Below are all benchmark queries Q1 to Q6 and their corresponding DataLog formulation, SQL queries before and after AQIT transformation

Query Q1 finds when and on what machines, the pressure readings of class A were higher than @thA from its
expected value:

Original query Q1 in SQL is translated to DQ1 in DataLog $DQ1(m,bt,et) \leftarrow$ SELECT va.m, va.bt, va.et measuresA(m,s,bt,et,mv)AND 2 sensor(m,s,_,_,ev,_,_) FROM measures A va, sensor s AND 3 WHERE va.m = s.m AND va.s=s.s AND v1 = ev + @thAAND va.mv > s.ev + @thA

Since the DataLog query DQ1 exposes *idx(measuresA.mv)* already. Therefore, AQIT will not transform DQ1. Finally, it returns Q1 unchanged.



• Query Q2 identifies abnormal behaviors based on absolute deviations: When and for what machines did the pressure reading of class B deviate more than @thB from its expected value? AQIT translates the query into the following SQL query T2:

```
Q2
                                                       DQ2(m,bt,et) \leftarrow
                                                         measuresB(m,s,bt,et,mv)
                                                                                         AND
   SELECT vb.m, vb.bt, vb.et
                                                                                         AND
                                                          \verb"sensor(m,s,\_,\_,ev,\_,\_)
   FROM
          measuresB vb, sensor s
3
                                                                                         AND
                                                          v1 = mv - ev
   WHERE vb.m =s.m AND vb.s=s.s AND
4
                                                          v2 = abs(v1)
                                                                                         AND
          abs(vb.mv - s.ev) > @thB
5
                                                          v2 > @thB
```

AQIT transforms the DataLog query DQ2 into TDQ2 exposing idx(measuresB.mv). Finally, it translates TDQ2 to T2 in SQL

```
TDQ2(m,bt,et) \leftarrow
                                                     SELECT vb.m, vb.bt, vb.et
     measuresB(m,s,bt,et,mv) AND
2
                                                     FROM measuresB vb, sensor s
     sensor(m,s,_,_,ev,_,_)
                               AND
                                                     WHERE vb.m = s.m AND va.s = s.s
                                                                                             AND
3
     v1 = @thB + ev
                               AND
      v2 = - @thB + ev
4
                               AND
                                                        (vb.mv > @thB + s.ev
                                                                                             OR
5
     (mv > v1 OR mv < v2)
                                                        vb.mv < - @thB + s.ev
```

• Query Q3 identifies two different abnormal behaviors of the same machine at the same time based on two different measurement classes: When and for which machines were the pressure readings of class A higher than @thA from its expected value at the same time as the pressure reading of class B were deviating @thRB % from its expected value? After the AQIT transformation Q3 becomes T3:

```
Original query Q3 in SQL is translated to DQ3 in DataLog
                                                      DQ3(m,gt,lt) \leftarrow
    SELECT va.m,greaest(va.bt,vb.bt)
                                                        measuresA(m,s,bt1,et1,mv1)
1
                                                                                       AND
                                                        measuresB(m,s,bt2,et2,mv2)
                                                                                       AND
2
            least(va.et, vb.et)
                                                         sensor(m,s,_,_,ev1,_,_)
                                                                                       AND
3
    FROM
         measuresA va, measuresB vb,
                                                         sensor(m,s,_,_,ev2,_,_)
                                                                                       AND
4
           sensor sa, sensor sb
                                                        bt1 <= et2
                                                                                       AND
5
    WHERE va.m=sa.m AND va.s=sa.s
                                         AND
                                                         et1 >= bt2
                                                                                       AND
6
        vb.m=sb.m AND vb.s=sb.s
                                         AND
                                                         gt = greatest(bt1, bt2)
7
        va.m=vb.m
                                         AND
                                                         lt = least(et1, et2)
                                                                                       AND
8
       va.bt<=vb.et AND va.et>=vb.bt
                                         AND
                                                         v2 = mv - ev
                                                                                       AND
9
       va.mv - sa.ev > @thA
                                         AND
                                                         v2 > @thA
                                                                                       AND
                                                         v3 = mv2 - ev2
                                                                                       AND
10
       abs((vb.mv - sb.ev)/sb.ev)>@thRB
                                                         v4 = v3 / ev2
                                                                                       AND
11
                                                                                       AND
                                                         v5 = abs(v4)
12
```

