1 Part 1

id	name	country
1	Toronto	Canada
2	Rome	Italy
3	Frankfurt	Germany

Table 1: City

code	name
1	Air Canada
2	Lufthansa

Table 2: Airline

id	firstName	surName
1	Sadia	Li
2	Sadia	Li
3	Sadia	Li

Table 3: Passenger

tailNumber	model	airline
1	Boeing 777	1
2	Boeing 777	2
3	Boeing 777	2

Table 4: Plane

id	plane	row	letter	class
1	1	1	A	Economy
2	2	2	A	Business
3	3	3	A	First

Table 5: Seat

code	name	city
YYZ	Toronto Pearson International Airport	1
FCO	Leonardo da Vinci International Airport	2
FRA	Frankfurt Airport	3

Table 6: Airport

flightNumber	airline	source	destination
AC890	1	YYZ	FCO
LH231	2	FCO	FRA
LH470	2	FRA	YYZ

Table 7: Route

id	route	plane	schedDeparture	schedArrival
1	AC890	1	2025-05-01 23:40	2025-05-02 8:05
2	LH231	2	2025-05-22 8:00	2025-05-22 10:00
3	LH470	3	2025-05-22 11:55	2025-05-22 20:20

Table 8: Flight

flight	dateTime
1	2025-05-01 23:45
2	2025-05-22 8:00
2	2025-05-22 11:55

Table 9: Departure

flight	dateTime
1	2025-05-02 8:15
2	2025-05-22 10:00
2	2025-05-22 20:20

Table 10: Arrival

flight	class	price
1	Economy	600
2	Business	950
3	First	1200

Table 11: FlightPrice

id	passenger	seat	flight	price	dateTime
1	1	1	1	600	2024-12-06 21:00
2	2	2	2	950	2025-05-09 9:00
3	3	3	3	1200	2025-05-09 9:00

Table 12: Booking

2 Part 2

The result of the given query is:

id	passenger	seat	flight
1	1	1	1
2	2	2	2

Table 13: Part 2 answer

3 Part 3

id	name	country
1	Toronto	Canada
2	Rome	Italy
3	Frankfurt	Germany

Table 14: City

code	name
1	Air Canada
2	Lufthansa

Table 15: Airline

id	firstName	surName
1	Sadia	Li
2	Sadia	Li
3	Sadia	Li

Table 16: Passenger

tailNumber	model	airline
1	Boeing 777	1
2	Boeing 777	2
3	Boeing 777	2

Table 17: Plane

id	plane	row	letter	class
1	1	1	A	Economy
4	1	1	B	Economy
2	2	2	A	Business
3	3	3	A	First

Table 18: Seat

code	name	city
YYZ	Toronto Pearson International Airport	1
FCO	Leonardo da Vinci International Airport	2
FRA	Frankfurt Airport	3

Table 19: Airport

flightNumber	airline	source	destination
AC890	1	YYZ	FCO
LH231	2	FCO	FRA
LH470	2	FRA	YYZ

Table 20: Route

id	route	plane	schedDeparture	schedArrival
1	AC890	1	2025-05-01 23:45	2025-05-02 8:15
2	LH231	2	2025-05-22 8:00	2025-05-22 10:00
3	LH470	3	2025-05-22 11:55	2025-05-22 20:20

Table 21: Flight

flight	dateTime
1	2025-05-01 23:50
2	2025-05-22 8:00
2	2025-05-22 11:55

Table 22: Departure

flight	dateTime
1	2025-05-02 8:25
2	2025-05-22 10:00
2	2025-05-22 20:20

Table 23: Arrival

flight	class	price
1	Economy	600
2	Business	950
3	First	1200

Table 24: FlightPrice

id	passenger	seat	flight	price	dateTime
1	1	1	1	600	2024-12-06 21:00
4	1	4	1	600	2024-12-06 21:00
2	2	2	2	950	2025-05-09 9:00
3	3	3	3	1200	2025-05-09 9:00

