3: \[(a + b) + c = a + (b + c)\]
\[(a \cdot b) \cdot c = a \cdot (b \cdot c)\]

Proof: (ideas)

A ‘nonlinear proof’ - has an architecture

Prove 1

\[ (a + a \cdot (b \cdot c)) \]
\[ 1 \parallel \]
\[ (a + (a \cdot b) \cdot c) \]
Associativity Theorem

Theorem 3: \[(a + b) + c = a + (b + c)\]
\[(a \cdot b) \cdot c = a \cdot (b \cdot c)\]

Proof: (ideas)

A 'nonlinear proof' – has an architecture

Prove 1
\[(a + a \cdot (b \cdot c))\]
\[\parallel\]
\[(a + (a \cdot b) \cdot c)\]

Prove 2
\[(\bar{a} + a \cdot (b \cdot c))\]
\[\parallel\]
\[(\bar{a} + (a \cdot b) \cdot c)\]

multiply
Theorem 3: \[(a + b) + c = a + (b + c)\]

\[(a \cdot b) \cdot c = a \cdot (b \cdot c)\]

Proof: (ideas)

A ‘nonlinear proof’ - has an architecture

Prove 1: \[(a + a \cdot (b \cdot c)) \cdot (\bar{a} + a \cdot (b \cdot c))\]

Prove 2: \[(a + (a \cdot b) \cdot c) \cdot (\bar{a} + (a \cdot b) \cdot c)\]

Prove 3 and 4: multiply
**Associativity Theorem**

**Theorem 3:**

\[(a + b) + c = a + (b + c)\]

\[(a \cdot b) \cdot c = a \cdot (b \cdot c)\]

**Proof:**

**B wins:**

\[(a + b) \cdot (\bar{a} + b) = b\]

Prove 1

\[(a + a \cdot (b \cdot c)) \cdot (\bar{a} + a \cdot (b \cdot c)) \equiv (a \cdot (b \cdot c))\]

Prove 2

\[(a + (a \cdot b) \cdot c) \cdot (\bar{a} + (a \cdot b) \cdot c) = (a \cdot b) \cdot c\]

Prove 3 and 4

Multiply
1. Prove 1

\[(a + a \cdot (b \cdot c)) \cdot (\overline{a} + a \cdot (b \cdot c)) = a \cdot (b \cdot c)\]

\[(a + (a \cdot b) \cdot c) = (a \cdot b) \cdot c\]

Prove 1

\[a + a \cdot (b \cdot c) = a\]

\[= a \cdot (a + c)\]

\[= (a + (a \cdot b)) \cdot (a + c)\]

\[= a + (a \cdot b) \cdot c\]

QED

- **A1. Identities:**
  \[a + 0 = a\] and \[a \cdot 1 = a\]

- **A2. Complements:**
  \[a + \overline{a} = 1\] and \[a \cdot \overline{a} = 0\]

- **A3. Commutativity:**
  \[a + b = b + a\] and \[a \cdot b = b \cdot a\]

- **A4. Distributivity:**
  \[a + (b \cdot c) = (a + b) \cdot (a + c)\] and \[a \cdot (b + c) = (a \cdot b) + (a \cdot c)\]

- **T0. Duality:**
  Correctness is maintained when interchange + and \(\cdot\), as well as 0 and 1.

- **T1. Distinct Complement:**
  Every element has another element that is its unique complement.

- **T2. Absorption:**
  \[a + ab = a\] and \[a \cdot (a + b) = a\]
(a + a \cdot (b \cdot c)) \cdot (\overline{a} + a \cdot (b \cdot c)) = a \cdot (b \cdot c)

Prove 2

Will appear in HW#3

A1. Identities:
    \[ a + 0 = a \quad \text{and} \quad a \cdot 1 = a \]

A2. Complements:
    \[ a + \overline{a} = 1 \quad \text{and} \quad a \cdot \overline{a} = 0 \]

A3. Commutativity:
    \[ a + b = b + a \quad \text{and} \quad a \cdot b = b \cdot a \]

A4. Distributivity:
    \[ a + (b \cdot c) = (a + b) \cdot (a + c) \quad \text{and} \quad a \cdot (b + c) = (a \cdot b) + (a \cdot c) \]

T0. Duality:
    Correctness is maintained when interchange + and \cdot, as well as 0 and 1.

T1. Distinct Complement:
    Every element has another element that is its unique complement.