AQIT transforms the DataLog query DQ3 into TDQ3 exposing idx(measuresB.mv) and idx(measuresA.mv). Finally, it translates TDQ3 to T4 in SQL

```
TDQ3(m,gt,lt) \leftarrow
                                                        Т3
                                                        SELECT va.m,greaest(va.bt,vb.bt)
1
      measuresA(m,s,bt1,et1,mv1)
                                     AND
2
                                                               least(va.et, vb.et)
      measuresB(m,s,bt2,et2,mv2)
                                     AND
3
       \verb"sensor(m,s,\_,\_,ev1,\_,\_)
                                     AND
                                                              measuresA va, measuresB vb,
4
       sensor(m,s,_,_,ev2,_,_)
                                     AND
                                                               sensor sa, sensor sb
5
      bt1 <= et2
                                     AND
                                                       WHERE va.m=sa.m AND va.s=sa.s
                                                                                             AND
6
       et.1 >= bt.2
                                     AND
                                                           vb.m=sb.m AND vb.s=sb.s
                                                                                             AND
7
       gt = greatest(bt1, bt2)
                                     AND
                                                            va.m=vb.m
                                                                                             AND
8
       lt = least(et1, et2)
                                     AND
9
                                                            va.bt<=vb.et AND va.et>=vb.bt AND
       v1 = @thA + ev
                                     AND
10
                                                            va.mv > @thA + sa.ev
      mv > v1
                                     AND
                                                                                             AND
11
       v2 = @thB + 1
                                     AND
                                                          ((vb.mv>(1+@thRB)*sb.ev AND sb.ev >0)
12
                                     AND
       v3 = -@thB + 1
                                                                (vb.mv<(1+@thRB)*sb.ev AND sb.ev<0)
13
       v4 = v2*ev2
                                     AND
                                                          ΩR
                                                                (vb.mv<(-@thRB+1)*sb.ev ANDsb.ev>0)
14
       v5 = v3*ev2
                                     AND
                                                                (vb.mv>(-@thRB+1)*sb.ev AND sb.ev<0))
15
       ((mv2 > v4 AND ev2 > 0) OR
16
       (mv2 < v4 \text{ AND } ev2 < 0) \text{ OR}
17
       (mv2 < v5 AND ev2 > 0) OR
18
       (mv2 > v5 AND ev2 < 0))
```

• Query Q4 identifies when were the pressure readings of class B deviating more than @thB for the machines in the list machine-models? Here, if a query spans many machine models the impact of AQIT should decrease since many different index keys are accessed. We thus varied the size of @machine-models.

```
Original query Q4 in SQL is translated to DQ4 in DataLog
```

```
DQ4(m,bt,et) \leftarrow
   SELECT vb.m, vb.bt, vb.et
                                                       measuresB(m,s,bt,et,mv)
                                                                                     AND
2
   FROM measuresB vb, sensor s, machine ma
                                                        sensor(m,s,_,_,ev,_,_)
                                                                                     AND
   WHERE vb.m = s.m AND va.s = s.s AND
                                                        machine(m, mm)
                                                                                     AND
                                   AND
      vb.m = ma.m
                                                        mm in @machine-models
                                                                                      AND
     ma.mm in @machine-models
                                                        v1 = mv - ev
                                                                                     AND
6
     abs(vb.mv - s.ev) > @thB;
                                                        v2 = abs(v1)
                                                                                     AND
7
                                                        v2 > @thB
```

AQIT transforms the DataLog query DQ4 into TDQ4 exposing *idx(measuresB.mv)*. Finally, it translates TDQ4 to T4 in SQL

```
TDO4(m,bt,et) ←
1
                                                    SELECT vb.m, vb.bt, vb.et
     measuresB(m,s,bt,et,mv) AND
2
     sensor(m,s,_,_,ev,_,_)
                              AND
                                                    FROM measuresB vb, sensor s, machine ma
     machine(m, mm)
                               AND
                                                    WHERE vb.m = s.m AND va.s = s.s
4
                              AND
                                                      vb.m = ma.m
                                                                                           AND
     mm in @machine-models
5
                                                      ma.mm in @machine-models
                                                                                           AND
     v3 = @thB + ev
                               AND
6
     v4 = - @thB + ev
                               AND
                                                      (vb.mv > @thB + s.ev
                                                                                           OR
7
                                                      vb.mv < - @thB + s.ev)
     (mv > v3 OR mv < v4)
```