Table 25: Booking

4 Part 4

1. Not expressable
2. **FlightRename**(flight, tailNumber, schedDeparture, flightNumber) := $\Pi_{id,plane,schedDeparture,route}$(**Flight**)

   DelayedFlight(flight, tailNumber, schedDeparture,dateTime, flightNumber) :=

   $$\sigma_{\substack{dateTime-schedDeparture\geq 1hour \\ \bigcap \\ schedDeparture.year=2024}}\left(\textbf{FlightRename} \bowtie \textbf{Departure}\right)$$

   DelayedFinal(flight, tailNumber, schedDeparture,dateTime,airline, flightNumber) :=
   $\Pi_{flight,plane,schedDeparture,dateTime,airline,flightNumber}$(**DelayedFlight** $\bowtie$ **Plane**)

   $$\textbf{AtLeastThree}(\text{airline}) := \Pi_{airline}\sigma_{\substack{T1.airline=T2.airline \\ \bigcap \\ T2.airline=T3.airline \\ \bigcap \\ T1.flight\neq T2.flight \\ \bigcap \\ T2.flight\neq T3.flight \\ \bigcap \\ T1.flight\neq T3.flight}}\left(\rho_{T_1}\textbf{DelayedFinal}\times\rho_{T_2}\textbf{DelayedFinal}\times\rho_{T_3}\textbf{DelayedFinal}\right)$$

   AtLeastThreeAllFlights(flight,airline, scheDeparture, flightNumber):=
   $\Pi_{flight,airline,schedDeparture,flightNumber}$(**AtLeastThree** $\bowtie$ **DelayedFinal**)

   NotMostRecentFlight(flight, airline, scheDeparture, flightNumber) :=

   $$\Pi_{T4.flight,airline,T4.schedDeparture,T4.flightNumber}\left(\sigma_{\substack{T4.airline=T5.airline \\ \bigcap \\ T4.schedDeparture<T5.schedDeparture}}\left(\rho_{T_4}(AtLeastThreeAllFlights)\times\rho_{T_5}(\textbf{AtLeastThreeAllFlights})\right)\right)$$

   AtLeastThreeMostRecentFlights(flight,code,flightNumber) :=
   $\Pi_{flight,airline,flightNumber}$(**AtLeastThreeAllFlights** − **NotMostRecentFlight**)

   $\Pi_{code,name,flightNumber}$(**AtLeastThreeMostRecentFlights** $\bowtie$ **Airline**)

3. $\textbf{CityWithAirport}_{(city)} := \Pi_{city}(\textbf{Airport})$

   $\textbf{CityWithRouteEnding}_{(city)} := \Pi_{city}(\textbf{Airport} \bowtie Airport.code = Route.destination \textbf{Route})$

   $\textbf{CityWithoutRouteEnding}_{(city)} := \textbf{CityWithAirport} - \textbf{CityWithRouteEnding}$

   $\textbf{Answer} := \Pi_{name,city}(\textbf{CityWithoutRouteEnding} \bowtie_{CityWithoutRouteEnding.city=city.id} \textbf{City})$

4. $\textbf{FlightRoutePrice} := \textbf{Flight} \bowtie_{Flight.route=Route.flightNumber} \textbf{Route} \bowtie_{Flight.id=FlightPrice.flight} \textbf{FlightPrice}$

   $\textbf{SameRoutePair} := \sigma_{\substack{R1.id \neq R2.id \\ R1.airline \neq R2.airline \\ R1.source \neq R2.source \\ R1.destination \neq R2.destination \\ (R1.price < R2.price) \vee (R1.id < R2.id)}} \left(\rho_{R1}(\textbf{FlightRoutePrice}) \times \rho_{R2}(\textbf{FlightRoutePrice}) \right)$

   $\textbf{Answer} := \Pi_{R1.id,R1.flightNumber,R2.id,R2.flightNumber}(\textbf{SameRoutePair})$

5. $\textbf{F}_{(id,source,destination,schedDeparture,schedArrival)}$
   $:= \pi_{id,source,destination,schedDeparture,schedArrival}(\textbf{Flight} \bowtie_{Flight.route=Route.flightNumber} \textbf{Route})$