T2. Absorption:
    \[ a + ab = a \quad \text{and} \quad a \cdot (a + b) = a \]
Associativity Theorem

Theorem 3:

\[(a + b) + c = a + (b + c)\]

\[(a \cdot b) \cdot c = a \cdot (b \cdot c)\]

\[(a \cdot b) \cdot c = a \cdot (b \cdot c)\]  \(\square\)

Proof:

Proved 1

\[(a + a \cdot (b \cdot c)) \cdot (\bar{a} + a \cdot (b \cdot c)) \equiv a \cdot (b \cdot c)\]

Prove 2 - HW#3

\[(a + (a \cdot b) \cdot c) \cdot (\bar{a} + (a \cdot b) \cdot c) = (a \cdot b) \cdot c\]

Proved 3 and 4

1 \(\parallel\) 2 \(\parallel\) 3 \(\parallel\) 4

multiply
Boolean Algebra

DeMorgan Theorem

The complements of the sum and product

\((a + b) = \overline{a} \cdot \overline{b}\)

\((a \cdot b) = \overline{a} + \overline{b}\)
DeMorgan Theorem

Theorem 4:

\[
\overline{(a + b)} = \overline{a} \cdot \overline{b}
\]

\[
\overline{(a \cdot b)} = \overline{a} + \overline{b}
\]

We will prove the other one follows by duality.
DeMorgan Theorem

Proof: Need to prove:

\[ (a \cdot b) = \bar{a} + \bar{b} \]

Need to prove that \((a \cdot b)\) and \(\bar{a} + \bar{b}\) are complements
DeMorgan Theorem

Proof: Need to prove:

\[(a \cdot b) = \overline{a + \overline{b}}\]

Need to prove that \((a \cdot b)\) and \(\overline{a + \overline{b}}\) are complements.

Need to prove:

\[(a \cdot b) + (\overline{a} + \overline{b}) = 1\]

HW#3

Idea: need to validate A2

next

\[(a \cdot b) \cdot (\overline{a} + \overline{b}) = 0\]

- A1. Identities:
  \(a + 0 = a\) and \(a \cdot 1 = a\)
- A2. Complements:
  \(a + \overline{a} = 1\) and \(a \cdot \overline{a} = 0\)
- A3. Commutativity:
  \(a + b = b + a\) and \(a \cdot b = b \cdot a\)
- A4. Distributivity:
  \(a + (b \cdot c) = (a + b) \cdot (a + c)\) and \(a \cdot (b + c) = (a \cdot b) + (a \cdot c)\)
DeMorgan Theorem

\[(a \cdot b) \cdot (\bar{a} + \bar{b})\]
\[= (a \cdot b) \cdot \bar{a} + (a \cdot b) \cdot \bar{b}\]
\[= b \cdot (a \cdot \bar{a}) + a \cdot (b \cdot \bar{b})\]
\[= b \cdot 0 + a \cdot 0\]
\[= 0 + 0\]
\[= 0\]

T3. \((a \cdot b) \cdot c = a \cdot (b \cdot c)\)

Q

HW#3

\[(a \cdot b) + (a + \bar{b}) = 1\]
\[= 1\]
\[= 0\]

A4

Q

L1. Self Absorption: 
\(a + a = a\) and \(a \cdot a = a\)

L2. Simple Absorption: 
\(a + 1 = 1\) and \(a \cdot 0 = 0\)

A1. Identities: 
\(a + 0 = a\) and \(a \cdot 1 = a\)

A2. Complements: 
\(a + \bar{a} = 1\) and \(a \cdot \bar{a} = 0\)

A3. Commutativity: 
\(a + b = b + a\) and \(a \cdot b = b \cdot a\)

A4. Distributivity: 
\(a + (b \cdot c) = (a + b) \cdot (a + c)\) and \(a \cdot (b + c) = (a \cdot b) + (a \cdot c)\)
DeMorgan Theorem

Theorem 4:

Q: Simple proof of DeMorgan without Associativity??

\[
\begin{align*}
(a + b) &= \overline{a} \cdot \overline{b} \\
(a \cdot b) &= \overline{a} + \overline{b}
\end{align*}
\]

We will prove

Michael Gottlieb
IST4 2009

Brian Lawrence
IST4 2009
DeMorgan Theorem

Proof with Associativity:

\[(a \cdot b) \cdot (\bar{a} + \bar{b}) \]

is 0

\[= (a \cdot b) \cdot \bar{a} + (a \cdot b) \cdot \bar{b} \]

Identify a lemma

\[= b \cdot 0 + a \cdot 0 \]

\[= 0 + 0 \]

\[= 0 \]

T3. \((a \cdot b) \cdot c = a \cdot (b \cdot c)\)

HW#3

\((a \cdot b) + (a + \bar{b}) = 1\)

\((a \cdot b) \cdot (\bar{a} + \bar{b}) = 0\)

• L1. Self Absorption:
  \(a + a = a\) and \(a \cdot a = a\)

• L2. Simple Absorption:
  \(a + 1 = 1\) and \(a \cdot 0 = 0\)

• A1. Identities:
  \(a + 0 = a\) and \(a \cdot 1 = a\)

• A2. Complements:
  \(a + \bar{a} = 1\) and \(a \cdot \bar{a} = 0\)

• A3. Commutativity:
  \(a + b = b + a\) and \(a \cdot b = b \cdot a\)