• Query Q5 identifies when the pressure reading of class B deviates more than @thB for two specific machine models using a temporal join. The query involves numerical expressions over two indexed variables, which are both exposed by AQIT.

```
Original query Q5 in SQL is translated to DQ5 in DataLog
```

```
DO5(m,qt,lt) \leftarrow
    SELECT vbl.m, vb2.m,
1
                                                         measuresB (m1,s1,bt1,et1,mv1) AND
             greatest(vb1.bt, vb2.bt),
2
                                                          sensor(m1,s1,_,_,ev1,_,_)
                                                                                           AND
3
             least(vb2.et, vb2.et)
                                                                         `M_1')
                                                          machine(mal,
                                                                                           AND
4
             measuresB vbl, sensor sl,
                                                         measuresB (m2,s2,bt2,et2,mv2)
                                                                                           AND
5
             machine mal, measuresB vb2,
                                                                                           AND
                                                          \mathtt{sensor}(\texttt{m2}, \texttt{s2}, \_, \_, \texttt{ev2}, \_, \_)
             sensor s2, machine ma2
6
                                                          machine(ma2, 'M_2')
                                                                                           AND
7
    WHERE
                                                          bt1 >= et2
                                                                                           AND
8
     vb1.m = s1.m AND vb1.s = s1.s
                                           AND
                                                          et1 >= bt2
                                                                                           AND
     ma1.m = vb1.m AND ma1.mm = 'M_1'
                                          AND
                                                          gt = greatest(bt1, bt2)
                                                                                           AND
10
     vb2.m = s2.m AND vb2.s = s2
                                           AND
                                                          lt = least(et1, et2)
                                                                                           AND
11
     ma2.m = vb2.m AND ma2.mm = 'M_2'
                                          AND
                                                          v1 = mv1 - ev1
                                                                                           AND
     vb1.bt<=vb2.et ANDvb1.et>=vb2.bt AND
12
                                                          v2 = abs(v1)
                                                                                           AND
13
     abs(vb1.mv - s1.ev)> @thB
                                                          v3 > @thB
                                                                                           AND
14
     abs(vb2.mv-s2.ev)> @thB
                                                          v4 = mv2 - ev2
                                                                                           AND
15
                                                          v5 = abs(v4)
                                                                                           AND
                                                          v5 > @thB
```

AQIT transforms the DataLog query DQ5 into TDQ5 exposing *idx(measuresB.mv)* twice. Finally, it translates TDQ5 to T5 in SQL

```
Т5
    TDQ5(m,gt,lt) \leftarrow
                                                      SELECT vb1.m, vb2.m,
1
      measuresB (m1,s1,bt1,et1,mv1) AND
       sensor(m1,s1,_,_,ev1,_,_)
machine(ma1, 'M_1')
2
                                                              greatest(vb1.bt, vb2.bt),
                                       AND
3
                                                              least(vb2.et, vb2.et)
                                       AND
      measuresB (m2,s2,bt2,et2,mv2)
                                                              measuresB vbl,sensor sl,
4
                                                      FROM
                                       AND
       sensor(m2,s2,_,_,ev2,_,_)
5
                                                              machine mal, measuresB vb2,
                                       AND
       machine(ma2, 'M_2')
6
                                       AND
                                                              sensor s2, machine ma2
7
                                       AND
                                                      WHERE
                                                              vb1.m = s1.m AND vb1.s = s1.s AND
       bt1 >= et2
       et1 >= bt2
                                                        ma1.m = vb1.m AND ma1.mm = 'M 1'
8
                                       AND
                                                                                               AND
                                       AND
                                                         vb2.m = s2.m AND vb2.s = s2.s
                                                                                               AND
9
       gt = greatest(bt1, bt2)
10
       lt = least(et1, et2)
                                       AND
                                                         ma2.m = vb2.m AND ma2.mm = 'M_2'
                                                                                               AND
                                                         vb1.bt<=vb2.et AND vb1.et>=vb2.bt
11
       v1 = @thB + ev1
                                       AND
12
       v2 = -@thB + ev1
                                       AND
                                                         ((vb1.mv > @thB + s1.ev)
                                                                                       OR
13
       v3 = @thB + ev2
                                       AND
                                                         (vb1.mv < -@thB + s1.ev)
                                                                                       OR
14
       v4 = -@thB + ev2
                                                         (vb2.mv > @thB + s2.ev)
                                                                                       OR
                                       AND
15
                                                         (vb2.mv < -@thB + s2.ev))
       (mv1 > v1
                                       OR
       mv1 < v2
                                       OR
       mv2 > v3
                                       OR
      mv2 < v4)
```