   $\textbf{AfterJune17}_{(id,source,destination,schedDeparture,schedArrival)} := \sigma_{schedArrival > 2025-06-17} \textbf{F}$

   $\textbf{Direct}_{(schedDeparture,schedArrival)} := \pi_{schedDeparture,schedArrival} \left(\sigma_{\substack{source='YYZ' \\ \wedge destination='LIS'}} \textbf{AfterJune17} \right)$

   $\textbf{Layover}_{(schedDeparture,schedArrival)}$
   $:= \pi_{\substack{F1.schedDeaparture, \\ F2.schedArrival}} \left(\sigma_{\substack{F1.source='YYZ' \\ F1.destination=F2.source \\ F2.destination='LIS' \\ 1hour \leq F2.schedDeparture - F1.schedArrival \leq 24hours}} \left(\rho_{F1}(AfterJune17) \times \rho_{F2}(AfterJune17) \right) \right)$

   $\textbf{YYZToLIS}_{(schedDeaparture,schedArrival)} := Direct \cup Layover$

6. **BookingRename**(id,flight) := $\Pi_{passenger,flight}$(**Booking**).

   FlightRename(flight, schedDeparture) := $\Pi_{id,schedDeaparture}$(**Flight**).

   PairWithDiffTirp(id1,flight1,schedDeparture1,id2,flight2,schedDeparture2):=

   $\Pi_{T1.id,T1.flight,T1.schedDeparture1,T2.id,T2.flight,T2.schedDeparture1}(\sigma_{T1.flight \neq T2.flight \bigcup T1.id \geq T2.id}\Big(\rho_{T_1}(\textbf{FlightRename} \bowtie \textbf{BookingRename}) \times \rho_{T_2}(\textbf{FlightRename} \bowtie \textbf{BookingRename})\Big))$

   InvalidPairs(id1,id2):=$\Pi_{id1,id2}$(**PairWithDiffTirp**)

   AllPairs(id1,id2):=$\Pi_{id1,id2}(\rho_{T_1}(\textbf{FlightRename} \bowtie \textbf{BookingRename}) \times \rho_{T_2}(\textbf{FlightRename} \bowtie \textbf{BookingRename})$

   ValidPairs(id1,id2):=$\Pi_{id1,id2}(AllPairs - InvalidPairs)$

   PairsOfSameName(id1,id2):=$\Pi_{id1,id2}\sigma_{T3.surName=T4.surname \bigcap T3.id<T4.id}\Big(\rho_{T_3}\textbf{Passenger} \times \rho_{T_4}\textbf{Passenger}\Big)$

   FinalPair(id1,id2) := **ValidPairs** $\bigcap$ **PairsOfSameName**

   GetNotMostRecentTrip(id1,id2,flight) := $\Pi_{T5.id1,T5.id2,T5.flight}$ $(\sigma_{T5.schedDeparture<T6.schedDeparture \bigcap T5.id1=T6.id1 \bigcap T5.id2=T6.id2}$

   $\Big((\textbf{FinalPair} \bowtie_{id1=id} (\textbf{BookingRename} \bowtie \textbf{Flight})) \bowtie_{T5.id1=T6.id1 \bigcap T5.id2=T6.id2} (\textbf{FinalPair} \bowtie_{id1=id} (\textbf{BookingRename} \bowtie \textbf{Flight})))\Big)$

   AllTrip(id1,id2,flight):=$\Pi_{T5.id1,T5.id2,flight}(\sigma_{T5.id1=T6.id1 \bigcap T5.id2=T6.id2}(\textbf{FinalPair} \bowtie_{id1=id} (\textbf{BookingRename} \bowtie \textbf{Flight})))$

   MostRecentTrip(id1,id2,flight) := **AllTrip - GetNotMostRecentTrip**

   $\Pi_{P_1.firstName,P_1.surName,P_2.firstName,P_2,surName,flight}(\sigma_{P_1.id=id1 \bigcap P_2.id=id2}(\textbf{MostRecentTrip} \times \rho_{P_1}\textbf{Passenger} \times \rho_{P_2}\textbf{Passenger}))$