• A4. Distributivity:
  \(a + (b \cdot c) = (a + b) \cdot (a + c)\) and \(a \cdot (b + c) = (a \cdot b) + (a \cdot c)\)
DeMorgan Theorem

Proof without Associativity:

Proof of the lemma:

\[(a \cdot b) \cdot \overline{a}\]

\[= (a \cdot b) \cdot \overline{a} + 0\] \quad \text{A1}

\[= (a \cdot b) \cdot \overline{a} + (a \cdot \overline{a})\] \quad \text{A2}

\[= \overline{a} \cdot ((a \cdot b) + a)\] \quad \text{A3 A4}

\[= \overline{a} \cdot a\] \quad \text{A3 T2}

\[= 0\] \quad \text{A2 A3}

- A1. Identities:
  \[a + 0 = a\] and \[a \cdot 1 = a\]

- A2. Complements:
  \[a + \overline{a} = 1\] and \[a \cdot \overline{a} = 0\]

- A3. Commutativity:
  \[a + b = b + a\] and \[a \cdot b = b \cdot a\]

- A4. Distributivity:
  \[a + (b \cdot c) = (a + b) \cdot (a + c)\] and \[a \cdot (b + c) = (a \cdot b) + (a \cdot c)\]

- T0. Duality:
  Correctness is maintained when interchange + and \(\cdot\), as well as 0 and 1.

- T1. Distinct Complement:
  Every element has another element that is its unique complement.

- T2. Absorption:
  \[a + ab = a\] and \[a \cdot (a + b) = a\]
So Far so Good...

- **A1. Identities:**
  \[ a + 0 = a \quad \text{and} \quad a \cdot 1 = a \]

- **A2. Complements:**
  \[ a + \bar{a} = 1 \quad \text{and} \quad a \cdot \bar{a} = 0 \]

- **A3. Commutativity:**
  \[ a + b = b + a \quad \text{and} \quad a \cdot b = b \cdot a \]

- **A4. Distributivity:**
  \[ a + (b \cdot c) = (a + b) \cdot (a + c) \quad \text{and} \quad a \cdot (b + c) = (a \cdot b) + (a \cdot c) \]

- **L1. Self Absorption:**
  \[ a + a = a \quad \text{and} \quad a \cdot a = a \]

- **L2. Simple Absorption:**
  \[ a + 1 = 1 \quad \text{and} \quad a \cdot 0 = 0 \]

- **T3. Associativity:**
  \[ (a + b) + c = a + (b + c) \]
  \[ (a \cdot b) \cdot c = a \cdot (b \cdot c) \]

- **T4. DeMorgan Laws:**
  \[ \overline{a + b} = \bar{a} \cdot \bar{b} \]
  \[ \overline{a \cdot b} = \bar{a} + \bar{b} \]

- **T0. Duality:**
  Correctness is maintained when interchange \(+\) and \(\cdot\), as well as \(0\) and \(1\).

- **T1. Distinct Complement:**
  Every element has another element that is its unique complement.

- **T2. Absorption:**
  \[ a + ab = a \quad \text{and} \quad a \cdot (a + b) = a \]
Syllogism to Algebra
George Boole, 1847

George Boole
1815 -1864
George Boole
1815-1864

George Boole
Early Days

Born in Lincoln, England, an industrial town

His father was a shoemaker with a passion for mathematics and science

When George was 8 he surpassed his father’s knowledge in mathematics

By age 14 he was fluent in Latin, German, French, Italian and English... and algebra...

When his was 15 he had to go to work to support his family, he became a math teacher in the Wesleyan Methodist academy in Doncaster (40 miles...)

Lost his job after two years....

Lost two more teaching jobs...

When he was 20 he opened his own school in his hometown - Lincoln
Born in Lincoln, England, an industrial town.

In 1841 (26) he published three papers in the newly established Cambridge Mathematical Journal (edited by DG).

In 1844 (29) he published "On a General Method of Analysis"; he considered it to be his best paper. This paper won the first (newly established) Gold medal for Mathematics awarded by Royal Society.

In 1846 (31) he applied for a professor position in the newly established Queen's College - 3 campuses in Ireland.

In 1847 (32) 'while waiting to hear from Ireland', he published "The Mathematical Analysis of Logic".

In 1847 (32) ‘while waiting to hear from Ireland’, he published “The Mathematical Analysis of Logic”

In 1849 (34), his was offered a position of the first professor of mathematics at Queen’s college at Cork

He married Mary Everest (1832- 1916) in 1855 (23,40) and they had five daughters

Niece of George Everest (Mt. Everest…) led the expedition to map the Himalayas

In 1864, died of pneumonia (49)

source: wikipedia
1849-1864, taught at Queen's college in Cork

Born in Lincoln, England, an industrial town

1849-1855: lived here until got married

Cork, Ireland

Source: www.flickr.com
Celebrating George Boole's Bicentenary