• Query Q6 is a complex query that identifies a sequence of two different abnormal behaviors of the same machine happening within a given time interval, based on two different measurement classes: On what machines the pressure readings class B were out-of-bounds more than @thB within 5 seconds after the pressure readings of class A were higher than @thA from the expected value. Here, both idx(measuresA.mv) and idx(measuresB.mv) are exposed by AQIT.

Original query Q6 in SQL is translated to DQ6 in DataLog

```
D06(m,bt,et) \leftarrow
    SELECT vb.m, vb.bt, vb.et
1
                                                       measuresA(m,s,bt1,et1,mv1)
                                                                                      AND
2
            measuresA va, measuresB vb
                                                       measuresB(m,s,bt2,et2,mv2)
    FROM
                                                                                     AND
3
                                                        sensor(m,s,_,_,ev1,_,_)
            sensor sa, sensor sb
                                                                                     AND
4
    WHERE
            va.m = sa.m AND va.s=sa.s AND
                                                                                     AND
                                                        sensor(m,s,_,_,ev2,_,_)
5
            vb.m = sb.m AND va.s=sb.s AND
                                                        v1 = bt2 - et1
                                                                                     AND
            va.m = vb.m
6
                                        AND
                                                        v1 <= 5
                                                                                      AND
7
            vb.bt - va.et <= 5
                                        AND
                                                        v2 = mv - ev
                                                                                     AND
8
            va.mv - sa.ev > @thA
                                        AND
                                                        v2 > athA
                                                                                     AND
            abs(vb.mv -sb.ev) > @thB
9
                                                       v3 = mv2 - ev2
                                                                                     AND
10
                                                        v4 = abs(v3)
                                                                                     AND
11
                                                        v4 > @t.hB
```

AQIT transforms the DataLog query DQ6 into TDQ6 exposing idx(measuresA.mv) and idx(measuresB.mv). Finally, it translates TDQ6 to T6 in SQL

```
TDQ6(m,bt,et) \leftarrow
1
     measuresA(m,s,bt1,et1,mv1)
                                                     SELECT vb.m, vb.bt, vb.et
                                   AND
2
     measuresB(m,s,bt2,et2,mv2)
                                   AND
                                                     FROM
                                                             measuresA va, measuresB vb
3
                                                             sensor sa, sensor sb
     sensor(m,s,_,_,ev1,_,_)
                                   AND
4
                                                     WHERE
                                                             va.m = sa.m AND va.s = sa.s AND
     sensor(m,s,_,_,ev2,_,_)
                                   AND
5
      v1 = bt2 - et1
                                   AND
                                                             vb.m = sb.m AND va.s = sb.s AND
                                                             va.m = vb.m
6
     v1 <= 5
                                   AND
     v2 = @thA + ev
                                                             vb.bt - va.et <= 5
                                                                                          AND
                                   AND
8
                                                             va.mv > @thA + sa.ev
     mv > v2
                                   AND
                                                                                          AND
9
     v3 = @thB + ev2
                                   AND
                                                             ((vb.mv > @thB + sb.ev)
                                                                                           OR
      v4 = -@thB + ev2
                                   AND
                                                             (vb.mv < -@thB + sb.ev))
     (mv2 > v3 OR mv2 < v4)
```