   $\textbf{PBF}_{expanded}$:= **Passenger** $\bowtie_{Passenger.id=Booking.passenger}$ **Booking** $\bowtie_{Booking.flight=Flight.id}$ **Flight**
   PBF := $\Pi_{id,passenger,firstname,surName,flight,schedDeparture}(\textbf{PBF}_{expanded})$

   SameSurnameFlight := $\sigma_{P1.passenger \neq P2.passenger \; P1.surname=P2.surname \; P1.flight=P2.flight}\Big(\rho_{P1}(\textbf{PBF}) \times \rho_{P2}(\textbf{PBF})\Big)$

   AtLeastOneMismatch

7. **AtLeastFourTimes**(tailNumber):=$\Pi_{plane}(\sigma_{T_1.plane=T_2.plane=T_3.plane=T_4.plane \bigcap T_1.id\neq T_2.id\neq T_3.id\neq T_4.id}\Big(\rho_{T_1}\textbf{Flight}\times\rho_{T_2}\textbf{Flight}\times \rho_{T_3}\textbf{Flight}\times\rho_{T_4}\textbf{Flight}\Big))$

   AllPlanes(tailNumber):=$\Pi_{tailNumber}$(**Plane**)

   PlanesLessThanFour(tailNumber) := **AllPlanes** - **AtLeastFourTimes**

   $\Pi_{tailNumber,airline}$(**PlanesLessThanFour** $\bowtie$ **Plane**)

8. **PassengerEverBookAtLeastTwo**(id):= $\Pi_{T_1.passenger}\sigma_{T_1.passenger=T_2.passenger \bigcap T_1.flight=T_2.flight \bigcap T_1.seat\neq T_2.seat}(\rho_{T_1}\textbf{Booking}\times\rho_{T_2}\textbf{Booking})$

   PassengerEverBookAtLeastThree(id):= $\Pi_{T_3.passenger}\sigma_{T_3.passenger=T_4.passenger=T_5.passenger \bigcap T_3.flight=T_4.flight=T_5.flight \bigcap T_3.seat\neq T_4.seat\neq T_5.seat}(\rho_{T_3}\textbf{Booking}\times \rho_{T_4}\textbf{Booking}\times\rho_{T_5}\textbf{Booking})$

   PassengerEverBookAtMostTwo(id):=$\Pi_{passenger}$ **PassengerEverBookAtLeastTwo** - **PassengerEverBookAtLeastThree**

   PassengerEverBookAtMostOne(id):=$\Pi_{passenger}$**Booking** - **PassengerEverBookAtLeastTwo**

   PassengerAlwaysBookTwo(id):= **PassengerEverBookAtMostTwo** - **PassengerEverBookAtMostOne**

   PassengerBookSameRow(id):= $\Pi_{T_6.passenger}\sigma_{T_6.passenger=T_7.passenger \bigcap T_6.flight=T_7.flight \bigcap T_6.seat\neq T_7.seat \bigcap T_6.row=T_7.row}(\rho_{T_6}\textbf{Booking}\bowtie_{Booking.seat=Seat.id}\textbf{Seat})\times\rho_{T_7}\textbf{Booking}\bowtie_{Booking.seat=Seat.id}\textbf{Seat})$

   PassengerNeverBookSameRow(id):=$\Pi_{passenger}$**Booking** - **PassengerBookSameRow**

   PassengerNeverBookSameRow $\bigcap$ **PassengerAlwaysBookTwo**

9. Not expressable

10. $\textbf{PassengerPaidEqualOrMore}(\text{id}) := \Pi_{Passenger}\sigma_{Booking.price \geq FlightPrice}((\textbf{Booking} \bowtie_{FlightPrice.flight=Booking.flight} \textbf{FlightPrice}) \bowtie_{\substack{Booking.seat=Seat.id \\ \bigcap \\ FlightPrice.class=Seat.class}} \textbf{Seat})$

$\Pi_{passenger}\textbf{Booking}$ - $\textbf{PassengerPaidEqualOrMore}$

11. $\mathbf{B}_{(bookId,seat,flight,paidPrice)} := \rho_{B_{(bookid,seat,flight,paidPrice)}}\left(\pi_{id,seat,flight,price}\textbf{Booking}\right)$

$\mathbf{F}_{(flightId,route)} := \rho_{F_{(flightId,route)}}\left(\pi_{id,seat,flight,price}\textbf{Flight}\right)$

$\mathbf{R}_{(routeId,airline)} := \rho_{R_{(routeId,airline)}}\left(\pi_{flightNumber,airline}\textbf{Route}\right)$

$\mathbf{S}_{(seatId,class)} := \rho_{S_{(seatId,class)}}\left(\pi_{id,class}\textbf{Seat}\right)$

$\mathbf{P}_{(flight,class,price)} := \rho_{S_{(flight,class,price)}}\textbf{FlightPrice}\Big)$

$\textbf{RoutesDetail}_{(bookId,routeId,price,paidPrice,airline)}$

$:= \pi_{\substack{B.bookId, \\ R.routeId, \\ P.price, \\ B.paidPrice, \\ R.airline}}\left(\mathbf{B} \bowtie_{\substack{B.flight \\ =F.flightId}} \mathbf{F} \bowtie_{\substack{F.route \\ =R.routeId}} \mathbf{R} \bowtie_{\substack{B.seat \\ =S.seatId}} \mathbf{S} \bowtie_{\substack{F.flightId=P.flight \\ \wedge S.class=P.class}} \mathbf{P}\right)$

$\textbf{UnpopularRoutes}_{(routeId,airline)} := \pi_{routeId,airline}\left(\sigma_{paidPrice \leq price/2}\textbf{RoutesDetail}\right)$

$\textbf{AllRoutes}_{(routeId,airline)} := \rho_{tmp_{(routeId,airline)}}(\pi_{flightNumber,airline}\textbf{RoutesDetail})$

$\textbf{PopularRoutes}_{(routeId,airline)} := \textbf{AllRoutes} - \textbf{UnpopularRoutes}$

$\textbf{AirlinesOperatedPopularRoute} := \pi_{airlines}\textbf{RoutesDetail} - \textbf{PopularRoutes}$

Part 5

1.

Cannot be expressed.

2.

$$\sigma_{\text{Booking.dateTime} \geq \text{Flight.schedDeparture}} \Big(\textbf{Booking} \bowtie_{\text{Booking.flight = Flight.id}} \textbf{Flight} \Big) = \varnothing$$

$$\sigma_{\text{Departure.dateTime} < \text{Flight.schedDeparture}} \Big(\textbf{Departure} \bowtie_{\text{Departure.flight = Flight.id}} \textbf{Flight} \Big) = \varnothing$$

$$\sigma_{\text{Arrival.dateTime} \leq \text{Departure.dateTime}} \Big(\textbf{Departure} \bowtie_{\text{Departure.flight = Arrival.flight}} \textbf{Arrival} \Big) = \varnothing$$

3.

Cannot be expressed.

4.

Cannot be expressed.

5.

$$\textbf{AllClassForAllFlight}_{(flight,class)} := \pi_{Flight.id,Seat.class} \Big(\sigma_{Flight.plane=Seat.plnae} \big(\textbf{Flight} \times \textbf{Seat} \big) \Big)$$

$$\textbf{AllFlightClassInFlightPrice}_{(flight,class)} := \pi_{flight,class} \textbf{FlightPrice}$$

$$\textbf{AllClassForAllFlight} - \textbf{AllFlightClassInFlightPrice} = \varnothing$$

$$\textbf{AllFlightClassInFlightPrice} - \textbf{AllClassForAllFlight} = \varnothing$$

6.

$$\mathbf{FR}\begin{pmatrix} id,\\ plane,\\ source,\\ destination,\\ schedDeparture \end{pmatrix} := \pi_{\begin{pmatrix} Flight.id,\\ Flight.plane,\\ Route.source,\\ Route.destination,\\ Flight.schedDeparture \end{pmatrix}} \mathbf{Flight} \bowtie_{\substack{Flight.route\\ =Route.flightNumber}} \mathbf{Route}$$

$$\mathbf{FRA1}\begin{pmatrix} id,\\ plane,\\ source,\\ destination,\\ schedDeparture\\ srcCity \end{pmatrix} := \pi_{\begin{pmatrix} FR.id,\\ FR.plane,\\ FR.source,\\ FR.destination,\\ FR.schedDeparture\\ ASource.city \end{pmatrix}} \mathbf{FR} \bowtie_{\substack{FR.source\\ =ASource.code}} \left(\rho_{ASource}\mathbf{Airport}\right)$$

$$\mathbf{FRA2}\begin{pmatrix} id,\\ plane,\\ source,\\ destination,\\ schedDeparture\\ srcCity\\ destCity \end{pmatrix} := \pi_{\begin{pmatrix} FRA1.id,\\ FRA1.plane\\ FRA1.source,\\ FRA1.destination,\\ FRA1.schedDeparture\\ FRA1.src\\ ADest.city \end{pmatrix}} \mathbf{FRA1} \bowtie_{\substack{FRA1.destination\\ =ADest.code}} \left(\rho_{ADest}\mathbf{Airport}\right)$$

$$\mathbf{FRC1}\begin{pmatrix} id,\\ plane,\\ source,\\ destination,\\ schedDeparture\\ srcCity\\ destCity\\ srcCountry \end{pmatrix} := \pi_{\begin{pmatrix} FRA2.id,\\ FRA2.plane,\\ FRA2.source,\\ FRA2.destination,\\ FRA2.schedDeparture,\\ FRA2.srcCity,\\ FRA2.destCity,\\ CSource.country \end{pmatrix}} \mathbf{FRA1} \bowtie_{\substack{FRA2.srcCity\\ =CSource.id}} \left(\rho_{CSource}\mathbf{City}\right)$$

$$\mathbf{FRC2}\begin{pmatrix} id,\\ plane\\ source,\\ destination,\\ schedDeparture,\\ srcCity,\\ destCity,\\ srcCountry,\\ destCountry \end{pmatrix} := \pi_{\begin{pmatrix} FRC1.id,\\ FRC1.plane,\\ FRC1.source,\\ FRC1.destination,\\ FRC1.schedDeparture,\\ FRC1.srcCity,\\ FRC1.destCity,\\ FRC1.srcCountry\\ CDest.country \end{pmatrix}} \mathbf{FRC1} \bowtie_{\substack{FRC1.destCity\\ =CDest.id}} \left(\rho_{CDest}\mathbf{City}\right)$$

$$\mathbf{F}_{(id,plane,src,dest,depart)} := \pi_{(id,plane,srcCountry,destCountry,schedDeparture)}\mathbf{FRC2}$$

$$\mathbf{NotDomesticFlights}_{(id,plane,src,dest,depart)} :=:= \sigma_{src \neq dest} F$$

$$\mathbf{D}_{(id,plane,src,dest,depart)} = \mathbf{F} - \mathbf{DomesticOnly}$$

$$\mathbf{FourOrMore}\begin{pmatrix} id,\\ plane,\\ src,\\ dest,\\ depart \end{pmatrix}$$

$$:= \sigma_{\begin{pmatrix} \forall i,j \in \{1,\ldots,4\}, month(D_i.depart) = month(D_j.depart)\\ \forall i,j \in \{1,\ldots,4\}, D_i.plane = D_j.plane\\ \forall i,j \in \{1,\ldots,4\}, D_i.id \neq D_j.id \end{pmatrix}} \left(\rho_{D_1}(D) \times \rho_{D_2}(D) \times \rho_{D_3}(D) \times \rho_{D_4}(D) \times \right)$$

$$\mathbf{FourOrMore} = \varnothing$$